# Agrivehicle: Design for the Vehicle Transporting Sugar Cane Cutters

Osmar V. Rodrigues

Thesis submitted in fulfilment of the requirements of the Royal College of Art for the degree of Doctor of Philosophy

September 2008

Royal College of Art
Postgraduate Art & Design

Sponsored by CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

# ABSTRACT

The driving social concern which motivated this project is the daily requirement for Brazilian agricultural companies to transport thousands of workers, tools and equipment, and the fact that this is currently done in unsuitable vehicles, not specifically designed for the task.

The aim of this research is to improve the transportation of rural workers – sugar cane cutters in particular – in off-road conditions. Appropriate design solutions will not only improve the workers' health, safety, welfare and consequently their everyday life, but also reduce transportation costs and increase agricultural production.

It is argued in this present thesis that a vehicle designed specifically for this purpose, and relevant to this transportation context, would generate a better-performing vehicle in off-road conditions. I suggest that a vehicle based on appropriate design solutions would increase mobility, ensuring better journey conditions, fewer accidents and consequent social damage for both the families of the victims and the government.

To achieve the aim of this research, account was taken of the role of the vehicle as a mobile facility centre on the plantation, and key issues were raised regarding not only the vehicle and the workers in a transportation context. Additionally, rather than just analysing the body of the vehicle (the shell that accommodates the users), its platform (the whole mechanical structure underneath the body) was also considered. In order to do so, this thesis has been written from an interdisciplinary perspective, mapping the current situation, and establishing key criteria for new vehicle types. The study was organized around five main issues: User Analysis, Vehicle Analysis, Terrain Analysis, Economic Analysis and Design Solutions.

The research concludes that there is evidence of improvements in the transportation of sugar cane cutters in Brazil, particularly in Sao Paulo State, due to the substitution of adapted trucks for buses. However, the current adaptations made to the buses are still not the answer to the problem. Therefore, I state that a solution to this situation is the development of a vehicle oriented towards real needs, trends and limitations in the context of this transportation.

To my parents,

Moacyr Vicente Rodrigues and

Maria de Fatima Duarte Rodrigues

For their example and lessons and particularly for constantly proving that family is the greatest treasury in life.

# ACKNOWLEDGEMENTS

First of all, thanks to God!

To the National Council for Scientific and Technological Development (CNPq) from Brazil (my sponsor) who through its sponsorship has made this research possible.

I would like to show my appreciation to my supervisor Dr. Paul Ewing for his tolerance, support and encouragement. This is the most important formal opportunity to thank him very much indeed. I am also deeply grateful to Prof. Dale Harrow (also my supervisor) for his support through his personal vision, typical of a first-class leader. Also, thanks to Dr. Andrew Nahum (Research Co-ordinator) for this useful insights and suggestions.

My special thanks to my external tutor Mr. Bruce Maclaurin (a former engineer from the Ministry of Defence – MoD) for his friendship, advice and technical support.

I am also indebted to my entire family members for their unconditional support and love. My special thanks to my youngest brother Moacyr Tadeu and my sister Simone who organised my personal arrangements in Brazil in my absence.

To all my friends from the Vehicle Design Research Group, in particular my friend Kleber Puchaski, with whom it has been possible to share this experience through his encouragement and cooperation. Also, thanks to Hélio Queiroz, Ehsan Moghaddampour, Dohyung Kim and Cathy Johns for their invaluable support.

To University of Sao Paulo State – UNESP (my employer) for a 20- year professional relationship. Many thanks to all my friends from the Industrial Design Department, in particular my special friend Dr. José Carlos Plácido and the MA students João Marcelo Soares, Marta Leite and the technician José Benedito Guerreiro.

Finally, big thanks to the rural workers and company directors who allowed me to access their specific knowledge, problems, achievements, and expectations.

Osmar V. Rodrigues

Figure 1: Brazilian sugar cane cutters and the buses used in their transportation
© Ministério Público do Trabalho (MPT)

*"The greater the change, the poorer the information, the less perfect the market, then the greater the potential for opportunity..." (Unknown)*

# CONTENTS


LIST OF TABLES .......... xiii

# LIST OF FIGURES

# LIST OF TABLES

## AUTHOR'S DECLARATION

1- During the period of registered study in which this thesis was prepared, the author has not been registered for any other academic award or qualification.

2- The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Osmar V. Rodrigues
September 2008

# CHAPTER 1 - INTRODUCTION

I was born in Macatuba in Sao Paulo State, Brazil, in a region dominated by sugar cane mills. During my childhood, bad news regarding accidents with trucks transporting sugar cane cutters was common, and consequently they became accepted as the norm in the local municipalities and for the local people, but not by me. In the late 1960s, I was already involved with design activities, creating and making my own wooden toy cars, aeroplanes and motorbikes. The new technological era, starting with man first landing on the moon, seemed to me not to reflect the limitations around the daily transportation of sugar cane cutters, or 'cold food workers' as they were popularly called – due to the fact that their food was always cold when it was eaten on the plantations. As a result of this, I grew up in midst of social, technological and economic gaps that still exist nowadays, and it seems that they will always do so, because they seem to be the counterpart of the technological progress.

In late 1980s, already a designer and having decided to do a MSc in Production Engineering, I found my first chance to use my professional skills to somehow address an aspect of these gaps. Thus, the subject of my MSc research was the transportation of sugar cane cutters, looking at the problem from an ergonomic point of view, considering the body of the vehicles only. However, at the end of it, the results showed that in order to make a real difference to this off-road type of transportation, it would be necessary to consider not only the body, but most importantly the platform of the vehicle and the relationship between the two. For this reason, I kept this idea in mind as a possible subject for further research.

In the early 2000s, the decision to apply for the PhD in Vehicle Design at Royal College of Art in London came about as a natural confluence of five factors: first, I wanted to carry on my research in this field in a vehicle design programme, and the RCA PhD programme was, and still is, the first and only one in this field in the world. Second, I had been for a while professionally involved with clients from both the automotive industry (bus manufacturing in particular) and the agricultural machinery industry. Third, new legislation in Brazil started signalling that finally the transportation of rural workers would be more effectively regulated and inspected. Fourth, the Brazilian government, now more interested in this subject than ever before due to the boom in the sugar cane industry, had decided to sponsor my research proposal to be developed abroad. Fifth, I was still looking for ways to address these social and economic gaps mentioned earlier.

Therefore, this research is the consolidation of over 30 years of personal aspiration to contribute to the social issues faced by both companies and the government towards the improvement of workers' everyday life.

## 1.1 Statement of the Problem

Since the beginning of time the necessity of people to move themselves and their possessions has driven the constant evolution of transportation and the history of the humankind. Early people had to travel on foot, as this was the only possible means of transportation. Then, learning how to domesticate animals, these animals were then used to carry goods and people from one place to another. Later on, motorized vehicles evolved, opening a new era in transportation, with currently 180 million people in the US depending on motor vehicles to commute daily. However, apart from the well known, widely-addressed challenge of urban mobility all over the globe, there is another one just as important as urban transportation but less widely-known: agricultural transportation.

According to the Food and Agricultural Organization (FAO) (2007), in 1994 there were 4.9 billion hectares of planted area in the world, with 2.5 billion inhabitants, rural workers mostly, who need to be transported daily on unpaved roads and unsuitable vehicles from one point to another in plantations, as we can see in Figure 2. Worse yet is that only 10% of the roads in the world are paved, constituting a traditional paradox in transportation in which the largest proportion of research and development in vehicle design is overwhelmingly related to on-road, rather than off-road vehicles. This means that significant technological improvements and solutions are far more frequently related to paved, rather than unpaved roads, even though the vast majority of the roads are not only unpaved, but also in poor condition.

Figure 2. Transportation of rural workers in Nicaragua.
© Amigosmarin

The term transportation is derived from the latin *trans,* 'across', and *portare,* 'to carry'. Therefore, as far as the etymology is concerned, transportation means to carry something or somebody across somewhere. According to the Oxford English Dictionary (2008), transport is *"to take or carry from one place to another by means of a vehicle, aircraft, or ship".* Although transportation technology evolved by humankind has allowed space exploration, the transportation of people, rural workers in particular, in off-road conditions is a problem that currently affects the whole world, particularly in countries with a strong agricultural basis.

With 550 million hectares of farmland (FAO, 2003), or 22% of world's planted area, Brazil is the world's largest exporter of important agricultural commodities such as soy, beef, sugar and coffee. As Brazil is currently the world's biggest producer and exporter of products derived from sugar cane, each agricultural company in this industry has to transport on average 2,000 cutters daily. The term "cutter" is used in this research to refer to those workers involved with manual sugar cane cutting, whereas the term "sugar cane workers" is used to refer to all other categories of workers involved with other agricultural activities in the sugar cane industry.

On account of this, the problem that motivates this project is the daily requirement for Brazilian agricultural companies to transport thousands of workers, tools and equipment from their homes to and from the plantations throughout the year, in all types of weather, in unsuitable vehicles not specifically designed for the task. Vehicles which are currently used in this context do not have the specifications that both workers and companies need, because the vehicles are normally adapted buses, not originally designed either for this kind of transportation or for the terrain over which they travel (see Figure 3).


Figure 3: Brazilian sugar cane cutters and the buses used for their transportation.
© MPT

Because the sugar cane companies are currently much stricter about the control of cutters' working hours (8 hour shifts on plantations), this means that in theory all cutters should arrive and leave the plantations around the same time. However, taking into account the number of cutters and consequently the number of vehicles per company (from 40 to 50 on average), and cutters and plantations located in different places, the transportation of sugar cane cutters has become an unprecedented logistical problem for many of the agricultural companies. This has resulted in massive investment in solutions to tackle the problem, such as the construction of exclusive terminals in surrounding towns in order to solve the logistics of this transportation.

Although this transportation reality is not new in Brazil, and has existed since the 1940s, very little research has been carried out about the effectiveness of this transportation system, and most importantly the situation for the users (the cutters). Likewise, from the 1940s little or no action was taken by the government until the 1990s, when Article 190 of the Constitution of Sao Paulo State and Regulation NR-17 was established, defining more clearly the responsibility of employers in relation to the working conditions of employees. The NR-17 is regulated by Brazilian Labour Ministry and it is the country's only legal regulation dedicated to ergonomics. However, only 13 years later, in 2005, Regulation NR-31 was published and the first time that an entire topic (31.16) had been dedicated specifically to the transportation of rural workers. Interestingly, NR-31 was not issued from the government's transport sector, but within its agriculture sector: i.e. the Brazilian

Ministry of Agriculture. This particular regulation determines the health and safety conditions in agricultural, livestock and forestry occupations.

Therefore, although this research acknowledges the legal conditions affecting this transportation, confirmed by recent moves and consequent improvements, the inadequacy of the vehicles used and the legislation about this context represents a serious research gap which needs to be filled. This is why, on the basis of the rapid expansion of the sugar cane industry during the last few years, the impact of accidents involved in this kind of transportation, and the resulting social concern have forced the Brazilian government to invest in solutions to this problem by sponsoring research which will tackle it. This research itself is an example.

In the present thesis, the transportation of Brazilian sugar cane cutters is analysed in depth, and design solutions developed as a result of this analysis. The current challenge of transporting rural workers, in which Brazil is one of the biggest players in terms of its requirements for off-road vehicles, is due to two main factors: first, unlike elsewhere, agricultural companies in Brazil are legally responsible for the transportation of their rural workers, even if it is contracted out. Second, unlike other countries, such as Australia, where agriculture is mainly based on small family-owned farms, in Brazil huge plantation fields are owned by large sugar cane companies, resulting in significant numbers of workers per company needing to commute.

Nevertheless, what about alternative options for this transportation? The simple solution would be to pave the unpaved roads. However, although building proper paved roads or even establishing a railway system are obvious options, they might be not economically or technically viable solutions. There is the other possibility of using an aircraft (a helicopter) as a solution. This would solve many of the problems, but the cost is also prohibitive, putting such a solution out of question. Therefore, we can conclude that the development of a more appropriate and specific land-based vehicle for the transportation of sugar cane workers might be the most appropriate solution.

## 1.2 Objectives

In comparison with more traditional fields of knowledge and study, design is relatively young, as is research in design, and particularly in vehicle design. Nonetheless, because research is not only about generating knowledge, but most importantly it is about creating new opportunities and possibilities capable of converting existing realities into better ones, this means that rather than merely studying the problem of transporting people over rough terrain, this research, above all, is about improving the sugar cane cutters' everyday life.

To achieve this, the wider context of this thesis is the creation of links between design, technology and people. In theory, this seems to be an easy thing to establish. However, in practice it is much more complicated than that. How can cultural and technological knowledge be combined to improve everyday life through design innovation? To answer this question, I also argue, through more specific and comprehensive research, for the possibility of moving towards the adoption of a cross-contextual analysis, instead of a traditional consumer-led approach. In order to do so, the **Research Objectives** are outlined as follows:

1. To improve the transportation of people - particularly rural workers - in off-road conditions, through appropriate vehicle design solutions
2. To improve the cutters' health, safety, welfare and consequently their everyday life
3. To offer the cutters a better transport experience
4. To reduce transportation costs
5. To increase agricultural production

Although cutters constitute the core element of this investigation, it also involves the consideration of other factors related to the problem, such as bus manufacturers, agricultural companies and legislators. This makes the possibility of implementing the solutions easier, taking into consideration the fact that by incorporating an awareness of legal aspects into the research, the legislation about this particular kind of transportation in Brazil will be able to take on board more relevant manufacturing and economic issues.

## 1.3 Research Design

Considering the fact that the results of this research will lead to a design specification and solutions, and based on the information presented so far, it is clear that the methodological approach of this research must to be interdisciplinary. This is because the evolving nature of the observed and discussed phenomena means that any aspiration to a linear and sequential methodological approach has to be compromised in favour of a network of inter-connected approaches.

Because this research is involved in tackling a new problem about which little is known, it could be classified as **exploratory research** as referred to by Phillips (2005). This kind of research involves extending the limits of knowledge in the hope that something useful will be discovered. However, it is also **problem-solving research** (Phillips, 2005) considering that it starts from a particular and real problem, bringing together the available intellectual resources to bear on its solution. Thus, this research is a combination of both problem-solving and exploratory research, and the result, referring to Evans (2007), is a mixture of creative thinking based on both hypotheses and rational thinking, and founded on the execution of methods, investigation and analysis of the results in the light of existing theory.

Taking into consideration the fact that the vehicle for the transportation of sugar cane cutters, rather than being merely a product, is involved in both production and a human interface, demanding a data-gathering process based not only on the vehicle's key factor of mobility, but also its interaction with the terrain over which it travels and the people it transports. According to Quarante (1994) quoted by Camara et al. (2001), *...in the development of design projects, it is important to observe three factors: the interpretation of the term product; the interpretation of the term user, and the context of the framing of the problem...* For this reason, the structure of this present investigation is based on what I name Research Interactive Analysis (RIA) (see Figure 4). It involves the three main factors as part of the transportation process as well as allowing an interaction among the three.

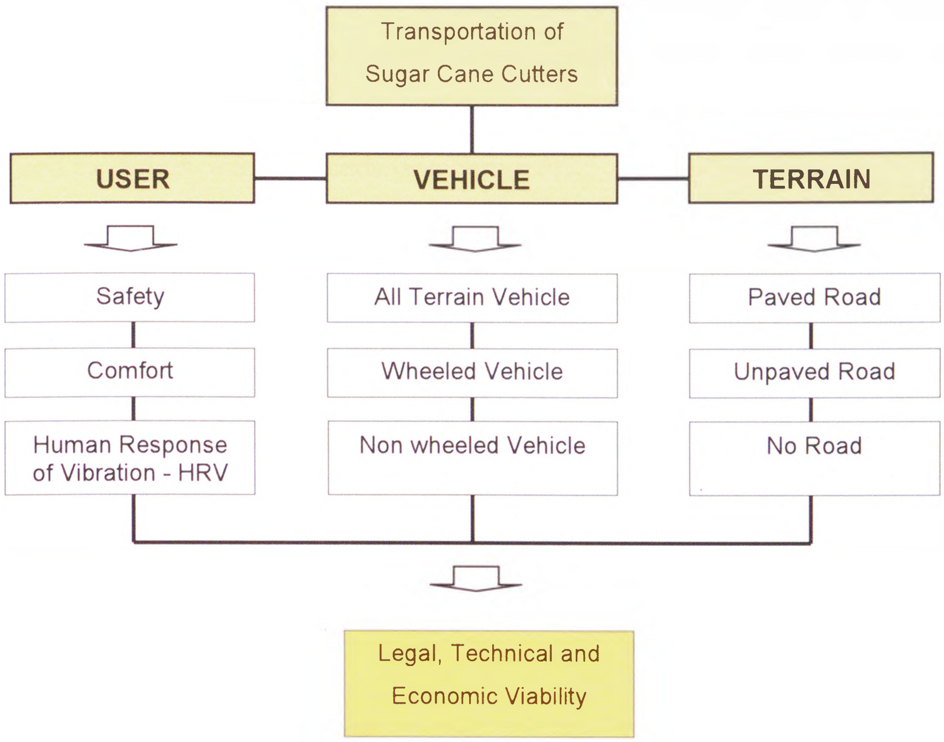



Figure 4: Research Interactive Analysis (RIA).

Part of the background chapter relies on examining the nature of sugar cane cutters' transportation in Brazil through a broader and multidisciplinary perspective, combining knowledge mainly from the fields of design, engineering and ergonomics. The insights gained from this work have been used to develop the content of the research structure and the relationship between its chapters. In this sense, this investigation is a combination of **qualitative** and **quantitative** methods, and ends up requiring four different research methods, as follows:

- Travel and road analysis
- Participant observation
- Survey and interviews, and comparative cost analysis of other alternatives
- Eestablishment of key criteria for new vehicle types

When adopting a qualitative mode of study such as participant observation, the challenge is to demonstrate that critical thinking has arisen from an inevitably more complex setting, such as the behaviour of the participants. In contrast, when carrying out a quantitative mode of study, the challenge is to present the collection of data in a clear fashion in accordance with the research framework. The social perspective of this investigation is primarily interpretative, involving both ethnographic and user experience research. The ethnographic study is much more related to the evaluation of users' behaviour, and is applied here to identify latent needs, whereas the user experience analysis is much more related to the interaction between the user and the product (in this case the vehicle) and it is used to identify explicit needs (see Figure 5).

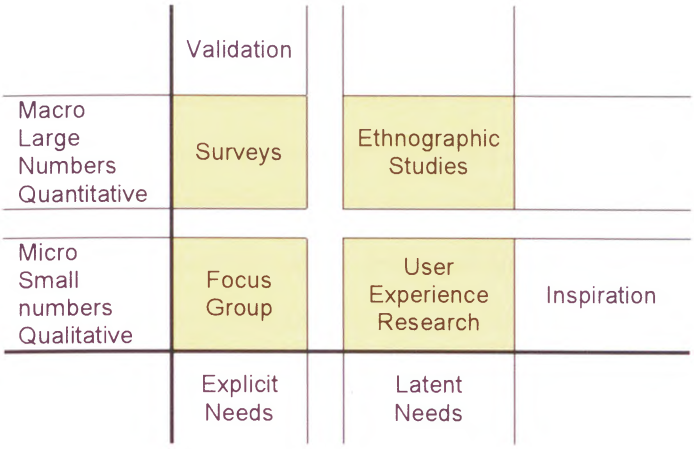



Figure 5: The field research approach.

Finally, it is important to make clear that this research is the result of a PhD by thesis, rather than by project. Although the problem analysed here is not hypothetical, and the design solutions proposed as part of the study are viable, feasible and ready to be implemented, they still represent a theoretical study, and the research does not include a prototype.

## 1.2 Overview of the Study

In setting out to achieve the aim of this research, this takes into account the importance of the vehicles as a mobile facility centre on the plantation, in order to better understand the importance of the vehicle itself to the workers in this context as well the importance of the facilities as part of it.

The literature review relating to off-road transportation, vehicle locomotion and terrain provides a long-term perspective which allows a better understanding of the current situation. It establishes how the actual use of the vehicle transporting sugar cane workers could contribute to improving the establishment of design solutions to tackle the problem. The participant observation focuses on reality of the everyday life of the cutters involved, and describes their work procedures, habits, preferences and behaviour when commuting and working on the plantation. Part of this data, when compared to the data gathered by Rodrigues (1993), allows an analysis of the cutters' new habits to the evolution of transportation since then. This approach helps to visualise this transportation, not only as an isolated activity, but as part of the whole context.

Chapter 2 (Background) positions Brazil as the current international reference point for management and technology regarding sugar cane production, and also the position of this industry in the history of the country. Regarding the transportation of sugar cane cutters, it argues that rather than analysing and discussing the adaptations incorporated in the vehicle, such adaptations need to be reconsidered as a whole. The chapter also positions the Brazilian sugar cane industry in comparison to the conditions in other sugar cane producing countries, and confirms the transportation of sugar cane cutters as a worldwide problem that needs urgent attention. The chapter concludes by presenting the hypotheses and research question.

Chapter 3 (User Analysis) looks at the lives of Brazilian sugar cane cutters, pointing out the problems encountered in commuting twice daily. It argues that the improvements in the transportation of cutters contribute to an increase in their production capacity. Regarding the mechanisation of sugar cane plantations in Brazil, it argues that despite the intention of the sugar cane industry to invest in mechanisation, the need for the transportation of sugar cane workers will remain for many years to come. This chapter also presents the methods used for the field research sessions which inform the user, vehicle and terrain analysis as well as forming part of the economic analysis.

Chapter 4 (Vehicle Analysis) explores the potentially suitable vehicles for off-road applications and the current vehicles used in the transportation of cutters. Analysing the off-road vehicles currently available on the market, ranging from hovercraft to military vehicles, it points out the pros and cons of each technology, in particular their capability of dealing with rough terrain. Second, it includes an analysis of the current vehicles used for the transportation of the sugar cane cutters, the necessary adaptations to comply with the NR-31, and an analysis of the most important mechanical parts. This analysis allows a more comprehensive understanding of how these parts work separately or together to influence vehicle dynamics, shock and vibration.

Chapter 5 (Terrain Analysis) points out general aspects of the types of terrain in Brazil in association with the climate, and their benefits to agriculture. It argues that a potential economy could be obtained by reducing travel time as well as the reduction of journey interruptions, usually caused by rain, if a vehicle more suitable for the terrain conditions that was used. It also not only points out the problem of the unpaved roads in relation to the resulting motion resistance limitations imposed on the vehicles, but also the way in which unpaved roads compromise safety, affecting the dynamics of the vehicle, and also its comfort. The chapter also presents the impact of soil compaction on agriculture, caused mainly by traffic of vehicles over plantation areas. Lastly, the chapter argues that the current terrain conditions and level of road maintenance revealed during the field research are inappropriate for the current vehicle type.

Chapter 6 (Economic Analysis) compares the costs of alternative solutions to tackle the observed transportation problem, discussing different journeys, travel distances and road types. As alternatives, the study examines the paving of the unpaved roads, the establishment of a new railway system or even the adoption of aircraft in comparison with the current method of transportation. It argues that apart from the inadequacy of the current system, the urban bus is in a better position compared to other analysed vehicles and it is by far the cheapest option for the transportation of sugar cane cutters. Thus, it should be considered as a reference point in the development of design solutions.

Chapter 7 (Design Solutions) focuses on design of the vehicle, supported by technical specifications and based on the literature review and field research. This chapter combines specific knowledge and approaches enabling the vehicle to fulfil the objectives of this research. It argues the suitability of the current design and manufacture models not only for the production of the vehicle design proposed by this study, but also for the production of buses in general. Moreover, it also argues that there was no opportunity for the cutters' vehicles to develop their own design language.

Chapter 8 (Conclusions) is dedicated to direct the hypotheses towards the fulfilment of its initial objectives. The results show that a combination of technical and ergonomic improvements developed specifically for this transportation can improve the everyday life of the cutters as well as their economic productivity. This chapter also includes recommendations related to the research problem focused on three essential elements in this context: the bus industry, the sugar cane companies and the government, and suggestions for further research.

# CHAPTER 2 - BACKGROUND

## 2.1 Introduction

The aim of this chapter is to provide a contextualisation of the significance of the research problem, positioning this problem both historically and geographically.

Although it is a subject of major importance, there has been little research done in the field of rural workers' transportation. Consequently, this research covers other areas such as soil mechanics and vibration in order to sustain the research hypotheses. This will help to make the research arguments stronger and at the same time show that the problem is not yet solved.

The chapter introduces the Brazilian sugar cane industry in a national and international context, to provide a better understanding of the wider field in which the research problem may be seen. However, as Brazil is not the only producer in the world, it is worthwhile to consider how the transportation of sugar cane cutters is managed in other producing countries, to better situate and understand the Brazilian reality. The cross-comparison of the data from this analysis thus demonstrates in detail the current nature of the rural workers' commute from and to the plantation.

## 2.2 The Transportation of Sugar Cane Cutters in Other Countries

Australia is another major player in the sugar cane industry, ranked 8th internationally. However, its sugar cane industry differs greatly from the majority of other sugar-producing countries. While in Brazil and in many other countries the sugar cane companies own enormous areas of plantation, in Australia the vast majority of sugar cane is grown in small family-owned farms. According to the National Farmers' Federation (2008) in Australia, 99% of the sugar cane industry in that country is based on individual family-owned and operated farms. Because the harvesting machine is one of the most expensive assets in the harvesting infrastructure, when the cane is ready to be cut farmers use the service of contractors, who do the job using their own harvesting machines and labour. The whole harvest infrastructure is thus provided by these contractors moving from farm to farm, harvesting the crop whenever necessary.

According to Stamford (2008), such a context, in conjunction with the more favourable topography of the plantations, makes the Australian sugar cane industry very highly mechanised, requiring the labour of few sugar cane cutters (see Figure 6), who travel from their homes to the plantation in their own vehicles. This means that because the sugar cane system is based on family farms in Australia, the groups of cutters to be transported from their homes to the plantations are small, so there is no necessity for a vehicle for the transportation of more than 30 cutters as in Brazil.

Figure 6: Sugar cane cutters in Australia.
© Ako Gallery

Thailand is one of the countries where the sugar cane industry has recently been growing fast, not only in terms of production, but also in terms of expansion, currently ranking 6th in the world. Sugar cane production has become one of the largest industries in the country, but mechanisation is not part of its industrial context yet, given the early stage of its development. This means that, like many other sugar cane-producing countries, such as Cuba, Jamaica and Guatemala, Thailand depends mostly on manual cutting labour (Chetthamrongchai, 2001). As we can see in Figure 7, the sugar cane cutters are transported by trucks, without any protection or attention to safety, which is similar to the way in which Brazilian sugar cane cutters were normally transported until the late 1970s. This means that despite the economically viable cost of the transportation of sugar cane cutters in Thailand, the vehicles are wholly inappropriate.

Figure 7: Transportation of sugar cane cutters in Thailand.
© Panos

India is currently the world's second biggest sugar producer, and the mechanisation of sugar cane harvesting is growing fast. However, as in Brazil, the majority of production relies on manual cutting, even though the system adopted by the sugar cane industry in India differs from other producing countries. There, instead of being transported, the cutters and their families live in improvised temporary 'villages' (see Figure 8) in which they stay for two or three weeks before relocating to another field.

Figure 8: Improvised sugar cane cutters' accommodation on plantations in India.
© Chullén

According to Bunsha (2002), there are two types of sugar cane workers in India: bullock cart workers and tractor workers. While bullock cart workers cut the cane, as well as transporting it to the mill on their carts, the tractor workers move from village to village, harvesting the cane and loading it on to the tractors. Both kinds of workers have to face challenges related to adequate water supply and all the other elements which are part of the range of facilities offered by the vehicle transporting sugar cane cutters in Brazil. Staying on the plantation reduces the necessity of sugar cane cutters in India to commute;

however, it creates another problem, the lack of access to the nearest town and its infrastructure when needed.

Cuba, which formerly occupied one of the highest positions in the world ranking of sugar cane production, is currently in 17th position, with its production also mostly dependent on manual cutting. Here, according to Ripoli (2008), the sugar cane cutters are transported in trucks in bad conditions and without protection. According to the same author, in sugar-producing countries in the Middle East the transportation conditions are similar to those in Cuba and Thailand, relying on normal cargo trucks or adapted pick-up trucks.

In the Dominican Republic, which also mostly depends on manual cutting, the conditions of the cutters' transportation are similar to the conditions in Cuba presented above. The Dominican Republic is 27th in the world in terms of production, and just as in Thailand, despite their convenience and acceptable cost, the vehicles transporting sugar cane cutters in Cuba and the Dominican Republic are inappropriate, as we can see in Figure 9.

Figure 9: Vehicle transporting sugar cane cutters in Dominican Republic.
© Batayouvrije

Despite the fact that the design solutions and specifications which are the outcome of this project could potentially be adopted by the sugar cane industry worldwide, their uptake will depend on a number of factors, such as government interest, the importance and scale of the sugar cane industry in the country and its agricultural policy. Based on information gathered about the reality of the transportation of sugar cane cutters in other countries presented in this chapter, it is evident that only countries in which the government is interested in this industry would have the potential to adopt a specific and appropriate vehicle for this kind of transportation. Thailand would seem to be one of these countries, for three reasons: First, because of the national programme of incentives and subsidies for sugar cane production; second, because its sugar cane planted area (1,097 million ha), as in Brazil, is divided into medium and large farms with vast plantation areas; third, because of its need to transport a considerable number of workers.

It is important to state here the difficulty of gathering information related to the transportation of sugar cane cutters in other countries. China, for example, is already the world's third biggest producer, and because of the strict control of any published data and information by the government, nothing was found relating to the transportation of its sugar cane cutters and even consultation with experts was not fruitful. Perhaps because of the social concern highlighted by the recent high profile of the sugar cane industry around the world in relation to ethanol production, this is definitely not the kind of information easily available in any published source.

Therefore, as we can see, by looking at sugar cane employment in other countries we can then confirm the transportation of sugar cane cutters is an urgent worldwide problem. The nature of the Brazilian sugar cane industry structure, based on vast plantation areas owned by private companies, thus became a decisive element in this transportation context, for two main reasons: first, because it results in a concentration of a vast number of workers in each company, requiring vehicles capable of transporting more than 30 people. Second, because in accordance with Brazilian law, the agricultural companies are responsible for the transportation of their workers, and thus they have to acquire a fleet of vehicles or contract the service from transport companies.

## 2.3 The Sugar Cane Industry in Brazil

Originating in Asia, sugar cane has been part of the range of Brazilian agricultural resources since 1532, when it was first brought to the country by the Portuguese. Because the sugar cane bagasse, generated after the process, is used by the industry to produce electric power, sugar cane companies are not only self-sufficient in energy, but are also able to sell part of it to energy companies. According to Hayes (2007), considering the vast residues of lignocelluloses present in the sugar cane bagasse, it could be an even richer source of ethanol in the future. Thus sugar cane has become one of the most important agricultural industries in Brazil, serving as an example for other producers around the world. With current annual production running at around 500 million tonnes of sugar cane, Brazil is currently the world leader in this field, followed by India and China.

Although discussion about bio-fuels is part of the global political agenda nowadays, the most important reason for Brazil's current leadership in this particular technology started over 30 years ago, with the oil crisis in the 1970s. Affected badly by the oil crisis, Brazil started developing other fuel alternatives in order to reduce its international dependency on oil, and alcohol was the most promising alternative. On account of this, an alcohol national programme (Programa Nacional do Álcool – Proálcool) was created. The result of 20 years' work, £2.5 billion on incentives, and technological development in tackling oil dependency, allowed the country to save 10 times the investment in oil imports alone. At present, taking into account the fact that the number of vehicles in the world is reaching one billion units, even the oil companies are admitting that bio-fuels will be crucial for serving the growing demand for fuel, predicting a figure of 10% of the market for this kind of fuel by 2030.

On account of this, no other country is better placed to cash in on the global quest for bio-fuels than Brazil, where investors are planning to spend some US$ 12.2 billion on 77 new ethanol plants over the next five years, as well as US$ 2.4 billion to expand existing ones. By 2012, a total of 412 distilleries will be producing 35 billion litres of ethanol (The Economist, 2007). Ultimately, Brazil would like to see ethanol traded as freely and widely as oil because it could potentially boost exports from the current 3 billion litres to as much as 200 billion litres by 2025. This would be enough to replace one tenth of the world's petrol consumption. Thus, because of the current position of sugar and ethanol production in Brazil as a strategic industry in the agricultural sector, the number of cutters and their transport requirements have increased proportionally, as we can see in Figure 10).

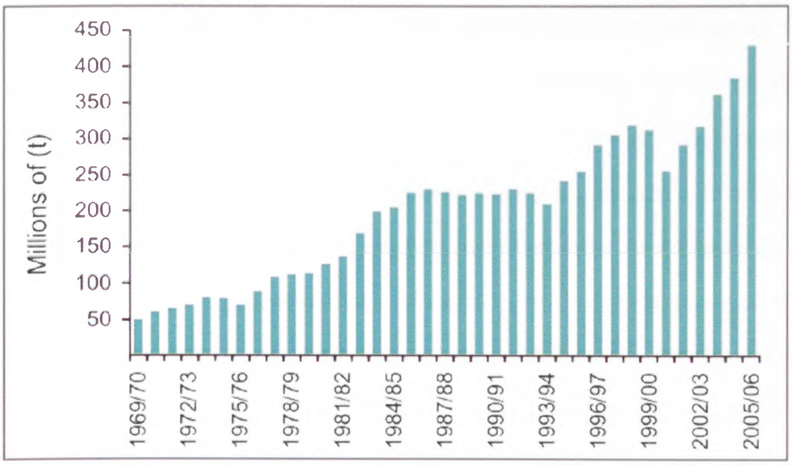



Figure 10: Brazilian sugar cane production expansion.
© Ministério da Agricultura, Pecuária e Abastecimento (MAPA)

Although the success of the sugar cane industry in Brazil is built on the best practices in production, handling and technology, much can still be done in terms of improvements in the overall efficiency of the industry. The part related to the sugar cane workers and their transportation has been monitored by the authorities for a while. As we saw previously in section 2.2, this particular kind of transportation in Brazil differs from other sugar cane producing countries because of the way the sugar cane industry in Brazil is structured, as discussed earlier.

Also, due to the favourable climate conditions in Brazil for sugar cane, two types of sugar cane normally grow in the country: year, and year and a half cropping varieties. They only need to be replanted (see Figure 11) after five or six harvest seasons on average, depending also on soil conditions and quality. In the traditional process of harvesting by manual cutting, the sugar cane plantation is burnt before it is cut (see Figure12).

Figure 11: Planting sugar cane.
Figure 12: Burning sugar cane before manual harvest.
© UDOP

Burning is highly efficient from the manual production point of view, taking into account the fact that it cleans the plantation by eliminating the dry sugar cane leaves, for example. However, sugar cane burning is undoubtedly not an environmentally friendly process, due to the resulting carbon emission. Even so, Brazil's level of carbon emission is one of best in the world, ironically, due to the adoption of ethanol in its vehicle fleet, which eliminated 600 million tonnes of carbon emission between 1974 and 2004. According to Amorim (2008), quoted by Rumsay and Wheatley (2008), Brazil currently presents a per capita carbon emission of 1.76 tonnes/year, while the average worldwide emission is 4.18 tonnes/year. Nevertheless, the carbon emission resulting from the burning process, and the inherent harsh conditions of the manual cutting, are the most important factors in the acceleration of mechanization. This is simply because a harvesting machine can cut the sugar cane without it being burned.

Despite the difficulties relating to transportation on plantations on rainy days, the sugar cane, once burned, starts a fermentation process which demands that it reaches the mill preferably within 24hours after the burning. This means that in this period of time the sugar cane has to be cut, transported and crushed, making transportation and logistics crucial in this process. At present, there are agreements established between the agricultural companies and the government focusing on the reduction of the burning of sugar cane plantations. However, it is important to bear in mind that in order to achieve this, the sugar cane mills have to improve their resources, being able to work more and more with un-burned sugar cane, with a necessary investment in more environmentally-friendly technologies to process the raw sugar cane with leaves and dust.

With an area of 249,000 km$^2$, equivalent to the area of Switzerland, Sao Paulo State (SP on the map below) is not the largest Brazilian State (it is the 12$^{th}$ largest in area) as we can see in Figure 13; however, with 3.8 million hectares of sugar cane planted area, it is far the biggest producer in the country, responsible for 60% of the national production.

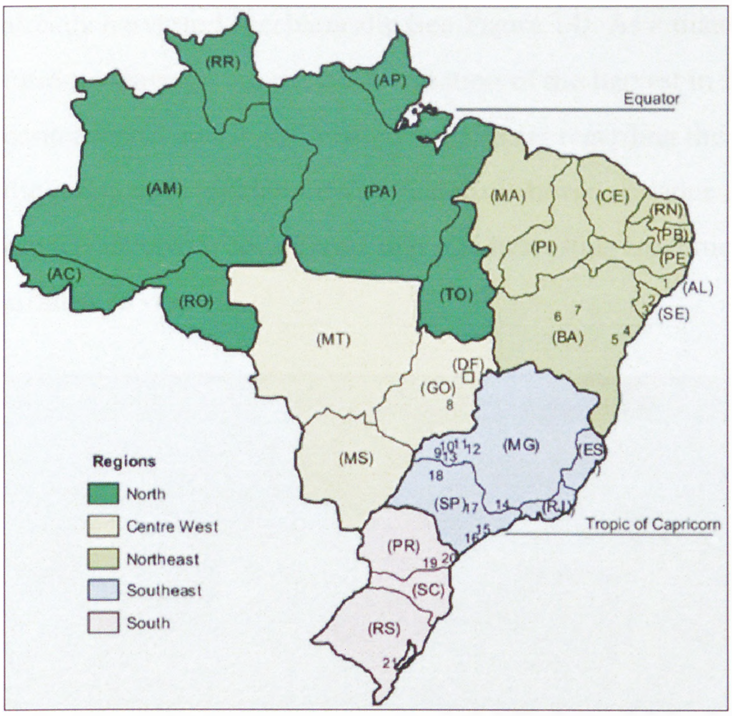



Figure 13: Map of Brazil.
© FAO adapted from ANDA

As we can see in Table 1, while in 1938 sugar cane occupied 0.8% of one particular plantation area (Jaboticabal municipality) in the interior of this state, in 1980 the proportion was 53%. This constitutes a 67-fold increase in a 42 year period.

| Year | Coffee Planted Area* | Orange Planted Area* | Sugar Cane Planted Area* |
|---|---|---|---|
| 1938 | 15,533 | 105 | 295 |
| 1950 | 3,321 | 31 | 1,371 |
| 1960 | 2,104 | 481 | 4,571 |
| 1970 | 601 | 1,132 | 13,929 |
| 1975 | 323 | 4,776 | 16,723 |
| 1980 | 457 | 2,496 | 31,251 |
| 2002 | 8 | 125 | 40,112 |
| * hectares | | | |

Table 1: Evolution of the sugar cane planted area in Jaboticabal SP - Brazil.
Source: Jose Baccarin (1985) and IBGE (2005)

The expansion of sugar cane planted area, combined with the expansion of the industry by 70% over the last five years in Sao Paulo State, has resulted in the number of sugar cane cutters being almost the same as it was in 1993, even having 30% of all sugar cane already harvested mechanically (see Figure 14). As a matter of fact, like in any other sugar cane-producing country, mechanisation of the harvest in Brazil is currently the most controversial and hotly debated social issue regarding the cutters. The main concern of the companies and labour associations is how to balance the social, economic and legal aspects involved, considering that one harvesting machine is capable of doing the job of around 75 cutters.

Figure 14: Sugar cane havesting machine.
© Uniao dos Produtores de Bioenergia (UDOP)

This research, then, acknowledges that because ethanol as a source of energy has become one of the most significant agricultural products in Brazil, this industry will be healthy for years to come, based on two main factors. First, because of the success of the Brazilian system for distributing ethanol to petrol stations resulting from the invention of flex-fuel cars which are able to run happily on any combination of ethanol and gasoline. Second, because the global awareness that fossil fuels overheat the planet and cost too much. The combined effect of the importance of this industry and its plantation areas, the necessity of transporting rural workers and the legal responsibility of the agricultural companies in relation to this, makes it evident that the transportation of sugar cane workers in Brazil will continue for years to come, and urgently needs solutions.

## 2.4 The Transportation of Sugar Cane Cutters in Brazil

Until 1940s the majority of rural workers in Brazil were living on farms, and as the farms were much smaller compared to the current size of the plantations, there was no requirement for transportation for these workers. Transportation of rural workers at that time was by horse, on foot, or exceptionally by bicycle. However, with the increase in the planted area, the improvement of the agricultural machinery and the beginning of agricultural enterprises, sugar cane companies in particular, this situation changed, with the number of workers soaring, consequently increasing the necessity of transporting them from the farm villages to plantations.

On account of this, according to Ferreira (1992), the first union mobilization demanding better transportation conditions for rural workers took place in 1945, when low lateral protections for the trucks used at that time were demanded. The second mobilization called for the adoption of canvas in the vehicles. However, even simple improvements like these started to be accepted and implemented only in the 1980s. Unlike today, the trucks used at that time for the transportation of rural workers were also used to transport cargo and crops. This might be one of the reasons why there was a strong resistance to implementing even small modifications to the truck in order to offer better conditions of transport for the workers.

In the 1970s, with the implementation of new educational plans and other government incentives, these rural workers left the farms for the towns surrounding the agricultural companies. This movement increased dramatically the need for the transportation of these workers from their city homes to the plantations. This transportation now involved more workers, longer distances and a higher diversity of terrain conditions and road types. For this reason, the problems related to transport accidents involving this occupational group travelling in very unsuitable vehicles (see Figures 15 and 16) soared, characterising one of the most challenging periods in terms of the transportation of rural workers, mostly in the sugar cane industry.

Figure 15: Exterior of an ordinary truck transporting sugar cane cutters in 1970s and 80s.
Figure 16: Interior of an ordinary truck transporting sugar cane cutters in 1970s and 80s.

Because of the increase in the number of accidents involving the cutters in the 1980s, the transport authorities in Sao Paulo State acted to make specific changes to the existing legislation regarding the use of trucks for the workers (see Figures 17 and 18).

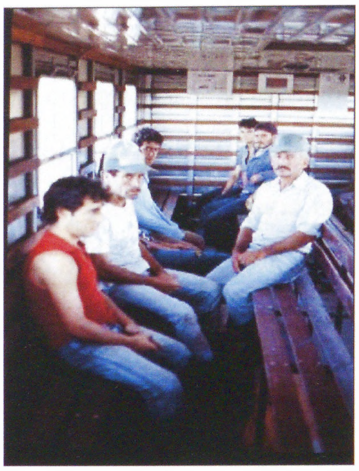


Figure 17: Exterior of an adapted truck transporting sugar cane cutters in 1980s and 90s.
Figure 18: Interior of an adapted truck transporting sugar cane cutters in 1980s and 90s.

In the early 1990s, with the publication of the Regulation NR-17 on ergonomics, stating in its item 17.1.2 that "*...it is responsibility of the employer to undertake an ergonomic analysis of the work activity, and for the evaluation of the adaptations of the work conditions to psychological and physiological characteristics of the workers"*. It was then that improvements in this transportation were noted. However, it was the publication of the Constitution of the Sao Paulo State, resulting from trade union and general attorneys pressure, that through its Article 190, these trucks were no longer permitted for the transportation of rural workers in many municipalities, which constituted an unquestionably historic achievement. Based on this article the use of second hand urban buses for the transportation of sugar cane cutters started (see Figures 19 and 20).


Figure 19: Exterior of an adapted urban bus transporting sugar cane cutters in 2000s.
Figure 20: Interior of an adapted urban bus transporting sugar cane cutters in 2000s.

Nevertheless, even in the early 1990s it was already possible to observe two main points: first, the impact of the lack of more precise and specific information about the transportation of rural workers to provide the necessary background and support to the legislators to better define transportation procedures and actions. Second, the problem had not being discussed by a group represented by all parties involved with this kind of transportation, such as workers, bus manufacturers, agricultural companies and legislators, in order to produce a more appropriate, suitable and effective solution for the problem. As a result, any initiative towards the improvement of the transportation of the sugar cane workers at that time still had many obstacles to overcome due to the fact that there was not enough technical background to the legislation.

With regard to distances travelled by the cutters, according to Rodrigues (1993), the commuting distances from their homes to the work area on the plantation varied from 40 to 60km (one way) in 30% of the cases (see Table 2), with travel times varying from 30 to 150 minutes in 20% of the cases (see Table 3).

| Travel Distances | 1993 |
|---|---|
| From 5 to 20km | 20% |
| From 20 to 40km | 50% |
| From 40 to 60km | 30% |

Table 2: Travel distances for the sugar cane cutters in SP State in 1993.

| Travel Times | 1993 |
|---|---|
| From 30 to 60 minutes | 30% |
| From 60 to 90 minutes | 30% |
| From 90 to 120 minutes | 20% |
| From 120 to 150 minutes | 20% |

Table 3: Travel times for the sugar cane cutters in SP State in 1993.

Taking into account the fact that the sugar cane cutters represent a very important group of workers within the Brazilian agricultural sector, it is worthwhile to note the proportion of transport accidents in this industry in comparison with the same transportation activity in other agricultural industries. Table 4 shows that from 1997 to 1999, a total of 51,644 agricultural accidents occurred, 16,778 or 32.8% of them being related to the sugar cane industry. In addition, according to Fundacentro, 929 of those accidents took place in Sao Paulo State alone.

| Rural Work Accidents by Economical Activity (National Classification) | Accident Types | Labour Diseases |
|---|---|---|
| | Total | Total |
| Agriculture | | |
| Sugar cane planting | 14,661 | 2,069 |
| Citrus fruits planting | 993 | 53 |
| Coffee planting | 216 | 11 |
| Cereals planting | 103 | 7 |
| Flower planting | 95 | 17 |
| Industrialisation | | |
| Ethanol | 1,118 | 210 |
| Sugar | 937 | 107 |
| Distilled drinks | 200 | 7 |
| Juices | 61 | 6 |
| Sao Paulo State from 1997 to 1999 | | |

Table 4: Rural work accidents according to activity in SP State from 1997 to 1999.
Source: Fundacao Seade and Fundacentro

More specifically, Rodrigues (1985) reveals data from a study including eight regions of the Sao Paulo State showing that in just one year (from 1979 to 1980) the number of fatalities as a result of traffic accidents involving sugar cane cutters increased by 100% and the number of slight injuries increased by 55% in relation to the number presented in 1978. More recently, according to Garcia (2006), 416 sugar cane workers died, mostly in accidents while commuting. Therefore, more serious concerns thus emerge, such as the social problem resulting from these accidents, which left the families of the victims, in many cases, without enough financial support.

Despite the clear improvement in the transportation of rural workers in Sao Paulo State, particularly in the last 15 years, it is very important to make clear that unfortunately these transportation conditions are not matched in the rest of the country, as we can see Figure 21. This vehicle was highlighted by research undertaken in Pernambuco State (North East region) by Fundacentro (2005). There, as in many other states in the north it is still common to see not only very inappropriate vehicles transporting sugar cane cutters, but also in bad conditions. It is thus confirmed that there are still many examples of transportation in worse conditions than the adapted trucks previously noted that were used in the 1980s in Sao Paulo State.

Figure 21: Rudimentary improved truck still in operation transporting sugar cane cutters.
© Delegacia Regional do Trabalho de Pernambuco.

Regarding the transportation experience of the cutters and their interaction with the vehicles during the journeys, apart from the research undertaken by Rodrigues (1993), there is no other study of the cutters' journeys from their homes to the plantations. Although the aim of the 1993 research was to identify and discuss the ergonomic aspects of this transportation, involving observation as part of the process, it did not include any formal behavioural study based on more appropriate methods such as user experience or ethnography. I propose that the relationship between the vehicles and the cutters must be taken into account not only as a mere means of transportation, but as a mobile facility centre in this context. If I am arguing that more specific and comprehensive research must be taken into account in order to move beyond traditional consumer-led approaches through cross-contextual analysis, then field research based on participant observation, and methods based on ethnography and user experience must be adopted in order to unpack the problem and interpret the findings in a more reliable and effective way.

Another important issue revealed by the 1993 research was that, based on the evidence of the first attempts and experience of some bus manufacturers to try to improve the conditions of the vehicle transporting sugar cane cutters at that time, Rodrigues (1993) stated that the problem was related much more to the legislation than the manufacturers themselves. It was pointed out that the manufacturer knew what to do to tackle the problem, but the solution was not progressing beyond that stage due to the discrepancy in the law. However, in the light of preliminary investigations for the present research, it is possible to see that this statement can be partially rejected. If current adaptations implemented to the buses are still not the answer to the problem: if the manufacturer, through its technology and resources, has conditions to produce the 'right vehicle' for the purpose, and the law has the power to request this 'right vehicle' for the task, then the law should wisely use its power to be more specific, including specifications which would lead the manufacturer towards these more appropriate design solutions. The goal of the law, in this case, would be to present 'what' to do, whereas the goal of the manufacturers would be to present, in a form of a vehicle, 'how' to do it.

Therefore, even though the best solutions in terms of the vehicles transporting sugar cane cutters in the early 1990s in Brazil were not adequate from the ergonomic, safety and technical point of view, and despite the evident improvements using buses, this transportation is currently suffering from the same problems experienced decades ago. This means that rather than analysing and discussing the adaptations incorporated in it, the current vehicle needs to be reconsidered as a whole.

## 2.5 Hypotheses

Based on the preliminary investigation presented in this chapter, including the research undertaken by Rodrigues (1993) in which the use of the adapted trucks transporting sugar cane cutters was analysed, there is an indication of an improvement in this transportation in the last 15 years. If the benefits that result from replacing the adapted trucks by adapted urban buses could improve these transportation conditions, and if adapted buses are still not good enough, then the sequence of chapters of the present research intends to test each of the following hypotheses, as follows:

1. It is believed that the inadequacy of the vehicles for this task represents an imminent risk to the rural workers, a challenge to the agricultural companies and a social problem for the country
2. It is suggested that the current vehicles do not meet the specifications that both workers and sugar cane companies need
3. It is suggested that the truck-based platform is inadequate for this transportation, and that the current combination of a platform and a body produced by different manufacturers for different purposes is even more inadequate

4. It is suggested that a better-performing vehicle in off-road conditions increases mobility, ensuring at the same time a better ride, a reduction in travel time and, most importantly, a reduction in the number of accidents
5. It is suggested that, land transportation using a bus-type vehicle remain the only viable option that should be explored for this transportation
6. It is believed that a holistic analysis is needed, involving all stakeholders but with focus on the users' needs
7. It is believed that a more appropriate vehicle designed for this purpose will improve not only the workers' everyday life, but also the sugar cane industry as well.

Therefore, the goal of improving this transportation through more appropriate design solutions and specifications is paramount. This is demonstrated by new regulations and rules introduced in Brazil in the last few years, such as the NR-31, the increase of official inspections on plantations to check workers' transportation conditions, and the interest of the agricultural companies in tackling the problem. However, despite the clear improvements in recent years, the transportation of sugar cane cutters in Brazil is not yet solved. As this chapter reveals, gaps in the theoretical framework were identified, and the intention of this research is exactly to fill these gaps. If the current adaptations on urban buses are still not the answer for the transportation of sugar cane cutters, then the research question is: **How would be possible for a vehicle to cross different kinds of terrain, transporting over 30 people from one place to another safely, quickly, comfortably and for an acceptable cost?**

## 2.6 Conclusions

The analysis of the sugar cane industry in Brazil indicates that the problems regarding the transportation of cutters is ironically a result of Brazil's agricultural industry's success.

The current position of Brazil as the world leader in this field gives a completely different dimension to this transportation problem. Two reasons can be highlighted for this: first, the fast growth of its agribusiness in terms of technology and productivity, elevating Brazil from an emerging country to a major player in the global scenario. Secondly, the ethanol produced from sugar cane is, in contrast with corn and maize, an efficient and economically viable alternative as a bio-fuel. However, there still a huge lack of investment in the transportation of workers. Third, a lack of studies in this field has been identified, resulting in regulations that did not parallel the situation in the rapidly-changing industry.

Analysing the situation regarding the transportation of cutters in other sugar cane-producing countries, it is clear that cutters elsewhere have been facing the same transportation problems found in Brazil. However, this analysis indicates that other aspects, such as agricultural policy, governmental interest and the structure of the plantations significantly affects this transportation. Furthermore, it shows that under the force of appropriate laws, the production of more suitable vehicles can definitely make a major difference to the workers' wellbeing.

This chapter also reveals that the number of sugar cane cutters in the last four decades has soared, turning their transportation into a significant challenge. As a result, this has resulted in the number of traffic accidents in the sugar cane industry being by far the highest among all the other agricultural industries in the country. Therefore, by comparing the data gathered from the literature with the preliminary research, it is clear that the inadequacy of the vehicles for this task represents a serious risk to the rural workers, and a challenge to the agricultural companies. Thus, based on this evidence, my first research hypothesis is confirmed.

In the next chapter I analyse the first, most important element of this research: the users.

# CHAPTER 3 - USER ANALYSIS

## 3.1 Introduction

The aim of this chapter is to provide an understanding of the cutters' everyday life, their aspirations, behaviour, preferences and needs.

To achieve this, the chapter starts by looking at a group of sugar cane cutters who is crucial to this research. For this reason, Hypothesis 2 is tested by contrasting their real needs and the specifics of the current mode of transportation in use. Hypothesis 2 suggests that the current vehicles do not meet the technical specifications which both workers and sugar cane companies require.

Therefore, the chapter examines the behavioural context of the cutters in relation to the transportation problem. Vibration is certainly one of the most challenging aspects of transportation, and by analysing its implications on the cutters' health and comfort during their journey, several issues might emerge. This phase involves field research in which some aspects of the cutters during their journey and on the plantation will be analysed. The method applied was chosen because it is believed that it is the most effective and reliable way to gather data from the field.

## 3.2 The Brazilian Sugar Cane Cutter

The sugar cane cutter epitomizes the kind of agricultural worker who is an integral part of the history of Brazil, having existed since the early $16^{th}$ century in the country. At that time, Brazil was already an important sugar exporter, and its sugar cane cutters produced much of the sugar that supplied the world. The industry, the technology and the working conditions have obviously changed since then. However, the last 20 years have seen the most significant improvements in this area. In Sao Paulo State the sugar cane cutters are currently transported in buses instead of trucks, and they are supplied with Personal Protective Equipments (PPEs) which they did not have few years ago.

The population of sugar cane cutters (see Figure 22) represent 40% of the total national rural labour force in Brazil, with 1.2 million people travelling on average 2,000km/month, costing £260,000/month/company. The sugar cane cutters' journey to work takes up to two hours, much of it on unmade roads which can be bumpy, and frequently become impassable because of high rainfall.

Figure 22: Manual sugar cane cutting.
© MPT

In Sao Paulo State, 30% of sugar cane harvesting is currently mechanised, and the sugar cane companies from that state are projected to achieve 100% mechanisation by 2021. However, an important factor to be considered in this context is the fact that, with the recent boom in this industry sparked by international awareness of the environmentally-friendly appeal of the use of ethanol as a cleaner fuel alternative, the number of sugar cane mills in Brazil will have doubled by 2012. Also, as the interviews confirm, many companies will not be able to mechanise their whole harvest. According to Damada (2007), unless a new model of harvesting machine able to deal with hills and unevenness of terrain is developed, it is already acknowledged at Sao Manoel mill, for example, that it will not be possible to mechanise more than 40% of its harvest.

This new high profile of the sugar cane industry, in conjunction with the Brazilian economic context, implies that it will be really difficult to mechanise 100% of the sugar cane production by 2021 as planned, for several reasons: firstly, because of the expansion in this industry, mainly in Sao Paulo, and secondly because of a combination of factors currently related to harvesting machines, such as:

- The loss of production due to the fact that these machines are not able to cut sugar cane as close to the ground as manual cutters, thus losing the 10cm sticks with the highest concentration of sucrose
- The high operational and maintenance costs of the machines - they cost 30% of the entire operation, compared to the cost of 19% of the manual cutting.
- Their limitation related to topography, because they are not capable of operating in irregular or hilly terrain (12° angle is the limit)
- Their disuse (five months at least) during out-of-harvest seasons.

Putting aside all the technical and economic aspects of the mechanization issue, there is another even more important issue, the social aspect of the inevitable and consequent reduction of number of cutters replaced by machines. Even from a strategic point of view, it is a logistic challenge, as a harvesting machine is not able to do any other agricultural operation out of the harvest season, whereas the cutters are usually transferred to other activities such as planting and plantation cleaning, according to the seasons.

Even if 100% of cutters are replaced by machines, sugar cane workers' transportation would remain necessary due the arrival of new type of rural workers' transportation. This is the issue of the transportation of harvesting machine operators, truck and tractor drivers, and all the extra and support workers. By increasing mechanisation, the industry will be reducing the number of cutters, but increasing the number of other rural workers on the plantation. At present, minibuses for 20 to 25 people have being adopted for this new transportation, doing at least three return trips per day in order to suit the needs of three shifts/day of this occupational group. By confirming the increase in this transportation, the answer for the questions number 5 and 7 from the sugar cane company survey (see Appendix 4.3), show that, even though this new transportation increased fast only in the last 3 or 4 years with the mechanisation, the number of vehicles used for it already represent 50% of the fleet of buses.

With the proportion of this category of sugar cane workers growing fast in Brazil due to the increase in mechanization, it is important to emphasise here that the design solutions and technologies proposed in this research could be slightly adapted and applied to this new category of sugar cane workers. This is possible particularly because the design solutions have to consider the option of changing the length of the vehicle, based on the need to serve a different number of workers according to different agricultural crops. For example, while 60 is the ideal number of workers in a sugar cane plantation, 40 workers is the ideal number in an orange plantation.

Therefore, taking into account the fact that originally it was not envisaged that mechanization would become such a large part of the industry, this means that even though the level of mechanisation will continue to increase, the industry, and consequently the level of production, will be expanding as well. Thus, it is possible to envisage that for years to come, the sugar cane industry in Brazil will still have sugar cane cutters sharing production with the harvesting machines.

## 3.3 Transport Accidents

From a global perspective, every year traffic accidents cause about one million deaths around the world. According to the World Health Organisation (WHO) (Gencat, 2007), in 2000 over 1.2 million people died in the world as a result of traffic accidents. Even worse is the fact that for each registered fatality over 1,000 people are left disabled or suffering the long-term consequences of accidents, putting traffic accidents throughout the world as the tenth most common cause of death for all ages.

In the European Union alone, over 120 people die every day as a result of traffic accidents, resulting in 43,000 deaths and over 4,500 injuries per year. A third of these related to young people under 25. Unfortunately, it is anticipated that the number of deaths in 2020 from traffic accidents will exceed 2.4 million.

In Brazil, however, based on statistics from Brazilian Ministry of Transport showing that in 2,000, 174,316 vehicles were involved in accidents on unpaved roads, government institutions involved with transportation have stated that the current traffic accident rate has already became a difficult problem to solve. In Sao Paulo State for example, the highest percentage (58%) of work accidents is related to transportation, confirming that the transportation of workers is also a problem for Brazil, to be tackled not only in the agricultural sphere, but also in other economic activities.

In this context, Article 455 of the 'Consolidacao das Leis do Trabalho' (CLT) (Brazilian labour law), which legislates about responsibility for work accidents states that in the case of a transport accident with a vehicle transporting workers, if the vehicle does not belong to a company and the contractor cannot afford the consequences such as to pay for damages and compensation, the responsibility is transferred to the company involved. Therefore, this implies that any small amount of effort and/or initiative from the private sector (forestry and agricultural companies, in the case of this research, for instance) could constitute an important and feasible way to tackle the problem, improving the current safety context significantly.

## 3.4 Health and Comfort Implications of Vibration

Users' perception of comfort is based on road shock and vibration. Thus, vibration constitutes one of the biggest challenges from the technical point of view, as well as from the ergonomic point of view. However, vibration has not received the attention that it deserves when compared to other occupational hazards. Therefore, this research looked more closely at the transmissibility, effects and influence of shock and vibration to the cutters during their transportation. This particular part of the study took longer than expected because of its crucial importance to the sugar cane cutters' health, comfort and safety, constituting one of main reasons motivating my decision to research the platform of the vehicle rather than just the body.

If it were possible to see vibration in action and in slow motion, it would be possible to see movements in different directions. The speed and distance of these movements determine some of the most important aspects of vibration, such as frequency, amplitude, acceleration and resonance. No matter what the conditions of the suspension of the vehicle, it is essential to minimise the harmful effects of vibration upon the users. The further the users are from the vehicle's Centre of Gravity (CG) the bigger the amplitude of vibration movements tends to be. Consequently, this problem has an important bearing on the decision about the number and distribution of people in the vehicle interior and, as a result, the establishment of its dimensions.

Frequency can be defined as the number of cycles (movement from one extreme position to another, and back again) that a vibrating object completes in a period of one second (see Figure 23). Its unit is the Hertz (Hz), so 1Hz equals one cycle per second. Amplitude is the maximum distance between these extreme positions and the mid positions and its unit is the metre (m). Acceleration is a measure of how quickly the movements change their speed in a given period of time. Resonance can be defined as the natural frequency within an object that vibrates, according to its material, structure, size and shape.

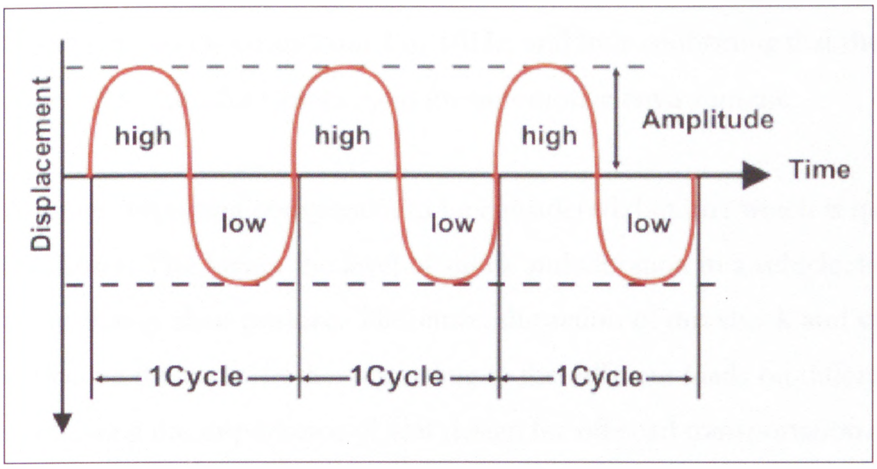



Figure 23: Representation of vibration.
Source: Canada's national Centre for Occupational Health and Safety (CCOHS)

According to ISO Standard 2631 (1997) on vibration, even though there are many ways to classify human exposure to vibration, none can be considered suitable for all situations, simply because none is universally accepted. This is because each organ of the human body has its own natural frequency, meaning that the effect of vibration exposure also depends on the frequency of vibration. However, it is possible to form some conclusions from the many studies which have been undertaken to analyse vehicle vibration and its effects on human beings.

The lack of specific and more specialised data about the effects of vibration in vehicles has also motivated some useful documentation and bibliographic initiatives (see reference list). However, according to Stayner (2001) "*comprehensive measurement of vibration magnitudes was not feasible before about 1970, and for some years after that it was a separate activity from studies of occupational health*".

In transportation, because of the higher vibration acceleration, fatigue can take place, and this is mainly because the effort and speed of the users' muscles and nervous system trying to protect the body are not enough to counter the shock and vibration. Although the vehicle is essentially mobile, constantly demanding more and more sophisticated equipment for the evaluation and measurement of vibration, there are some results of measurements related to resonant frequencies in land vehicles which can be considered here. Studies undertaken by Wilder et al. (1982), Hosea et al. (1986) and Pope et al. (1987), all quoted by Peacock & Karwowiski (1993), indicate land vehicle frequencies varying from 4.9 to 12.7Hz, from 6.8 to 12.8Hz and from 2 to 16Hz respectively. The problem here is that most of these results fit within the range of the human body's natural frequency, which varies from 4 to 16Hz, and thus confirming that the human body is exposed to harmful vibrations in the automotive environment.

Another important component to be considered, but one which is quite often neglected, is posture. The higher the level of shock and vibration in a vehicle, the more often the users change their posture. Therefore, the action of this shock and vibration has different effects on the users' bodies according to the different loads on different parts of the body, confirming the importance of seat design for off-road transportation.

According to tests undertaken by the Health and Safety Executive (HSE) in the UK, the level of vibration may be even higher when measured on the seats in comparison with the level measured on the floor (immediately above the suspension). However, ideally the seat's frequency level should be lower than frequency level produced by the platform of the vehicle. In most cases the suspension amplifies, rather than reduces vibration rates. Measuring the vibration acceleration levels on the floor and on the seat of the same vehicle operating in off-road condition it is possible to confirm this, as we can see in Figures 24 and 25.

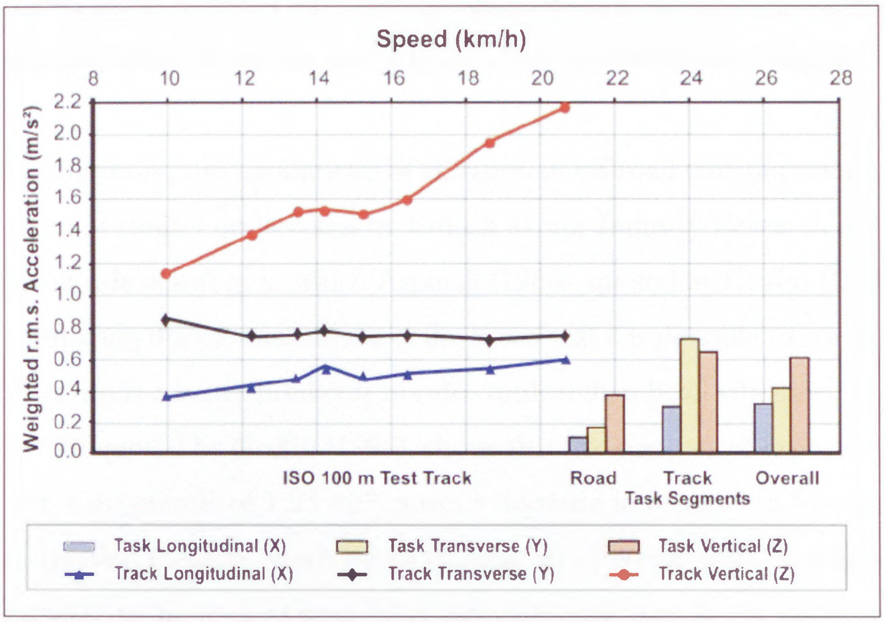



Figure 24: Vehicle equipped with coil spring suspension: Floor acceleration.
Source: HSE

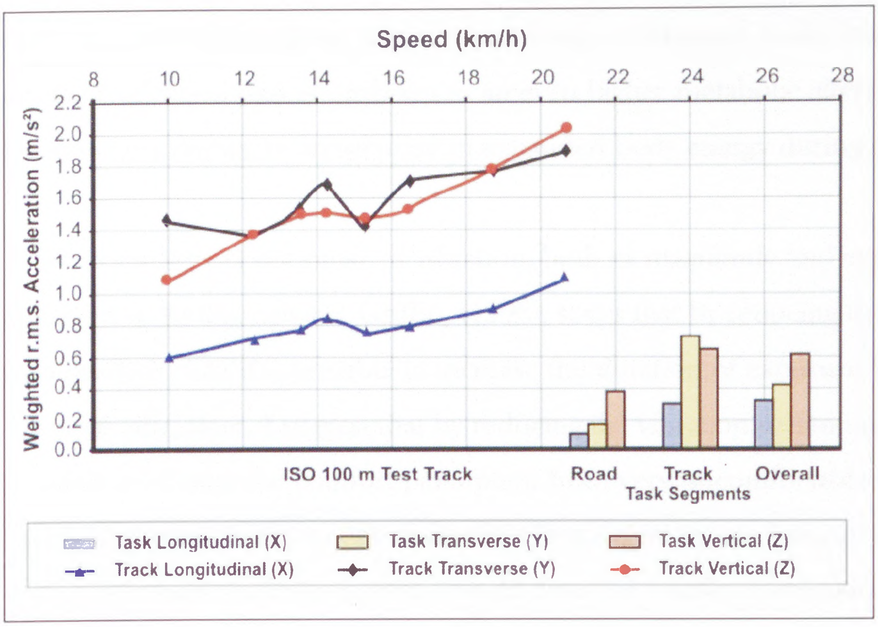



Figure 25: Vehicle equipped with coil spring suspension: Seat acceleration.
Source: HSE

The only research which demonstrates the relationship between exposure standards and health problems is by Tenschke et al. (1999). In this research, data from 25 studies are compared with the Occupational Health and Safety Regulations of the Workers' Compensation Board of British Columbia in Canada, showing that the results exceed the exposure standards' limits, highlighting the ongoing risks after five years of exposure. However, it is important to consider other aspects as well, such as the relationship between vehicle types (different dynamic features, structure, mass, suspension and wheels), different terrain and periods of use (intermittent or regular).

Furthermore, the significance of vibration in off-road transportation is confirmed in a series of studies undertaken by Brtitish Motor Industry Research Association (MIRA) about ride comfort, in which Aspinall (1960), quoted by Griffin (1996), states that by comparing the measurements of the z-axis seat it is possible to see that vertical seat vibration is a better predictor of ride comfort than head vibration. In addition, Dupuis (1969) quoted by Griffin (1996), shows that five minutes of exposure to vertical vibration with a magnitude of 1.25 $ms^2$ causes a decrease in respiration frequency but an increase in respiration volume, which might be related to findings from Rodrigues (1993) showing an increase in the level of heat, $H^2O$ and $CO^2$ emissions by the cutters during their transportation. Also, as confirmed by Moss (1930) quoted by Perseguim (2005), people exposed to vibration during transportation suffer a reduction in the capacity of their blood to eliminate carbon dioxide when, paradoxically, the same vibration effects demand more body energy to deal with the situation - having to eliminate more heat, $H^2O$ and $CO^2$ as a result. This figure thus contributes to an even higher metabolic alteration in the cutters' bodies, contributing to an increase in expanded body energy during transportation.

Thus, regardless of the cause of vibration, both its magnitude and exposure have to be considered. In this context, Griffin, (1998), states that by reducing the vibration magnitude by half it is possible to increase the duration of exposure by 16 times. Theoretically, then, I suggest that by reducing the vibration magnitude by 13% it would be possible to change the comfort perception from **very uncomfortable** (equivalent to two hours of cutters' travel) to **uncomfortable** (equivalent to one hour of travel). In other words, the same two hour journey would have the comfort perception equivalent of a one hour journey. Reducing the vibration magnitude further, by 38%, it would be possible to turn the **very uncomfortable** comfort perception into **comfortable**, the equivalent comfort level of a 20-minute journey (see table 5).

| Relationship between vibration reduction and comfort | | | |
|---|---|---|---|
| Vibration evaluation | Actual Travel Time | Vibration Level | Equivalent Travel Time |
| Very uncomfortable | 120min. | 100% | 120min. |
| Uncomfortable | 120min. | 87% | 60min. |
| Comfortable | 120min. | 62% | 20min. |
| Based on current sugar cane cutters transportation | | | |

Table 5: Vibration impact on sugar cane cutters comfort.

Therefore, even though the measurement of vibration was not part of the scope of this research, the information from the literature, in association with the evaluation of travel conditions during the field research sessions, was enough to confirm that three of the most important factors affecting the cutters were compromised during their journey: safety, comfort and welfare.

The next chapter will establish a better understanding of the impact of vibration on dynamics and shock and vibration transmissibility, in its analysis of the influence of the mechanical parts of the vehicle as a whole.

## 3.5 Methods

The field research was divided into two sessions, in July/August 2006 and January/February 2007. Having analysed the data from the first session, the findings confirmed clearly the importance of an ethnographic study to this research. It was now appropriate to gather the most important data regarding the sugar cane cutters' everyday life, by sharing their daily journey as well as their working day. These sessions were designed and undertaken to provide the right support not only for the user analysis in this chapter, but also to the vehicle analysis in chapter 4, terrain analysis in chapter 5 and part of the economic analysis presented in chapter 6 of this thesis.

The documentation was carried out through filming, photography and surveys, accompanying the sugar cane cutters from early in the morning when the buses picked up them in town until their return in the late afternoon. The reality of the sugar cane cutters' lives recorded on video in the field constituted an essential part of the research. However, even though video is important as a tool to capture this reality, offering evidence for further analysis, it is important to state that it does not allow a full understanding of the situation without the presence of the researcher in the field. In situations like this, the camera can merely record the activities, requiring challenging work in further interpreting the film. So, rather than being edited, the five hours of video recorded during this investigation was carefully analysed and reviewed, selecting certain key moments, referred to by Flanagan (1954) quoted by Raijmakers (2007) as "*incident analysis: an event occurring during a task performance that relates to the subject*".

For this reason, the footage produced during field research sessions was used as a language, in order to make the interpretation easier, as well as allowing access to the relevant phenomena. As Ferguson (2006), quoted by Raijmakers (2007) explains, phenomenology requires the researcher to perceive the phenomena she/he studies intuitively, and consequently interpret them, gaining insights from personal experience. To better illustrate this, during the observational studies it was revealed that some of the cutters – women in particular – changed their clothes for working on the plantation. This could be interpreted as absolutely normal behaviour; however, this behaviour was not observed by Rodrigues (1993), and can be interpreted as one of the positive consequences of the improvements of transportation conditions, such as a cleaner vehicle interior, for instance. Thus, after having understood more clearly the agricultural reality, expectations and needs, a structure which I named User Activity Cycle (UAC) (see Figure 26) was established as a guide for the field research. The UAC basically takes the main analysed activity, which in this case is the transportation, and divides it into three blocks of time: the cutters' journey on the streets in their towns, on the roads, and on the plantation. After this, each one of these blocks of activities is divided into specific tasks to be considered.

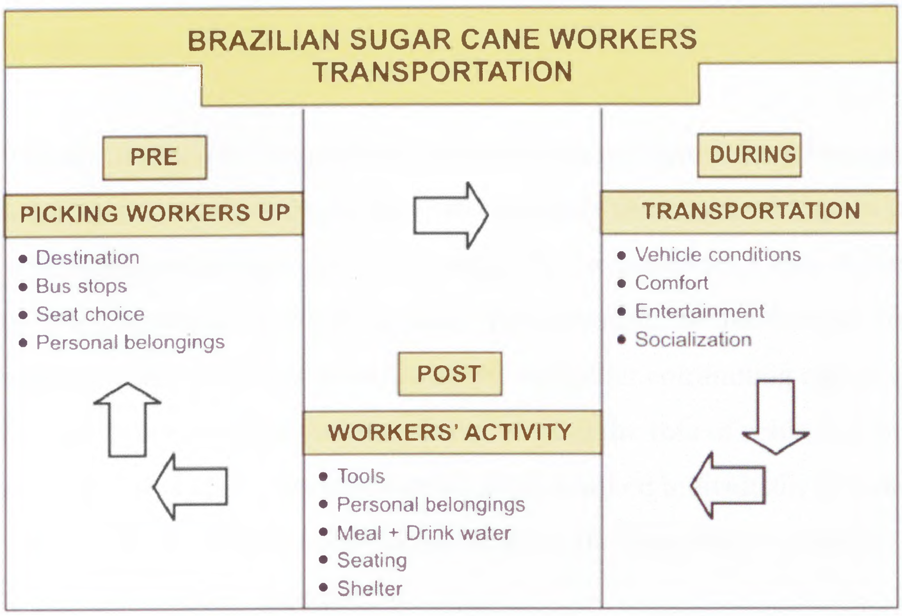



Figure 26: UAC - User Activity Cycle.

The process started with the team taking the bus between 5am and 5.30am from one of the bus stops, recording details about picking up the cutters and the trip to the plantation, with the vehicle using paved, unpaved roads and corridors crossing the sugar cane plantations. Once on board, the team was introduced to the cutters by the supervisor or driver, who also explained briefly the purpose of the field research and its final purpose as a whole. The equipment used in this activity was as follows:

- A photographic camera: Nikon Coolpix model 4600, 4 megapixels, 14.5 MB of memory, D lighting function and USB connection
- A film camera: miniDV Panasonic model AG-DVC 7
- Cutters' questionnaires
- Drivers' questionnaires.

Once on the plantation, the interviews took place with the cutters and the drivers, respecting their privacy and work schedule, and asking for their cooperation, preferably at moments when they were not in production, such as on their arrival on the plantation while they were preparing themselves and the tools for the job, during their breaks, and at the end of their shift. All of these procedures (submitted in advance to the managers in charge) were designed to disturb the cutters as little as possible. As a result, the attitude of the cutters to the research process was very welcoming and participative, with only one of cutters declining to take part. Furthermore, it is also important to state that during the entire session of field research, only one of the invited sugar cane companies, and one agricultural labour union, both in the interior of Sao Paulo State, declined the opportunity to take part in this research.

The interviews always started by creating a relaxed atmosphere between interviewer and interviewee, encouraging the latter to talk freely about general aspects of his/her relationship with sugar cane work and his/her experiences. Once the interviewee seemed to be more relaxed and talking more spontaneously, the interviewer then started asking more specific questions related not only to his/her commuting experience, but also about his/her daily experience on the plantation, and the role of vehicle as a mobile facility centre there. Finally, the interviewees were thanked individually and there was thus an opportunity to explain a little bit more about the importance of his/her information for the purpose of the research.

This approach, with the researcher asking questions, rather than the cutters filling out the questionnaires aimed to make the survey as reliable as possible. The process was:

- Less embarrassing for the cutters due to their low level of education
- More informal, by adopting the cutters' vocabulary
- More interactive, by adopting a 'chatty' approach

Even though research based on user experience and observation is the best way to analyse case studies like this, the survey based on 143 cutters (96 men and 47 women) and eight drivers was important in supporting this research. It helped to quantify the data based on observation, providing a broader dimension in terms of validation for the interpreted data as well as detecting points that for whatever reason needed to be clarified. It is important to acknowledge here the fact that the number of drivers interviewed was small and possibly unrepresentative, but it far exceeds the actual cutter/driver ratio, which is 50:1.

The questionnaire (see Appendix 3) was divided into three parts: The first part consisted of questions relating to the vehicle, aiming to identify aspects of the interface between the cutters and the vehicle. The second part was dedicated to the transportation, aiming to identify factors relevant to their experience as users. The third involved questions about the cutters' activity, and the aim here was to identify important aspects of their everyday life that could be associated with either the vehicle or the transportation experience.

Comparing evidence related to the cutters' behaviour revealed in the research carried out by Rodrigues (1993) with new information gathered from an ethnographic study as part of this present research, it should be possible, through observing the cutters' change of habits for the better, to associate these improvements with the adoption of the bus-based transportation. In doing so, it will then confirm that the introduction of a specific vehicle, based on appropriate design solutions and the right specifications, is the best way to tackle the problem.

Furthermore, to make this work as representative as possible, two sessions of interviews (see Appendix 2) were also undertaken independently, and it was thus possible to analyse the viewpoints of the agricultural companies, the bus manufacturers and the legislators (see Appendices 3 and 4). In order to ensure the accuracy of the data resulting from the information obtained, the interviews were always recorded, when the interviewee agreed.

We can now conclude, then, that taking into consideration the level of specificity of both the research approach and the social group involved, an interpretation of the data gathered by means of ethnography – recording with video and photos the daily activity of the cutters and their habits – will contribute to design solutions which are focused towards more appropriate specifications. As Heath and Hindmarsh (2002), supported by Raijmakers (2007), state, intensive research analysing the interaction between user and a particular product is very useful because it allows us to *"demonstrate the relevance of environment to actual courses of action."*

## 3.6 Field Research

Sao Paulo State was chosen to represent the current best practice in terms of the transportation of sugar cane cutters, due to a combination of factors that have combined to produce improvements, for example:

- The fact that the Constitution of Sao Paulo State in 1990 legislated for the use of buses for this kind of transportation. This means that buses were already part of the sugar cane companies' working practices 13 years before the implementation of the NR-31 Regulation, passed in 2005
- The activity of better organised and more influential agricultural unions in the state
- More access to power by the general attorneys for labour in this state
- The fact that agricultural companies here are currently far better equipped for transporting their workers than any other state in Brazil.

The North West area of the Sao Paulo State was chosen because of the diversity of sugar cane companies in that area. In this area there are three major companies (Usina Barra grande, Usina Sao Jose and Usina da Barra), not to mention dozens of other smaller companies connected to the sugar cane industry. This diversity ensured that the research methods could be applied to different terrain and road conditions, different vehicles and journeys and a range of agricultural activities with different groups of workers on plantations. Therefore, for all reasons presented above, the group of sugar cane cutters from the North West of the Sao Paulo State in Brazil was the most representative of this occupational group. If the conditions of this kind of transportation in Sao Paulo are better compared with conditions in other states, and if the research case study examines the conditions in that state, then it follows that the design solutions will be based on current best practice in terms of cutters' transportation conditions.

In order to optimise the research resources, time in particular, it was necessary to undertake this field research session in the same region. Fortunately, all the companies contacted (see Appendix 1) have many different plantations, covering a vast area. This allowed the study to combine different terrain types, surface conditions and vehicles in the same region, in order to provide not only a more effective, but also a more reliable data gathering process. As a result of this, plantations located in areas belonging to four different towns in the same region were chosen, as follows:

- Borebi
- Lencois Paulista
- Macatuba
- Perderneiras

The travelling time documented by the field research varies from 20 minutes to 90 minutes, and in the majority of cases the vehicles also spend 90 minutes collecting the cutters from different places in town. This means that if the destination of a particular plantation requires a 60-minute journey and needs another 90 minutes to pick up the cutters, the vehicle has to start at 4.30am, with the vehicle and all the cutters on board and ready to go at 6am, in order to be able to arrive on the plantation at around 7am (see Table 6).

| Sugar cane cutters Daily Shift (Field Research) | |
|---|---|
| Buses Picking the Cutters up | 4.30am to 6am |
| Work Starting on the Plantation | 7am |
| Time for Lunch One | 6.30am to 7am |
| Time for Lunch Two | 10am to 11am |
| Time for Coffee Break | 1.30pm to 2pm |
| Work Finishing on the Plantation | 3.30pm to 4pm |
| Travel Times | 20 to 90min. |

Table 6: Sugar cane cutters' daily shift according to 2007 field research

However, we can note that the commuting distances have been increased in comparison with the study undertaken by Rodrigues (1993). Currently, as we can see in Table 7, 30% of the cutters travel distances of between 50 and 70km, as opposed to the range from 40 to 60km documented in 1993.

| Travel Distances | 2005 |
|---|---|
| From 5 to 30km | 20% |
| From 30 to 50km | 50% |
| From 50 to 70km | 30% |

Table 7: Travelling distances for the sugar cane cutters in SP State in 2005.

Because in transportation distance equals time, as we can see in Table 8, the range of travelling times varies from 30 to 150 minutes, which is practically the same as presented by Rodrigues (1993) even with larger plantations. This could be because of the increase in unpaved road maintenance by the sugar cane companies, if compared with the 1993 results.

| Times of Travel | 2005 |
|---|---|
| From 30 to 60 minutes | 30% |
| From 60 to 90 minutes | 20% |
| From 90 to 120 minutes | 30% |
| From 120 to 150 minutes | 20% |

Table 8: Travelling time for the sugar cane cutters in SP State in 2005.

As this research demonstrates, two important points have to be considered here in relation to the cutters' journey. First, during transportation they are not actually productive. Second, and most importantly, by saving time on transportation, the cutters could manage their shift times and their production better. This is because in off-road transportation travelling times are dependent on the performance of the vehicle, which is limited by the terrain conditions. On very rough bumpy terrain, as well as soft soil, the vehicles have to reduce their speed significantly or risk being immobilised in mud. This research registered the speed of the vehicles transporting sugar cane cutters as ranging from 5 to 20km/h on narrow corridors through plantations, from 10 to 40km/h on unpaved roads surrounding the plantations and not exceeding 80km/h on paved roads (the speed limit for these vehicles).

### 3.6.1 Social Interaction among the Users

The results of the ethnographic study show an impressively high level of socialisation among the workers. Even early in the morning (around 6am), travelling from home to the plantation, 45% of the cutters talk during the journey, whereas 52% sleep. This reinforces the definition of mobility stated by Roberts (2007) and quoted by Kunur & Gheerawo (2007) saying that *"Mobility in many ways is synonymous with sociability. So the first positive outcome of transportation is social health – an ability to maintain and create relationships and interactions with people beyond the home."*

One of the reasons for this high level of socialisation, among other things, might be the fact that with this kind of transportation the group of cutters in each bus is always the same, which means that they travel together as well working together on the plantation. This naturally makes interpersonal relationships easier (see 27 and 28), in contrast to the situation in any other means of public transportation.

Figure 27: The social interaction among the cutters on the bus (A).
Figure 28: The social interaction among the cutters on the bus (B).

Because they share the same working area on the plantation, it follows that the same level of social interaction registered on board was continued on the plantation as well. On account of this, the cutters seem to use every opportunity for spare time - when taking a break, eating, or even when they sharpen tools - to do it together, forming small groups and talking to each other. (see Figure 29).

Figure 29: The social interaction among the cutters on the plantation.

Thus it is apparent that the normal internal layout of the buses, with two rows of seats longitudinally positioned one after another is definitely inappropriate for a vehicle to transport sugar cane cutters. This layout works well for public transport, in which the time on board is shorter, and the people mostly do not know each other, but not for a group of cutters who like to socialise in groups.

3.6.2 User Satisfaction

Despite the fact that the there are so many things which need to be improved in this mode of transportation, the study confirms that because of the visible improvement noted by the cutters having the adapted trucks replaced by adapted buses, there is a higher level of satisfaction among them compared to the level revealed by Rodrigues (1993). As this research reveals, 62% of the cutters pointed to comfort as the major advantage of the bus, and the seats are just one example of improvement. As we can see in Figure 30, the adapted trucks in 1980s were equipped with long wooden communal seats, whereas more recently the adapted buses have double plastic seats (see Figure 31).

Figure 30: Body trucks interior in 1980s.
Figure 31: Current bus interior.

Regarding the journey experience, 53% of cutters do not mind about the considerable length of time spent travelling as much as they did in 1993, even though spending less time being transported means more available time on the plantation and consequently higher production and higher income. The correlation of questions 4, 17 and 18 of the cutters' survey (see Appendix 4.1) confirms that the improvement in comfort is addressed by 62% of the cutters when comparing the buses to the adapted trucks. The implication of this finding is that improvements in their transportation are very welcome to the cutters, and they are willing to incorporate any improvements into their daily working routine.

Another important finding was related to radios on board. Two out six of the buses analysed during the field research in 2007 were equipped with a radio, in contrast to those analysed by Rodrigues (1993). This was probably due to a high level of reverberation revealed at that time in the interior of the adapted trucks, hindering the listening experience as a result. As this research shows, the adoption of this simple device has not only unanimous approval among the cutters, but most importantly it has contributed to an even warmer environment on the vehicle, increasing the cutters' sense of relaxation, creating a more enjoyable journey and minimising the inherent negative effects of this transportation.

Thus, the impact of the simple substitution of the vehicles used in this transportation was more than enough to cause a change in the cutters' behaviour in using the facilities. According to this research, 47% of the cutters enjoy the trip on the buses, seeing it as not only part of the work activity or a simple necessity, but also as a transport experience, again very different from the findings of Rodrigues (1993). This is very important, particularly considering that according to the results of the survey 70% of the interviewees had travelled on adapted trucks before, which means that the majority have a previous experience to compare it with.

### 3.6.3 **Users Looking after the Vehicle**

The results of the field research also indicate that the cutters are not only open and eager for improvements to the vehicle, but they also look after the bus as if it were an extension of their home. Contrary to the popular belief, stemming from pure ignorance, which associates a low level of education with an inability to look after equipment properly, in this case the opposite is true. This might be the reason why this research reveals that currently the Brazilian sugar cane companies are much more interested in improving the conditions of the vehicles to transport sugar cane cutters than was anticipated. Therefore, it is an important element to be considered in the establishment of the design solutions, particularly related to materials and finishing for the interior of the vehicle.

### 3.6.4 Users' Backpacks and Drinking Water Containers

As the range of facilities available to the cutters on plantations does not include a restaurant, each of them takes their own food from home. Thus, backpacks and drinking water containers constitute very important components in this context. Backpacks are used to carry the meal (100% of the cases), and also to carry among other things, PPEs

(92%), clothes (84%) and coffee, biscuits and bread (22%). Once on board, the cutters lay both the backpack and the water container on the bus floor or underneath the seats (see Figure 32). Taking into account that each of the 5 litre water containers (the most common type in use) measures 250mm wide, 250mm deep and 350mm high, together they end up requiring a significant amount of space. Once on the plantation, they are taken by the cutters wherever they go (see Figure 33).

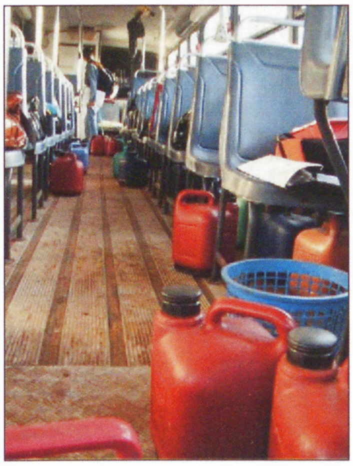


Figure 32: Drinking water containers on the bus.
Figure 33: Drinking water containers taken onto the plantation.

The backpacks and drinking water containers can thus be considered part of the tools and equipment for work, rather than mere accessories taken to plantations. However, as this research noted, the size of the individual backpacks, as well as the number of personal belongings, has increased if compared to those registered by Rodrigues (1993). This is also the result of the improvement in transportation conditions (the substitution of adapted urban buses for adapted trucks), allowing the cutters to change their habits, carrying extra items in their backpacks rather than just the meal, coffee and gloves, as was the case in 1993.

### 3.6.5 Users Seating on the Plantation

Rather than just being a portable storage item, the drinking water containers have another function related to the cutters' habits on the plantation. According to this research, the vast majority of the cutters (91%) use their drinking water container as a seat on the plantation, for simple convenience and out of habit in the absence of a proper seat (see Figure 34). Cutters, however, are unanimous in admitting that they are really uncomfortable. Moreover, 88% of them use a container with a 5 litre capacity and 12% use those with a 3 litre capacity, which constitutes determining data in the establishment of the internal layout of the vehicle.

Figure 34: Cutters using the drinking water container as seats.

There is obviously, then, a clear need for seats on plantation, particularly during coffee breaks and lunch, considering that many cutters do not go back to the bus during breaks, particularly in harvest seasons, because the bus is too far away from the cutters, sometimes over 600m.

### 3.6.6 Users' Personal Belongings

The cutters tend to use the upper handle of the seat structure in the vehicle to hang plastic bags containing small personal belongings (see Figure 35). This was observed particularly among the female cutters who, even in these demanding working conditions, environment and physical effort, use make-up, lipsticks and moisturising creams, usually carried in supermarket plastic bags.

Figure 35: Seat handles used for hanging plastic bags on board.

The personal belongings of the drivers and supervisors as well as their work equipment and materials, remain spread out all over the dashboard of the buses, as we can see in Figure 36, due to the lack of a proper storage area for these items on the vehicle. These conditions the belongings have no protection, they compromise the visibility of the driver and increase the risk of accidents.

Figure 36: Driver and supervisor's belongings spread out over the dashboard.

### 3.6.7 Tables and Chairs

The legislation also requires tables and chairs to be available on the plantations for workers' use (see Figure 37). The number of tables and chairs should be compatible with the number of cutters, but they are not, as revealed by this research. This means that most of cutters feel uncomfortable about sitting on chairs, knowing that there are not enough for everyone. They end up using their drinking water container as a seat, and staying outside the awnings. In addition, even though the number of tables and chairs is smaller than it should be, they still require a lot of storage space and there would not be enough compartments to accommodate enough tables and chairs for the whole group of cutters.

Figure 37: Cutters underneath the awnings.

Because of this, the inspectors have suggested, as a possible solution, that cutters do not all take breaks at the same time, so that there would be sufficient tables and chairs for a smaller group (20 cutters, for example). However, this contradicts the level of social interaction observed and described before, meaning that this might be not only more difficult to manage, but also unpopular among the cutters.

Also, despite the unquestionable benefits of tables and chairs as part of the range of facilities, another problem arises from the lack of proper ergonomic provision. This is the case of a recent ingenious solution: a table that remains completely fitted underneath the bus floor when not in use, being pulled out for use whenever necessary (see Figure 38). The problem is that the height of the table in this case is directly influenced by several variables related to the vehicle, such as height and conditions of suspension, size and pressure of the tyres and evenness of the terrain. As a result, as we can see in Figure 39, many cutters have to improvise, using their drinking water containers on the top of the seats in order to compensate for the difference in height.



Figure 38: Table hidden underneath the bus floor.
Figure 39: Inadequate table height and the use of a water container to compensate it.

Therefore, although the requirement of tables and chairs on plantations is very recent, as a basic requirement for the cutters, it should certainly have been made available to the cutters a long time ago. A solution should combine practicality with efficiency, providing seats and tables for the whole group of cutters transported by the vehicle, with appropriate storage. However, considering the amount of space necessary to accommodate the right number of tables and chairs, the solution is related to the products rather than the storage capacity for them.

### 3.6.8 Flooring underneath the Awnings

There is no paved road built on the plantation, and every day the vehicle and the cutters move to different plantation areas and farms, which means that the conditions beneath the awnings depend on the weather and the stage of plant growth in each area. In any case, the tables and chairs have to be on unpaved plantation terrain, which demands a certain amount of preparation and time for cleaning the area up (see Figure 40). These circumstances, together with muddy ground on rainy days, make the use of tables and chairs both impractical and messy.

Figure 40: Cleaning the terrain underneath the awnings.

Therefore, the adoption of tables and chairs on the plantation does not work without a practical and mobile flooring system for them, particularly in rainy days. In mud, and without a proper support, the tables and chairs end up sinking into the ground, making their use almost impossible in many cases.

### 3.6.9 Users' Accessibility to the Vehicle

The cutters' access to the buses, including doors and stairs (see Figure 41) is narrow, needing extra care when getting on or getting off (see Figure 42). However, taking into account the cutters' backpacks and drinking water containers, this makes access even more difficult. For this reason, it was observed that there is a clear preference for using the back door of the bus because it is wider, providing much easier access.

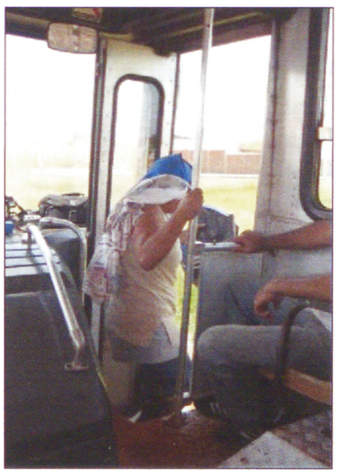


Figure 41: The access to the interior of an urban bus by front door.
Figure 42: Cutter using the stairs to get off the bus.

Therefore, the efficiency of, and real necessity for, the front door must be questioned here. It is the most problematic issue in terms of accessibility, and in this kind of transportation it is not necessary to have the two or even three independent doors usually available in urban buses. Because the need for quick embarkation and disembarkation demanded in a normal public transportation service is absent here, one efficient wide door would be enough for the sugar cane cutters' vehicle, especially because in terms of safety requirements six windows are normally available as emergency exits.

The driver's access is traditionally one of the biggest concerns of an urban bus design. This is mainly due to the mechanical layout, with the engine positioned in the front, which constitutes the majority of the platform configurations for this kind of bus in Brazil. The result of this layout is the inevitable box covering the engine inside the vehicle, taking part of the space that should be used for the driver's cockpit. This ends up seriously compromising his/her access (see Figure 43), demanding some effort to reach the driving position.

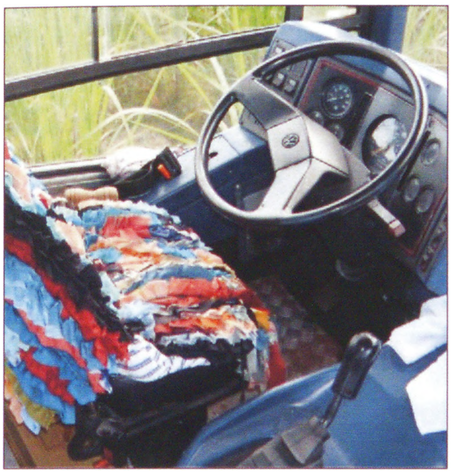


Figure 43: Urban bus driver's work place.

### 3.6.10 Users' Behaviour on the Plantation

The insights gained from this approach informed the next step, which examined the production capacity of sugar cane cutters. It reveals that their individual production has increased by 40% in the last 15 years, taking into account the fact that during the study undertaken by Rodrigues (1993), the average individual production was around 10 tonnes/day/cutter whereas they are currently producing around 14 tonnes. As a significant part of their salary is related to their production, they try to work up to their physical limit in order to maximise their production and increase their income.

Taking into account the fact that this behaviour was documented in both studies (1993 and 2007), it may be concluded that the improvement of their transportation by replacing the adapted trucks (analysed in 1993) with buses, in conjunction with other factors, such as stricter shift timing control by the companies, has contributed to an individual increase in production. Thus, even though the current adapted urban bus is not ideal for the cutters' transportation, it is clear that looking for solutions to improve the cutters' health, safety and comfort through a more adequate means of transportation, has indeed been demonstrated to be a good rationale for this research.

### 3.6.11 Difficulties Encountered during the Field Research

Even though this research has obtained invaluable support from different sugar cane companies in Sao Paulo State in Brazil, it is important to state that to undertake any research regarding the sugar cane cutters is a difficult issue in Brazil at the moment. This is because of the current high international profile of the sugar cane industry, as a result of ethanol production. As a consequence, this industry has been more frequently and effectively inspected by federal government agencies, making many companies quite uncomfortable about either discussing the subject or allowing any research related to this topic on their premises.

As the areas chosen to undertake the research were very wet taking into account the fact that some took place on rainy seasons, it was necessary to manage the dates in a different way, swapping them according to more favourable weather conditions that would allow the vehicle to reach the work places on the plantation. In addition, the diversity of agricultural activities taking place at that time, increased the level of difficulty in managing the data gathering process among the cutters. This was because the distance between the groups of cutters and the plantation areas are on average 20ha each. It meant that the researchers were constantly on the move, spending a good part of their day reaching the cutters in different locations on the same plantation area.

Also, as the most significant part of the cutters' income is determined by their level of production, another problem was trying not to interrupt their work, using the times that they spontaneously took a break for eating, resting and drinking, which cost extra time for the researchers and, as a result, decreased the number of surveys per day in comparison with the number initially planned.

Lastly, a certain level of discomfort was perceived among the cutters during the interviews, showing an interesting combination of satisfaction in taking part in such important research directly related to their needs, with the individual fear of saying anything that could somehow compromise themselves or the company which he/she worked for, jeopardising, as a result, their job. Afterwards, it was understood that the reason for this was the constant inspection from the Brazilian Labour Ministry checking on standards and regulations, and characterising another strange paradox: on the one hand there is the inspectors' job, which is to protect and guarantee the workers' rights, and on the other hand there is a misinterpretation of their work by the cutters, who sometimes seen it as a threat.

## 3.7 Conclusions

This analysis of progress in the sugar cane industry in Brazil reveals that sugar cane cutters will continue to be part of this context for years to come. The analysis of the cutters during their journey indicates the effects of vibration during the current means of transportation compromises the cutters' health, comfort and welfare. This is mainly because of the range of frequency of both the body of the cutters and the vehicle, generating resonance which is harmful to the cutters.

The field research reveals that even though the current adapted buses are still not suitable for this purpose, it is clear that the improvements made in the last 15 years have already improved the cutters' experience, satisfaction and productivity. The improvement in the current level of productivity and behaviour among the cutters also indicates that the replacement of the adapted trucks by the adapted buses has contributed to this improvement. This is mainly due to the consequent reduction in the energy expended by the cutters' bodies now, responding to better conditions of the buses compared to the trucks.

This, therefore, confirms that a more appropriate vehicle, designed specifically for this purpose, can be really beneficial not only to the cutters, but also to the sugar cane companies. As a result, Hypothesis 3 has been supported.

In the next chapter I analyse the second parameter of this research: the vehicle.

# CHAPTER 4 - VEHICLE ANALYSIS

## 4.1 Introduction

This chapter aims to analyse the vehicle and its importance as a means of transportation to the sugar cane cutters.

Such an analysis will provide an understanding of the off-road vehicles currently available on the market as potential alternatives. It will also include an examination of the bus currently transporting sugar cane cutters, and the cutters' position in relation to the transportation context as the subject of this research. Furthermore, Hypothesis 3 is tested by contrasting current vehicle models and the real needs of the users. Hypothesis 3 suggests that the truck-based platform is inadequate for this transportation, as well as noting that the current combination of platform and body produced by different manufacturers for different purposes is even more inadequate.

To achieve this, the chapter starts by comparing several off-road vehicles currently available on the market as potential alternatives for the transportation context studied here. However, besides looking at other options, this study includes what I consider to be the core of this chapter, the mechanical functioning of the bus transporting the cutters, in the light of the NR-31 Regulation. While the analysis above considers the views offered by the literature review and transportation experts, the next stage involves field research in order to compare the conditions of the vehicles and the transportation with the data gathered from the literature. The combination of data from both the literature and the field research will lead to a reasoned assessment of the technical implications of vibration.

## 4.2 Alternative Vehicles for the Transportation of Sugar Cane Cutters

Off-road vehicles could be defined as any type of vehicle which is designed specifically for cross-country application on unpaved roads, travelling to terrain far away from paved surfaces. Their higher clearance levels and higher traction enables these vehicles to access trails and temporary roads that have rough and low traction surfaces or consist of very soft soil. A range of military vehicles were developed extensively for this purpose during World Wars I and II, resulting the creation of many heavy trucks and versatile small vehicles, such as the Jeep. These off-road vehicles subsequently became available for civilian use, becoming popular not only among farmers, for agricultural purposes, but also for recreational and hobby use.

This type of vehicle includes wheeled, tracked and even non-wheeled off-road versions, such as the air cushion vehicle. The adoption of wheels or tracks depends on three factors: cost, suitability and viability. Generally speaking, although traditionally tracked vehicles perform better in a cross-country context, they are more expensive, requires a more complex maintenance, and present a limited ability to travel over paved roads, whereas wheeled vehicles are cheaper, and also generally offer higher speeds. The next pages thus present an analysis of different vehicle types for off-road applications, in order to provide a better understanding of their strengths and weaknesses.

### 4.2.1 Air Cushion Vehicle (ACV)

I started this research with firm ideas about the adoption of this technology as a possible solution for the research problem. However, after months of research, the limitations of hovercraft technology became clear, not only for land-based applications, but particularly for the conditions involved in the transportation of sugar cane cutters in Brazil.

The working principle of a hovercraft (see Figure 14) is based on the adoption of low-pressure air beneath the vehicle that forms a cushion of air and thus lifts the vehicle. In such circumstances, a hovercraft becomes amphibious and able to travel across land, soft soil or water with minimal damage to the environment, precisely because of its low-pressure footprint.

Figure 44: Hovercraft model AP-88/100 with flexible skirt.

Although the hovercraft initially seemed to be a potential solution for the transportation problem in question, it is essential to note, firstly, that the maximum height of a hovercraft should be approximately one eighth of its width, due to the fact that any other ratio could adversely affect the stability of the vehicle. This also means that issues such as payload and weight distribution are very important in the design of this type of vehicle. Secondly, there is a slight time delay between activating a control and the reaction of the vehicle. This means that a hovercraft does not offer the best controllability and response for braking and steering functions. In other words, it does not have the same accuracy of control as ordinary vehicles with wheels that touch the ground.

In the early 1960s, the Fighting Vehicle Research & Development Establishment (FVRDE) at Chertsey, UK, started to experiment with hovercrafts over land (Maclaurin, 2006). Certain problems began to emerge, confirming the observations above. They are as follows:

- Difficulty of control
- Loss of pressure through skirts when passing over ditches
- High fuel consumption
- High noise level
- Inability to climb steeper gradients

The observations above were also variously supported by different experts in this field such as Westwood (2005), from the Victorian Hovercraft Club in Torquay, Victoria, Australia; Castendijk (2005), in the Netherlands, and Jacobs (2005), at the Hovercraft

Museum in Gosport, UK. It is thus clear that despite being an attractive solution, the ACV is not an affective answer to the problem of transporting sugar cane cutters.

Motivated by the ACV limitations pointed out above, the Air Cushion Crawler concept (ACC) (See Figure 45) was created in the late 1980s by Bertelsen (1986) in the US, to replace the traditional system based on skirts. This was a result of his experiments focusing mainly on ACV limitations such as lack of control (steering and braking) and the excessive power required from the engines due to the large amount of air needed to make the vehicle hover.

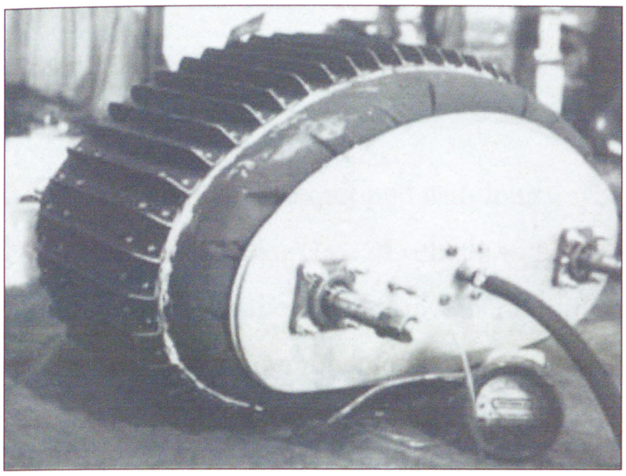


Figure 45: Prototype of Bertelsen's Air Cushion Crawler.
© William Bertelsen

These results revealed that the ACC provides excellent controllability, such as that found in a tractor or a truck. This means that it combines the ability to travel over rough terrain, including stumps, stakes and heavy brush, without incurring damage and, most importantly, with a grade-climbing capacity of 45°, which is not normally possible for air cushion vehicles. However, it is a completely new method of air cushion technology (it is not even mentioned in any of the categories of the 'Jane's Surface Skimmers' publications), and this research did not identify any recent documentation of this technology being put into production.

Therefore, even though on the one hand the ACV presents an excellent solution in terms of motion resistance and effect on soil compaction, due to the contact of the 'air cushion' with the ground and its low-pressure footprint, on the other hand it presents a poor option in terms of off-road performance, start-up investment and operational cost, even considering the possibility of adopting the ACC and its better climbing capacity, associated with a better ability to travel over rough terrain. This is because it still presents the same limitations faced by any other tracked vehicles operating on the paved roads that constitute 50% of the current commuting journey for the cutters. In addition, similarly to the ACV, the ACC represents a poor start-up investment because it is very specialized, and offers a much lower level of comfort compared to the ACV. This means that although it would be suitable for crossing different kinds of terrain, carrying more than 30 people from one place to another relatively safely, it could not do so quickly or comfortably, and the cost would be high.

### 4.2.2 All Terrain Vehicle (ATV)

The ATV is normally equipped with long travel suspension (see Figure 46), and constitutes a particular class of vehicle with its own characteristics and usefulness. One important factor is the travel (movement) of the suspension, sometimes more than twenty inches, which considerably raises the centre of gravity (CG) and as a result affects the controllability of the vehicle and the users' safety.

Figure 46: ATV - All Terrain Vehicle in operation.
© Rhino

As we will see in the discussion of military vehicle design, this research has revealed that while the All Terrain Vehicle (ATV) has been commonly associated with sporting or recreational activities, there are many other transport activities and needs that have benefited from the results of research and development into the components and systems of this kind of vehicle. Indeed, these results have contributed significantly towards pushing the boundaries of performance in terms of locomotion in off-road conditions.

However, the ATV is not the solution to the problem of transporting sugar cane cutters, either. Although on the one hand it produces excellent off-road performance, on the other it offers poor controllability and comfort to the users, a fairly expensive start-up investment, and poor cost benefit, due to its high specification.

### 4.2.3 Sport Utility Vehicle (SUV)

The use of an SUV (see Figure 47) as a daily transport solution for various needs has seen an increase in the market for these vehicles. Whatever the reasons for this, (whether connected to a sense of power or safety), this growth is now established, even though just 20% of the SUVs are used for off-road purposes, according to Land Rover (English, 2005). The profile of a typical current owner shows that SUVs are used like any other ordinary car, for activities such as commuting to work or driving the children to school, for instance, but rarely for activities that include going off-road.

Figure 47: SUV - Sport Utility Vehicle.
© Hummer

The SUV has represented a serious challenge for all manufacturers in the automotive field, including those involved with the auto-parts industry, such as shock-absorber manufacturers. One example of this technology is the recent development of a suspension designed to improve stability by means of hydraulic lines, establishing a cross-link between the right front and left rear suspensions, controlling the lateral movements of the vehicle. Air suspension is another improvement for the SUV. By means of height control, it not only guarantees extra ground clearance over rough terrain, but also ensures a much-improved ride. This can be seen in the Porsche Cayenne, for instance.

Although the SUV combines the majority of the attributes necessary for the transportation of people in off-road conditions, it is still not the ideal solution to the problem of transporting sugar cane cutters. Current SUV models provide an impressive off-road performance, and at the same time they are very comfortable, reliable and safe. They also present an excellent level of controllability, associated with a high level of shock and vibration absorption. However, all these attributes have a price, in that they depend heavily on sophisticated and expensive technology, which makes this option an unfavourable one.

#### 4.2.4 Military Wheeled Vehicle

The problem of the transport of people, ammunition, equipment and supplies over rough terrain has been researched by the military for centuries. Current technological advances in terms of electronic controls and new materials have contributed significantly to the development of ATVs for military purposes. From the beginning of military vehicle development, one of the most challenging aspects for designers has been the reduction of weight. As we saw before, the performance of any vehicle, particularly in off-road operations, is directly connected with motion resistance and speed, which in turn is influenced by the vehicle's weight, so that locomotion and weight coexist in this process. Military vehicles are normally heavy, for the following reasons:

- Most of them have to be armoured, which means extra material and thicker walls
- Most of them have to carry weapons and ammunition
- They need to be quite robust, not only in order to deal with all the extra weight on their structure, but also to resist the harsh conditions (a range of terrains, situations and weather) to which they are usually submitted whilst in combat
- In order for vehicles of this weight to achieve an acceptable performance level by military standards, they need more robust and heavier axles and suspension, along with more powerful and heavier engines

These requirements for military vehicles, as with aerial or naval military vehicles, have had a major effect on vehicle design development, new materials, and new locomotion and defence systems. It is useful to present a brief summary of the historical evolution of these vehicles, particularly because they constitute the most extensive reference point for any study of cross-country transportation, and also because of the way they have dealt with locomotion limitations, technical challenges and high-profile military demands.

The 1940s were undoubtedly the key moment for military vehicle development, due to the demand generated by World Wars I and II. The desert battle experience of the British in the early 1940s, for example, shows how effectively wheeled vehicles could operate in flat sandy areas of desert at relatively high speeds, with long range and good reliability. The adoption of independent suspension to provide a smoother and faster ride, hydraulic steering, and requirements of mass production in order to achieve lower costs also took place at this time. The T27 project is a good example of a military vehicle from this era (see Figure 48).

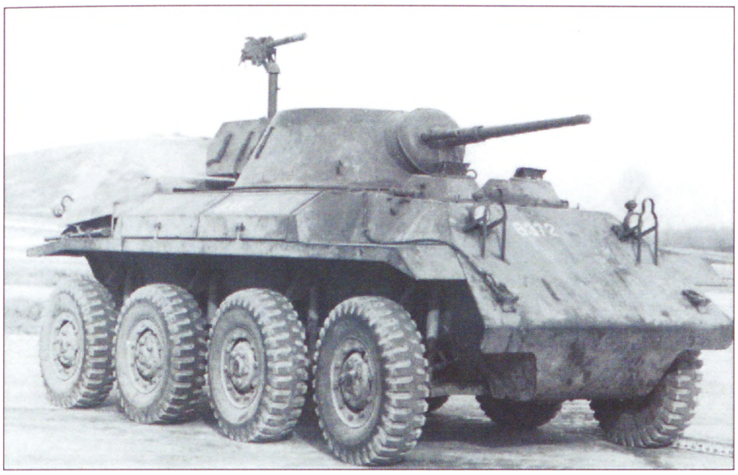


Figure 48: Military vehicle T27 from 1944.
© Hunnicut

In the 1950s, it was still difficult for military wheeled vehicles to compete with traditional tracked vehicles. For many strategic reasons, including technical and economic ones, the development of military wheeled vehicles was only taken seriously in the next decade. When this happened, it contributed enormously to the reduction of vehicle gross weight and more effective, lighter suspensions, which led in turn to a greater reduction in shocks transmitted to the crew.

One good example of the development of military wheeled vehicles in the 1960s was the 'Twister' by the US-based Lockheed Missiles and Space Company (see Figure 49). This involved the new concept of an eight-wheel vehicle (8x8) divided into two parts (bodies) joined by a pivotal yoke. The possibility of having all wheels in contact with the terrain, no matter the level of unevenness, was due to the articulation capability of each of the bodies. This allowed the vehicle to absorb shocks to an impressive extent, significantly reducing the level of vibration as a result (Hunnicut, 2002).

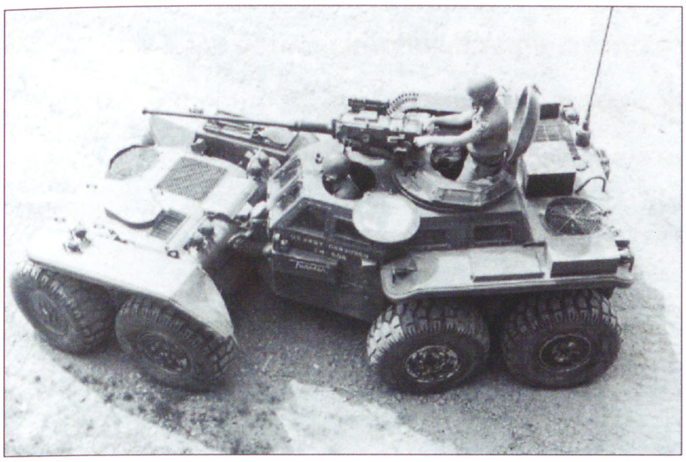


Figure 49: Lockheed Twister 1960.
© Hunnicut

However, an even more successful example of a wheeled military vehicle from the 1960s is an armoured car designed by Cadillac, the 'Commando' or 'V-100' (See Figure 50). Among other innovations, it had a wider body that extended over the axles' width and consequently the tyres, preventing mud being thrown up all over the car and most importantly, minimising the effects of landmine explosions due to an approximately 30° angled wall.

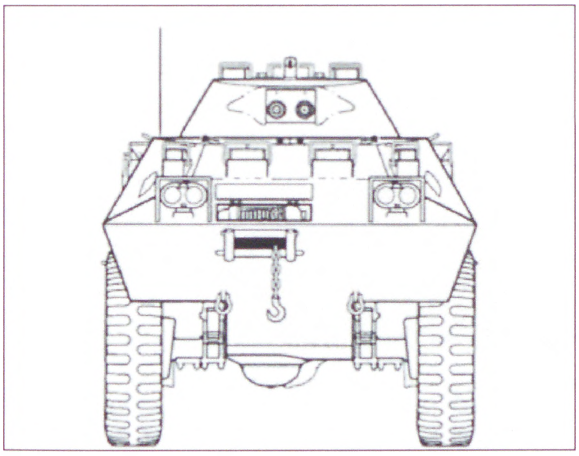


Figure 50: Cadillad Commando from 1963.
© Duplessis

The Commando was also equipped with 14x20 off/on road combat tyres. This tyre was developed as a result of recommendations of military research into a self-cleaning combat tyre. This tyre was also able to operate at 90km/h, even under a high level of deflection (internal low pressure), which is unquestionably a very good performance for a tyre if compared with ordinary cross ply or radial tyres in off-road conditions (Hunnicut, 2002).

In the 1980s, the Light Armoured Vehicle (LAV) has developed, as a result of important new military requirements which appeared in conjunction with those already in existence for decades. One of these important requirements was the increasing adoption of off-the-shelf parts and components. New limitations were also placed on the weight of these vehicles, related to the load capacity of helicopters used for transporting small vehicles for significant distances.

In the 2000s, concerns related to vehicle crew fatigue influenced the design of military vehicles towards a much more ergonomic approach, associated with the functionality of the system as a whole. Examples of this approach to contemporary military vehicle design can be seen in vehicles such as the JCB High Mobility Utility Vehicle (HMUV) (see Figure 51). This vehicle - particularly its interior - is an example of both good design and simplicity. Externally, its body is mainly constructed from special thermosetting (fiberglass) panels instead of steel, and its glazing is merely glued, instead of being attached by a rubber frame. Thus, it demonstrates the way in which design based on a combination of simple and appropriate solutions can make a difference, even in quite specialised applications.

Figure 51: JCB High Mobility Utility Vehicle (HMUV).
© JVB

Nevertheless, despite the invaluable example of military vehicle design in terms of the adoption of a wheeled vehicle and the prompting of solutions such as tyre development, the military vehicle as a whole is not the answer to the problem of transporting sugar cane cutters. Although most of them offer good off-road performance, a military vehicle is only moderately reliable. It also offers only moderate shock and vibration absorption, and is also poor in terms of soil compaction, motion resistance, start-up investment and operational cost.

### 4.2.5 Tracked Vehicle

Bulldozers and tanks are good examples of tracked vehicles. Among their many advantages, one that makes a major difference is without doubt the size of the contact area of the tracks compared to wheels. They consequently exert a much lower pressure on the ground compared to conventional wheeled vehicles of the same weight. This makes tracked vehicles appropriate for surfaces like mud and snow, as they are less likely to get stuck. They also have better mobility when travelling over rough terrain or overcoming small obstacles. However, compared to wheeled vehicles, tracked vehicles involve a much wider range of parts, and complex mechanisms which end up compromising the reliability of the system. They cannot achieve high speeds and they can severely damage hard surfaces like paved roads, even though there are currently versions of rubber tracks in use, particularly for agricultural use (see Figure 52) that minimize this problem.

Figure 52: A tractor equipped with rubber tracks.
© AGCO Toytractorshow

Nevertheless, the rubber tracks currently used in some vehicles are still vulnerable in many situations, including the agricultural. According to recent observations by Beleboni (2006), in Brazil, tractors with rubber tracks operating on sugar cane plantations need to have somebody alongside the vehicle to remove rocks and the remains of trees in its path in order to avoid serious damage to the tracks.

Therefore, despite the advantages pointed out above, a tracked vehicle is not the answer to the problem of transporting sugar cane cutters. Despite its excellent off-road performance and climbing capacity, the tracked vehicle is rather uncomfortable, offers little in terms of shock and vibration absorption and in addition is not straightforward to maintain, due to the higher number of parts and components, thus involving both a high start-up investment and a high operational cost.

Through this analysis of a group of off-road vehicles currently available on the market, this research thus reveals that none of these alternatives would be capable of fulfilling the requirements for this transport context. However, military vehicles constituted a very important source of data to this investigation, because this type of vehicle has to have good cross-country performance, dealing at the same time with significant weight, in particular from armour and ammunition. This makes military vehicle design a very important source of knowledge and inspiration regarding the coexistence of locomotion and weight, having contributed significantly to the development of the design solutions in this research. The requirements related to mass production on the one hand and an extensive use of off-the-shelf components on the other, are also a very interesting combination in order to achieve lower costs and ensure simpler maintenance.

### 4.2.6 Vehicle Transporting Sugar Cane Cutters

The current vehicle used for transporting sugar cane cutters in Brazil is an ordinary urban bus (see Figure 53), with the following characteristics:

- A conventional ladder chassis, usually with the engine in the front
- A traditional steel body, 12m long, 2.3m wide, 3m high, weighing approximately 9.5 tonnes and with the capacity for 47 seated people, in many cases adapted for 60


Figure 53: Urban bus Induscar Apache.
© Induscar

The point that even though the urban bus currently used in this kind of transportation is by far the cheapest option, as we will see later, in Chapter 6, it is based on adaptations in order to meet legislation. As there is not an existing vehicle specifically designed for this transportation, this means that so far this transportation situation has not been considered as a whole, as evidenced by the lack of technical and scientific studies related to this subject.

In the course of this research, it has been important to understand what the buses transporting cutters mean to all parties in this transportation equation. Thus, some differences were identified, as follows:

- For the cutters: the vehicle is a **mobile facility centre**, which means that for them usability is the key factor
- For the agricultural companies: the vehicle is a **resource for getting cutters to a plantation**, which means that value for money is a determining factor in any transportation decision, balancing the cutters' travelling conditions, regulations, and the costs involved
- For the manufacturers: the vehicle is really treated as a **vehicle** rather than just a product, as expected. Because reliability and ease of mechanical maintenance constitute the most important factors in the transportation business, they end up providing the key factors guiding the manufacturers' decision-making
- For the legislators: The vehicle signifies a physical representation of a **structure to serve the workers**, focusing on health, safety and well-being, indicating that here the key word is dignity

As we can see, out of all the different meanings presented above only the manufacturers consider the vehicle as a vehicle per se, confirming the current importance of designing not only the product itself, but beyond that exploring a more holistic solution to the problem. It is therefore important to emphasise that on the plantation there is nothing except soil and plants, which means that the cutters depend on a physical structure to serve and help them during their shift. This means that the focus of this structure ends up being the vehicle itself, justifying the regulations which highlight the vehicle's role in the preservation of the health, integrity and dignity of the cutters.

However, this research reveals that the sugar cane companies (the buyers, in this case) are unsure about the suitability of an urban bus for the transportation of cutters, as may be confirmed by question 30 in the sugar cane companies' survey (see Appendix 4.3); even though the bus is undoubtedly superior to the adapted trucks, it still presents many limitations, mostly mechanical, when operating in off-road conditions.

Lastly, during private communication, interviews and surveys with managers and directors of sugar cane companies (see appendices 2 and 4), it was confirmed that, instead of a vehicle based on adaptations to comply with the legislation, the ideal solution for the companies would be to acquire a better-made vehicle designed specifically for cutters' transportation. Thus, taking into account the fact that the average price of an urban bus produced in Brazil is around £60,000 (£25,000 for the body and £35,000 for the platform), this means that including £12,000 (20% of the cost of the vehicle) for adaptations, the final cost target would be around £72,000. It would therefore allow the development of an economically viable vehicle for both the manufacturers and the agricultural companies as buyers.

## 4.3 Analysis of Urban Bus Mechanical Parts

Inevitably the present study should address previous material on the subject of transporting sugar cane workers, or at least on the subject of transporting over 30 people or more in off-road conditions. However, we should take into account the fact that the work undertaken by Rodrigues (1993) is the only research specifically dedicated to this particular subject, and it does not include any analysis of the vehicle's platform. The most important mechanical parts of the vehicle were analysed in the light of the literature review and the experts' opinion. In the light of this research, a data classification structure (see Figure 54) has now been developed for the vehicle analysis, as follows:

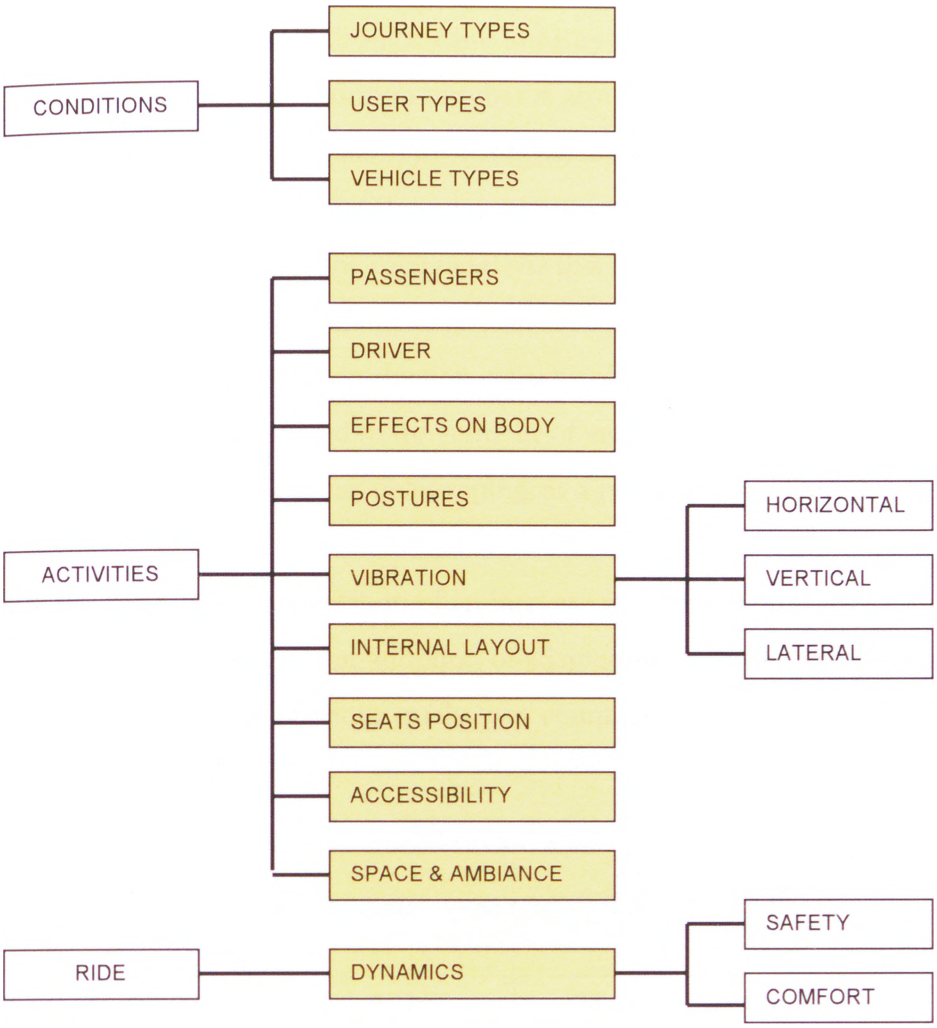



Figure 54: Data classification structure.

The aim of this analysis is to provide the necessary informational support to identify the gaps in understanding the influence of the vehicle platform on the relationship between the terrain and the body of the vehicle. Thus, in the present context, two aspects of this phenomenon are considered: the role of the mechanical parts in the transmission of shock and vibrations, and its effects in transportation. The challenge resides in establishing a correlation between interaction of mechanical parts and its effects in the light of the current conditions of the transportation of sugar cane workers.

### 4.3.1 Size of the Vehicle

Because the size of the vehicle has a decisive impact on many other aspects, such as weight, dynamics and internal layout, it is crucial to know the optimum number of cutters to be transported per vehicle. According to Beleboni (2006), the optimum number of cutters to be transported in sugar cane industry is around 60 per vehicle, whereas in orange plantations the optimum number is around 40, and even lower in coffee plantations, or in forest areas. This confirms the necessity of offering a solution in which manufacturers could serve different markets without the necessity of developing completely new vehicles for each need. As this research reveals, even in the future the capacity of the vehicles is likely to remain the same, simply because it is directly related to production strategy. The production capacity of each company is related to logistics, which, in its turn, is related to the number of vehicles and machines operating in each area of approximately 20ha, determining, as a result, the number of cutters working there.

For this reason, the expectation of an increase in square metres available to accommodate each person with the recent adoption of adapted urban buses transporting cutters in comparison with the previous trucks, was counteracted by the this optimum number of cutters per vehicle.

| Type of Vehicle | Occupied Area | Number of People | Square metres per person |
|---|---|---|---|
| Ford F4000 (1993) | 8.19m² | 23 | 0.40m² per person |
| Mercedes 1113 (1993) | 14.26m² | 40 | 0.35m² per person |
| Urban bus (2005) | 26.56m² | 60 | 0.44m² per person |

Table 9: Sugar cane cutters transported in different types of vehicles.

Therefore, as we can see in Table 9 above, even though the overall area of the current bus was increased by 86%, compared to that in the adapted trucks, but by accommodating 60 cutters, the current area per person increased by only 26% - which is an improvement, but still not ideal. This means that the $0.44m^2$ per person in the bus is closer to the area available in the adapted trucks adopted in early 1990s (from 0.35 to 0.40 $m^2$), instead of the ideal ergonomic figure of $0.80m^2$ per person.

### 4.3.2 Weight of the Vehicle

Due to the significance of this aspect of the transport context it was necessary to obtain data which is as accurate as possible. Regarding the weight of an ordinary urban bus, Barduco (2006) presents some important figures, as follows:

- The weight of a chassis equipped with the engine Mercedes Benz 1722 as a reference, is approximately 4,800kg
- The weight of an urban bus body based on an ordinary 2 axle 12m long vehicle, is approximately 4,700kg
- The weight of all side and rear windows, including metal and rubber frames is 401kg. This means that the weight represented by glazing, in this case, is 9% of the total weight of the vehicle's body, which is quite significant

The problem highlighted by Damada (2007) is that it is common to see divergences in the weight of the buses transporting cutters. This is mainly due to the fact that either the chassis or the body of these vehicles can be easily replaced, which means that a heavier body can be mounted over a chassis in which the engine and transmission, for example, were previously operated with a much lighter body, resulting in overloading.

Weight and its distribution is a determinant component in the design of a bus-type vehicle: the height and the concentration of weight in its side walls, which are highly increased by the weight of the glazing, have an impact on the vehicle's dynamics, particularly in off-road conditions. Such conditions, in conjunction with a higher CG increase the chance of rollover. Because of this, a wider window area obviously means more weight, which in turn means more dynamic problems and, as a result, undesirable suspension demands and vibration effects. Taking into account the fact that this research has revealed that a wider glazed area would be welcomed by the cutters, the adoption of a material lighter than glass must be considered in order to create the necessary weight reduction. In addition, the current metal structures of the seats are the major cause of excess weight on urban buses, constituting 30% of the weight of the body of the vehicle. Thus, considering the observations addressed regarding the improvement of vehicle dynamics and the minimisation of vibration effects, combined with the needs of the cutters once on board, the weight of the seat structure must be reduced as much as possible.

In the relationship between vehicle dynamics and vehicle design, as this research reveals, an important part of suspension design would be the initial establishment of the design of the interior of the vehicle, its ergonomic parameters and weight distribution. This is an important consideration to take into account when looking for an appropriate internal layout. However, the traditional way is the reverse of this, with the design of Brazilian urban buses based partly on an existing platform with specific mechanical characteristics, and modified further once combined with a body installed over it, forming then a third part unit with a different dynamic behaviour as a result of that combination. In this sense, a rational change of form-size-weight relationship in off-road locomotion may easily produce radical improvements only if both the platform and the body of the vehicle are considered together. Otherwise, improvements in the body will not sufficiently affect the performance of a new vehicle concept if such an improved body is mounted on a platform which remained the same for decades.

In this context, lightness is just one of the objectives to be achieved among many others in a complex system in which the weight reduction conflicts with other design demands. This is because the weight of a vehicle is important not only from a dynamic point of view, but also from the commercial point of view. The necessary power for moving the vehicle is proportional to its own weight plus the weight of its cargo, which means that the lighter the vehicle, the bigger its load capacity. Moreover, in terms of production in the automotive industry, weight reduction means a reduction in energy consumption, which is an obvious commercial advantage.

On account of this, there has been a huge development in terms of production processes and in materials such as steel, metal alloys and plastics, which have contributed significantly to vehicle weight reduction. According to Larica (2003) in the early nineteenth century the maximum acceptable tension for high quality steel was $9kg/mm^2$; in the 1960s it was around $18kg/mm^2$ and currently it is possible to reach $27kg/mm^2$. This is a very impressive achievement in the search for a combination of lightness and resistance. In addition to this, there still is a huge potential for plastic application in vehicles, confirmed by the amount of plastic currently used in a normal car, which is around 250kg on average, compared to just 70kg in 1977 (Larica, 2003). Such an achievement, among other benefits, according to the British Plastics Federation, has resulted in each 10% of plastic used in vehicles generating a fuel economy of 7.5%.

Another very important consideration in this section is what is called the 'modular concept' in bus manufacturing. In this concept, one third of the total weight of a bus is in the front axle, whereas the other two thirds are in the rear axle, and the vehicle is divided into five different parts as follows:

- The first part in the front is the 'cockpit' module where the driver, the chassis front edge, the instrumentation cluster and the engine is positioned
- The second module is where the front suspension is located
- The third, the intermediate module, has been the key module for changes in this kind of industry, determining the size of the vehicle
- The fourth module is where the rear axle is located
- The fifth module is where the chassis rear edge is located

This modular concept will inevitably be crucial to this research, offering the possibility of developing a vehicle with different lengths, keeping the same sectional structure as part of the vehicle design solution for the sugar cane cutters' needs, taking into account not only the differences in terms of workers' needs for facilities on the vehicle, but also the differences in the number of workers transported, according to the crop (sugar, coffee or orange, for example) and their specific agricultural activities.

### 4.3.3 Engine

Because the engine position is crucial for many aspects of vehicle design, directly affecting the internal layout, the first thing to do in relation to this design element was to understand why in Brazil is there a clear preference for an urban bus chassis equipped with a front engine. Barduco (2006) explains that there are two main factors that justify this preference: firstly, the variety of street and road surface conditions in Brazil, in conjunction with the fact that the vehicle has to deal with a wide range of topography. Secondly, the cost, taking into account that a chassis with an engine installed in the back is more expensive.

Taking into account all the technical data gathered, the purpose of transport, conditions of use, the terrain, and the vehicle's performance, 20hp/tonne is the optimum engine power of the proposed vehicle that should be aimed for. This is the same power/weight ratio that has been established for a new range of military trucks acquired by the British Army. However, even though the performance level of military vehicles, particularly in combat, clearly has to be higher than vehicles transporting sugar cane cutters, it is important to have this point of reference to work from, because of the similarities between these two off-road transport operations.

The power/weight ratio is obtained by dividing the engine power by the vehicle's weight: thus, considering the range of the most common diesel engines in urban buses in Brazil and the weight of the vehicle in question (approximately 13.5 tonnes fully loaded) the result is as follows:

- Engine MB 1015 (10 tonne/150hp) means 150 ÷ 13.5 tonnes 11.1hp/tonne
- Engine MB 1620 (16 tonne/200hp) means 200 ÷ 13.5 tonnes 14.8hp/tonne
- Engine MB 1722 (17 tonne/220hp) means 220 ÷ 13.5 tonnes 16.3hp/tonne

Therefore, the adoption of an engine able to develop at least 220 hp must be the target for a vehicle to transport sugar cane cutters, which weighs from 13 to 15 tons resulting in a power/weight ratio ≥ to 16 hp/ton. This figure is between the 20hp/ton currently required by military trucks and the current figure, which is from 12 to 13hp/ton.

At present, the automotive industry as a whole is looking for new propulsion alternatives for its vehicles. Recent developments in this area have involved either cleaner and more efficient alternative fuels, or the adoption of hybrid vehicles. Coincidentally, passenger service vehicles have been the first to use hybrid technology on a commercial scale, and both Fiat and Daimler-Benz were pioneers of this technology in the early 1980s. In the case of an electric hybrid vehicle, part of the traction energy is converted into electrical energy, and then into mechanical energy. In this way the electric motor is able to perform quite efficiently no matter what the load is upon it, optimizing engine operation, reducing noise and providing more flexibility in mechanical packaging, having the electric motor directly driving the wheels. However, one of the limitations of hybrid vehicles is related to the vehicle's weight, as the batteries in this vehicle type currently represents around 25% of its gross weight.

This research reveals that the preference of the sugar cane companies, expressed by their managers and directors during the field research sessions, would be for an ethanol/electric hybrid engine equipping the vehicle to transport workers. This is due to the fact that sugar cane companies in Brazil currently produce both sources of energy, which would make the transportation much cleaner and cheaper. However, there is no hybrid engine available on the market at the moment with the necessary capacity and power for a bus-like vehicle. Moreover, hybrid engines are in decline in Brazil at present due to the unfavourable combination of excessive weight and high cost. This problem could be easily solved with the adoption of superconductor technology; its cost is still prohibitive, however.

Another interesting alternative is the turbine engine, which has been successfully used to power many coaches, particularly in the US and Canada. De Old (2008), states that this engine offers a smooth, quiet ride (75% lower than a traditional diesel engine) and most importantly it vibrates much less, because it eliminates the up-and-down piston motion. This kind of engine has few parts, never needs oil or lubrication and burns fuel so efficiently that its level of emissions is so small that there is practically no air pollution. Its weight is another advantage: a bus equipped with a turbine engine weighs as much as one ton less than a vehicle equipped with diesel engine with the same capacity. This is because a turbine engine uses no gearbox or propeller shaft.

As diesel engines have a low specific power compared with turbines, it becomes evident that the diesel engine has to be larger and heavier than a turbine engine, whereas turbine engines also have no need of a radiator, water pump or belts. Examples of this alternative are the Capstone micro-turbines equipping the DesignLine buses, which demonstrate up to 100% improvement in fuel economy over a traditional diesel engine. As the turbine engine can be run on virtually any liquid or gas fuel, it could use, for example, ethanol – generating just one tenth of the nitrogen oxide generated by a conventional type of diesel engine.

However, the disadvantages are the fact it is more expensive and it is not as robust as a diesel engine. According to MacLaurin (2008), gas turbines are best run at high and constant load when efficiency is highest, and efficiency is particularly low at idle, compared to a diesel. There are ways to increase efficiency at part load but these would increase the cost of the engine even further. In addition, the air filters in this system also tend to be large because its air consumption is high compared to diesel engines.

Therefore, despite all the strengths of a diesel engine, such as its lower operational cost, ease of maintenance and longer life compared with a petrol engine, and even despite the fact that the vast majority of buses all over the world are equipped with diesel engines, as far as vibration is concerned it is not the most appropriate solution for the transportation of people in off-road conditions, in particular if combined with a ladder chassis, as used in the cutters' vehicles in Brazil.

### 4.3.4 Chassis

As we have seen, the chassis is the main element connecting the vehicle's platform and body, thus constituting a key part of the vehicle in terms of dynamics and safety, in association with other parts, such as the suspension. The ladder chassis (see Figure 55), adopted by urban buses transporting sugar cane cutters, because of the effects of the parts attached to it, such as the engine, the transmission and even the body of the vehicle itself, generates up to 30 different resonances when in operation, according to Costa Neto (2006). Such conditions are not beneficial for either the vehicle or the users.

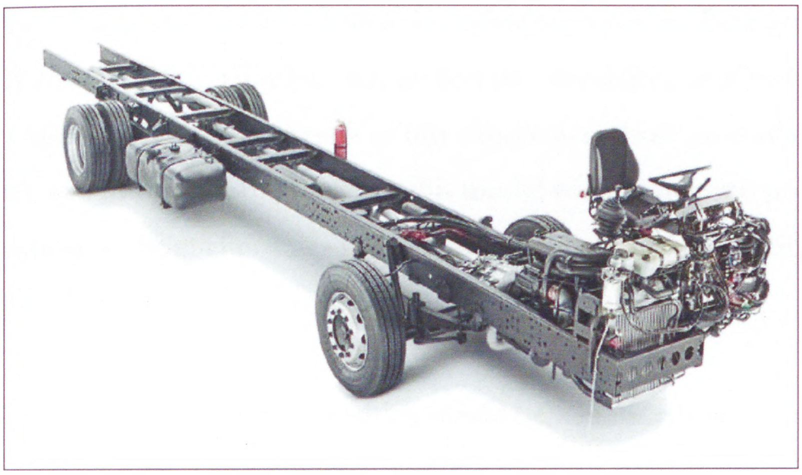


Figure 55: Example of ladder chassis used as urban bus platform.
© Mercedes Benz

The chassis of commercial vehicles, including buses, is generally based on two long parallel channel sections connected to each other which form a structure similar to a ladder, for which reason this kind of chassis is known in the UK as a 'ladder chassis'. Paradoxically, even though the torsional flexibility of a ladder chassis, as used in trucks, is advantageous for severe cross-country conditions, it is not the best option for transporting people on rough terrain, particularly in relation to vehicle dynamics. It can lead to ride vibration problems on rough bumpy track, where a more torsionally stiff chassis would be preferable. However, the ladder chassis is predominant in the bus industry in Brazil, due to the fact that it has been part of the bus manufacturing culture since the beginning of the twentieth century.

Although the adoption of a different ladder chassis for the same body requires many adaptations, it is simpler and more convenient for the transport companies and the bus manufacturers to have the chassis supplied by truck manufacturers. These suppliers not only provide the entire platform, including the chassis, power train, suspension, wheels/tyres and instrumentation cluster, but they are also able to offer technical assistance and an auto part replacement service for the platform once the final product is in operation. Despite the fact that improvements in the Brazilian bus chassis market are evident, with a current wider range of options, these options are related much more to changes in terms of engine, transmission and size rather than changes in relation to the concept, particularly concerning the structure.

Many manufacturers in Europe have successfully adopted a tubular chassis for some of their buses and coaches, with many advantages for the final product. According to Barduco (2006), an urban bus project was developed in Brazil in the early 1990s based on a tubular chassis. As a result of this experience, three prototypes were produced, which are still in operation. However, this model was not put into production because of concerns about after-sales service and also about the responsibility for auto parts, already noted above.

In order to find a solution which would benefit users without compromising mechanical requirements, a so-called 'backbone' frame was considered. This consists of one single longitudinal tube in the centre of the vehicle, as we can see in Figure 56. However, the engine and gearbox have to sit on the top of the frame, which means that this alternative for the chassis would lead to even poorer package, significantly compromising the internal layout of the vehicle.

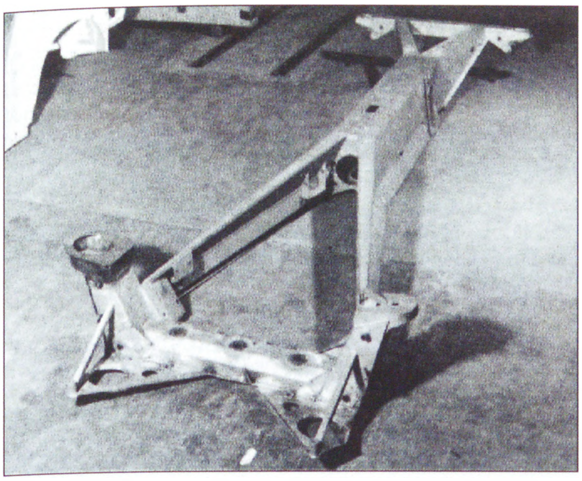


Figure 56: Example of backbone frame chassis.
© Happian-Smith

Another good example of a successful tubular chassis for commercial vehicles was developed not for commercial but, for military purposes. This is the chassis equipping one of the MAN military trucks, the so-called Extreme Mobility Truck System. Its chassis is formed by a box frame with tubular cross parts (see Figure 57), which, in conjunction with a softer suspension, is able to absorb extreme terrain irregularities even during fast off-road driving.

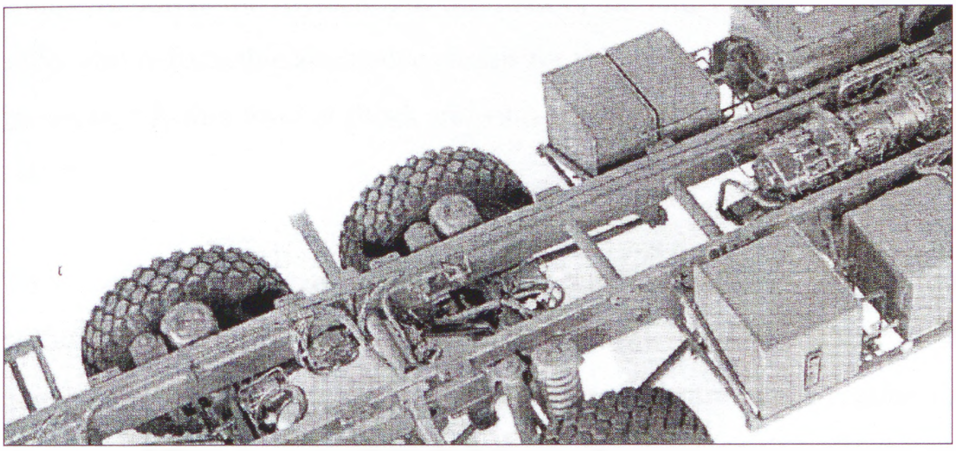


Figure 57: Tubular chassis of the SX MAN truck.
© MAN

Chassis deformation and safety are important not only to this research, but also to the design agenda of most car manufacturers, and new advances in this field must therefore be considered. From the available options, the most suitable concept for the type of vehicle analysed here is the controlled collapse system suggested by Ford (Fenton, 1999), in which asymmetric corner divots are introduced as triggers, as we can see in Figure 58. The divots help to reduce the bending moment of inertia at the cross-sections with short and long axes arranged to pair with one another, allowing a more controllable deformation of the chassis.

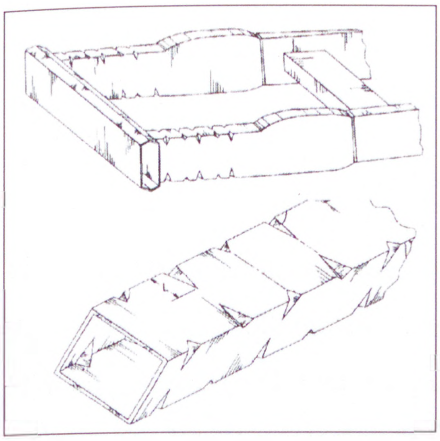


Figure 58: Chassis controlled collapse system suggested by Ford.
© Fenton.

Taking into account the fact that the ladder chassis was initially developed to support a payload bigger than the weight of the vehicle itself, there is a consequent level of over-engineering for the transportation of sugar cane cutters, for which, as we saw before, it would be desirable to reduce the unladen weight of the vehicle as much as possible as a compensation to the payload. For this reason, the vehicle must be equipped with a lighter, stiffer and deformable alternative chassis for this particular transportation context, providing a higher level of shock and vibration absorption and safety conditions for the cutters.

Therefore, despite the convenience to Brazilian bus manufacturers in acquiring it as part of the whole platform supplied by truck manufacturers, with a factory basically divided into just two major sections, body shop and assembly, for all the reasons presented so far the ladder chassis is definitely inadequate for the transportation of sugar cane cutters.

### 4.3.5 Body Structure

There are two distinct types of structure currently used in commercial vehicles such as trucks and buses: firstly, a body, or cabin, attached to a independent chassis, and secondly, a load bearing body concept called 'monocoque', first introduced in the US and France in the late 1930s. The monocoque concept combines both the body structure and the chassis structure in one single structure, as in most small vehicles. In the lower part, also called a 'platform', are situated, as the part of this integrated structure, a group of other parts and components, such as the engine, transmission and suspension. Because in this case the structure is designed to absorb a range of different kinds of impact, being essentially safe, concerns are related to the integrity not only of the platform itself, but also of the entire structure.

Paradoxically, even though the design of the majority of urban buses is currently based on the ladder chassis, the monocoque concept for buses is not new in Brazil. In 1958, Mercedes Benz developed and produced its first bus (the 0321 model) on a commercial scale for the Brazilian market. From 1958 to the early 1990s, when the company ended its bus production in the country with its 0371 model, all its buses were based on the monocoque concept. Thus we can see that recent urban bus production in Brazil has taken a backward step by using the ladder chassis and by not adopting an integrated (monocoque) structure. The current bus body structure is a tubular cage, generally formed by a base, a ceiling, two side walls, a front end and a rear end.

A different example of bus body structure is the concept adopted in the production of the American Rapid Transit Series (RTS) bus. As we can see in Figure 59, this is an innovative integral body structure in which individual 1.5m long modules are manufactured separately and then welded, forming a 12m long vehicle (De Old et al. (1986).

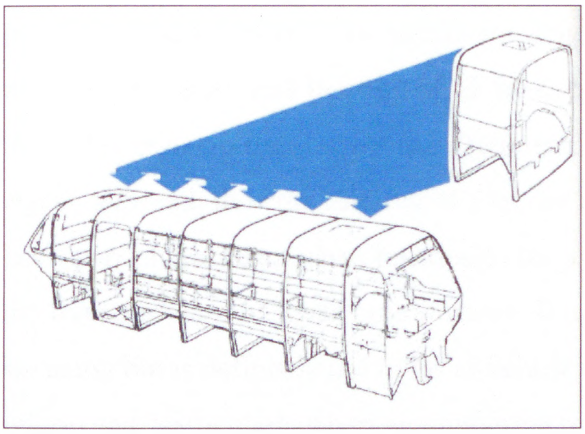


Figure 59: Body structure concept of the RTS bus.
© De Old *et al.*

Focusing on the structural integrity of the whole body, new solutions and approaches have been also considered. The body structure presented in Figure 60 is an example of the body structure construction suggested by Honda, in which almost the entire structure is made from extruded strips forming rings (Fenton, 1999), and allowing minimum material wastage in the form of off-cuts.

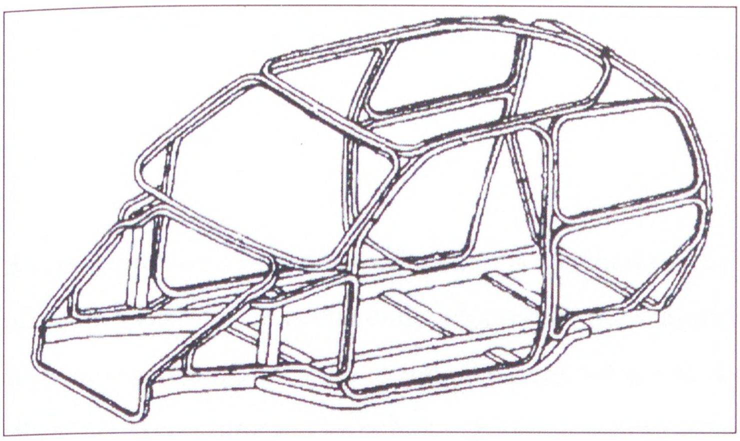


Figure 60: Body structured based on looped rings proposed by Honda.
© Fenton.

This research demonstrates that a significant proportion of damage to the body of the vehicle transporting cutters is caused by contact with plants when travelling through plantations. Thus, the shape of the transversal section of the vehicle should be inspired by military vehicles such as the Commando, presented earlier in this chapter. It would reduce contact of the vehicle body with plants such as sugar-cane sticks, coffee and orange trees, and so on.

The current body structure of the urban buses itself, however, is not specifically the problem. The problem is the significant weight of its side walls, already noted, due to the weight of the glass, and because of all the dynamic problems of the ladder chassis which inevitably ends up transferring the detrimental effects to the body structure.
Again, although the combination of a ladder chassis and a tubular body structure has been part of Brazilian urban bus design for a long time, it is not a good combination for the transportation of sugar cane workers. It might be a good choice economically speaking but is definitely not as far as vehicle dynamics, safety and comfort are concerned, particularly when encountering rough terrain.

The current body structure of urban buses in Brazil is assembled over a ladder chassis, which means that actually there are two independent structures with differences in strength, resistance, flexibility and, most importantly, in terms of response to shock and vibration. Thus, with the conditions of the transportation of cutters and the road types involved, the design solution for the body structure must be able to provide a lighter alternative, not only more compatible with the chassis, but also offering higher physical interaction with it, forming one single integral structure.

### 4.3.6 Suspension

Suspension based on multi-leaf springs is attached to a ladder chassis as part of the same platform. The system is currently adopted by the majority of the Brazilian urban buses, and contributes significantly to the problems related to the transmissibility of shock and vibration. According to Costa Neto (2006), it is not possible for a seat design to compensate for bad primary suspension design, and thus constitutes a highly demanding and challenging problem to be addressed by research and development in vehicle design. In simple terms, when automotive suspension deals with obstacles, the compressed spring – as part of the suspension – starts moving, acquiring potential energy, and part of this energy is transferred to the vehicle's mass, even when the spring has returned to its initial length. In this context, 'Longitudinal tyre forces act on the control of the vehicle, particularly in acceleration and braking, whereas side forces are necessary in order to achieve stability, rollover protection, and to obtain the required directional control. This means that variations of contact force because of road roughness tend to lower the vehicle's ability to be controlled. For this reason, suspension performance is usually considered as a balance between ride, the extent of the dynamic movement of the suspension (too much and the suspension will tend to hit the stops) and the amount of dynamic vibration of tyre force (too much and the road holding will not be good on rough roads).

The basic concept of stability is the capacity of a vehicle to maintain all its wheels in contact with the ground at all times, under the influence of different forces acting on the system as a whole. The function of vehicle suspension is to absorb the unevenness of the terrain, keeping the wheels in contact with the ground while still providing an adequate level of comfort to the users. However, it is important to bear in mind that the lower the unsprung mass the easier it is for the suspension.

Perseguim (2005), who undertook an experiment to measure the frequency range of a vehicle (a light truck) when its shock absorbers were removed, and was able to report a vibration level approximately 30 times higher in comparison with the data gathered from the same vehicle when equipped with shock absorbers. This explained the reason why, during practical tests involving the evaluation by its users, they began to feel sick just a couple of minutes after starting the tests in the vehicle without shock absorbers. The aim of the shock absorbers then is to dissipate the energy accumulated in the suspension and transferred to the vehicle's mass, reducing as a result the movements generated by the terrain's unevenness and/or obstacles.

Also, Perseguim (2005) states that the conversion from the elastic energy of a spring to the kinetic energy of the vehicle's mass also depends on the natural frequency of the system. In a system with a lower natural frequency, the mass acquires less kinetic energy than the system with a higher natural frequency in the same time interval. In a system with a higher natural frequency, the forces generated by spring deformation when crossing an obstacle will be higher because it has a spring with higher stiffness. This confirms once again the importance of keeping the level of natural frequency of the system as low as possible. In this case, a simple factor, stiffness, of a simple suspension component (the spring) can make a big difference in terms of final performance. The stiffer the spring the lower the absorption capability of the suspension and the higher the natural frequency, which means that increasing the stiffness of suspension springs would exacerbate the vibration effects and the level of comfort of the users would deteriorate.

On account of this, the balance between the suspension components and its variables is a key factor, particularly when the suspension presents a higher level of demand, which is true in the case of the vehicle type studied by this research. The suspension here has very high demands made on it, not only of the vehicle itself, the type of terrain covered and the conditions of use, but most importantly by the users' needs, taking into account their safety, welfare and comfort. The suspension of the vehicle transporting sugar cane cutters must include an option for paved road usage, and at the same time the suspension should be soft enough to deal with rough terrain. The solution must provide a higher level of shock absorption, without maximising undesirable effects on the users, in particular those generated by the lateral movements of the vehicle.

Therefore, three different types of suspension have to be considered here: firstly, the rigid axle suspension, because it is the most common type of suspension equipping commercial vehicles, including buses, today; secondly, independent suspension, because this is the type of suspension normally used in off-road vehicles, and thirdly air suspension, because it has been widely studied for the new generation of SUVs, and also because trucks and buses have used it most succesfully.

#### 4.3.6.1 Rigid Axle Suspension

The concept of rigid axle suspension in vehicles came before the invention of the internal combustion engine and consequently before the development of the motorized car. This system was developed from horse-drawn carriages, and also explains the term 'suspended mass' referred to in the literature, because the whole structure of the carriage was literally suspended and attached to the rigid axles by multi-leaf semi-elliptic springs (see Figure 61).

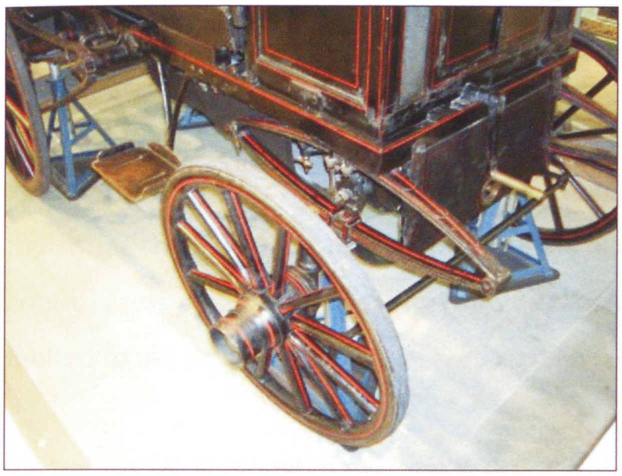


Figure 61: Carriage equipped with multi-leaf spring suspension.

A rigid axle suspension - also called beam axle suspension - has just a single axle linking each of the wheels. Because in this case the wheels do not work independently, this kind of suspension works as a single unit, not providing the most comfortable ride as a result. However, this characteristic of working as a unit is one of the main reasons why rigid axle suspension provides a much higher cargo capacity, even in off-road conditions. This reason in association with the fact that rigid axle suspension is cheaper than an independent one, explains why the majority of trucks and other heavy vehicles are usually equipped with this kind of suspension.

The absorption factor of a vehicle equipped with suspension based on rigid axle and multi-leaf springs can vary tremendously, depending on the position of the shock absorbers – known in the literature as either 'outboard position' or 'inboard position' (externally or internally to the multi-leaf springs respectively). Studies conducted by Perseguim (2005) confirm that shock absorbers positioned in outboard position present an increase of 88% in the vehicle's absorption factor compared with a situation in which they are positioned inboard. Fortunately, the vast majority of the analysed vehicles transporting sugar cane cutters in Brazil which were analysed have their shock absorbers positioned outboard.

The advantages of a rigid axle suspension are that it requires fewer parts, is smaller, and its construction is also simpler if compared with an independent suspension, which means that its maintenance is consequently simpler and cheaper. Also, due to the smaller change in terms of wheel alignment, there is less tyre wear. However, it provides a poor level of ride comfort due to a greater unsprung weight, and the effects from shock and vibration are higher because the movements of the wheel at one end of the axle affect the wheel at the other end. Motivated by its simplicity, new advances based on classic multi-leaf spring suspension have allowed promising design solutions, such as a system constituted by a transverse single leaf made from polymer composites, as well the development of lower control arms connecting the wheel and hubs. Nevertheless, this development is still limited to car design, rather than commercial vehicles.

Therefore, even though it presents a better ground clearance, for all the reasons demonstrated above, in addition to a higher CG and roll centre, a rigid axle suspension equipped with multi-leaf elliptic springs is inadequate for the transportation of sugar cane cutters. This combination, because it leads to vehicle dynamics problems, particularly when operating in off-road conditions, would result in directly compromising the cutters' safety, welfare and comfort.

#### 4.3.6.2 Independent Suspension

The invention of independent suspension (See Figure 62) marked an important milestone for the automotive industry. In place of the traditional and much heavier system based on rigid axles, independent suspension, allowed a much more suitable suspended/non-suspended mass ratio in the vehicles, providing more controllability and stability, resulting in a higher level of safety and a better ride, even over rough terrain, with a higher level of shock absorption and comfort.

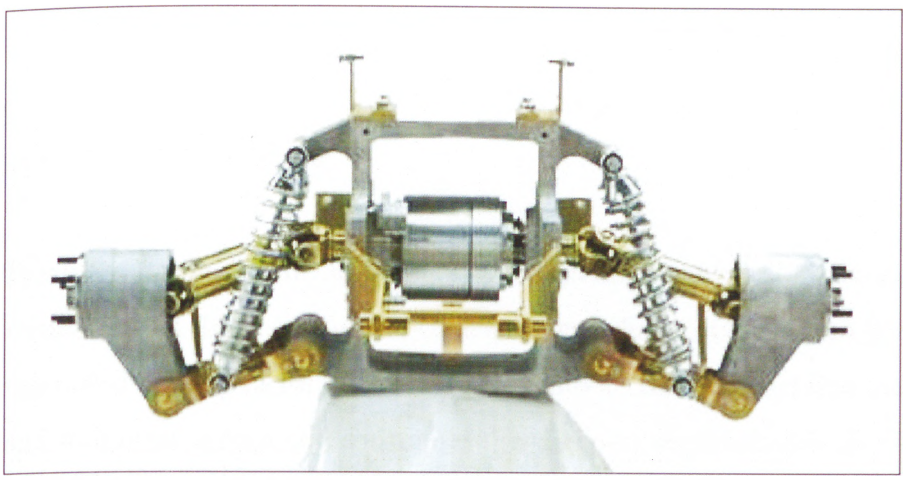


Figure 62: Independent suspension.
© Tri-cycles (DFTREAS)

In a vehicle in which the suspension works independently when passing over an obstacle, the side movement, also known as 'side thrust', is much lower and the package much better compared with that in vehicles equipped with a rigid axles (See Figure 63). Also, in the same conditions, the lower the non-suspended mass the lower the effect over the suspended mass of a vehicle, which is undoubtedly beneficial considering the transmissibility of shock and vibrations to the body of the vehicle, and consequently to the users.

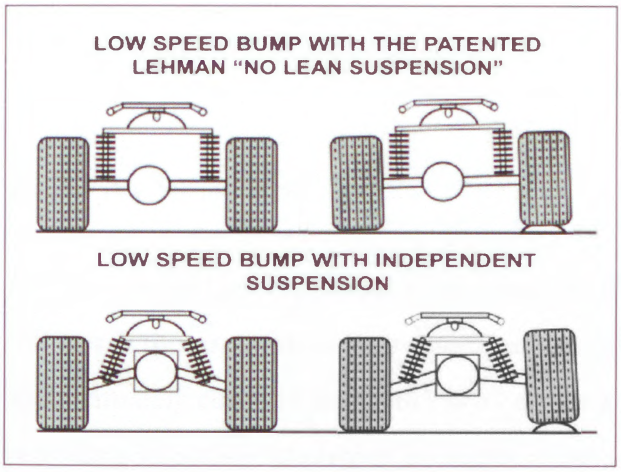



Figure 63: Rigid axle suspension (above) and independent suspension (below) in operation.
© Trikeit

Among other benefits, the adoption of independent suspension also allows a decrease in the weight of the suspension, allowing the adoption of lower stiffness in the springs and a reduction in the forces involved in the relationship between wheels and tyres, and improving the behaviour of the latter in operation, which means, again, more safety and comfort. As stated by Olley (1934) quoted by Perseguim (2005), independent suspension is a way to keep the vertical stiffness as low as possible without compromising the stability and control of the vehicle.

However, despite all the advantages of independent suspension, its application is more related to cars than commercial vehicles. According to Costa Neto (2006), the most important limiting factor is its cost, taking into account the fact that the use of a rigid axle and multi-leaf springs still constitutes the cheapest way to absorb shocks, which reminds us that in American light trucks or SUVs, with priority given to the final cost of the product, independent suspension is used only in the front, keeping the rigid axle arrangement in the rear. Even though there is much discussion around the adoption of independent suspension for commercial vehicles, particularly due to new regulations for disabled people (low floors, for instance), rigid axle suspension for commercial vehicles remains the common design choice.

The adoption of an independent suspension for buses would therefore be of great help in achieving an acceptable level of comfort and stability. We can conclude that despite a much higher cost in comparison with rigid axle suspension, independent suspension is wholly appropriate for a vehicle to transport sugar cane workers.

#### 4.3.6.3 Air Suspension

Air suspension (see Figure 64) is currently the best solution available, if lower vertical stiffness is required. More importantly, it can maintain a constant ride height and an approximately constant frequency level under a variation of load in the vehicle, also providing adjustable control of its height as needed. According to Stayner (2001), vehicles equipped with an air suspension system exhibit vertical motions with natural frequencies lower than 1Hz which is very beneficial indeed for the users in terms of vibration transmissibility. Another important advantage of air suspension is the fact that it can be part of either rigid axle suspension or independent suspension systems. As we can see in the example below, air suspension works in conjunction with rigid axle suspension, and this is normal practice in well-designed heavy trucks and buses.

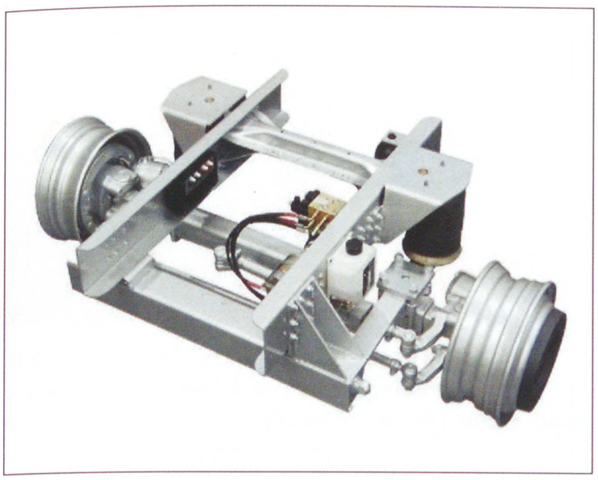
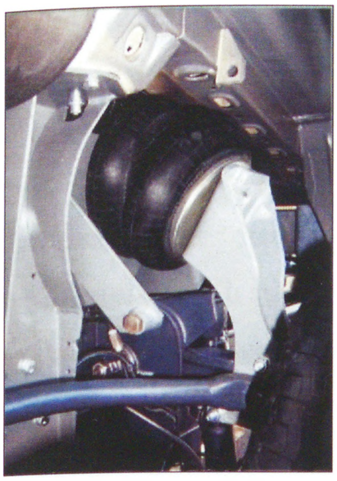


Figure 64: Example of air suspension.
© IMG/Alibaba

This research acknowledges that the 'Alero' mini-bus manufactured in the UK by Optare, is equipped with a very well-developed air suspension system based on rigid axle suspension in the rear and independent suspension in the front. This vehicle represents a good example of a combination of efficient solutions using appropriate materials and production processes leading to a good dynamic context, also incorporating principles of usability and manufacturability. As the air suspension developed for this bus performs impressively in a vehicle with a long wheelbase (7.2m), which is similar to the bus transporting cutters, it reinforces the suitability of air suspension as a potential solution for this kind of transportation. It would offer a desirable level of comfort, even in off-road conditions, without compromising, the safety of the users.

However, a very important development in this field is the new system (see Figure 65) developed by Goldschmitt for an 8 tonne motor-home. Even though the manufacturer highlights the comfort and levelling capacity as the main advantage of its suspension system compared to traditional air suspension, the most important aspect for the vehicle context of this research is the smaller space needed to accommodate this system, compared with that needed to accommodate the vertical air sacs (see Figure 66) in traditional air suspension. This new solution would thus combine a better platform layout, freeing up space that can be used for essential storage compartments in the lower part of the vehicle.



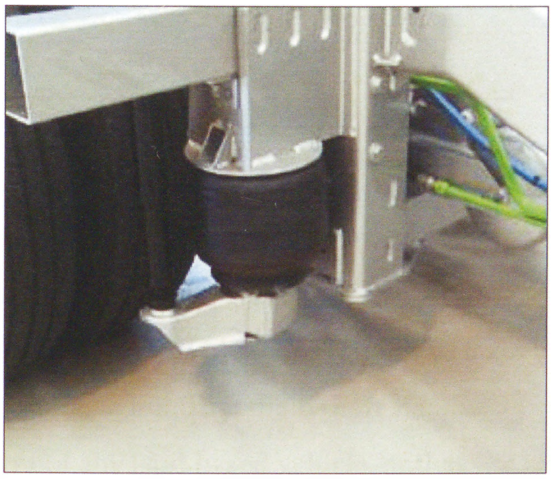


Figure 65: Goldschmitt air suspension system.
Figure 66: Example of rear air suspension.
© Goldschmitt AG and Daimler Chrysler, respectively.

Looking at the suspension system it is clear that there is a compromise between different vibration effects and different levels of comfort. This helps to explain the reason that in order to minimise the vibration effects, it is necessary to increase the level of suspension deflection, without increasing the risks of instability or roll-over. As the vibration generated in the whole suspension system of a vehicle is transmitted in its high frequency version, multiplying the resonant effect, from the design point of view the best approach would be to minimize the vibration inputs near the sources, particularly the tyres, as much as possible, remembering that the more parts there are between the input and output transmitting the vibration, the larger its scale. Air suspension is also favourable in this context requiring fewer parts if compared to other suspension systems. As a result, it would be able to minimise shocks considerably and provide much lower whole-body vibration.

It has also proved capable of improving performance as well as handling, increasing the longevity of the axles, brakes and body of the vehicle - particularly those sensitive components such as electrical systems - from excessive stress due to fewer chassis vibrations, and incorporating both acceptable costs with ease of repair. Also, comparing the system based on air suspension and a stiffer and lighter chassis with the traditional system based on multi-leaf spring suspension and a ladder chassis, the former combination would provide a better ride and a better package. This reinforces the conclusion that air suspension is definitely the most appropriate suspension system for vehicles transporting sugar cane cutters.

### 4.3.7 Tyres

The fact that the wheel as a locomotion solution struggles to deal with anything other than a hard and smooth surface, having difficulty with, for example, soft soil, snow, mud, swamp, sand and rocks, has opened the way for another remarkable invention to take place, constituting another milestone in the automotive industry: the tyre. It is undoubtedly the universal and standard element of any land-based vehicle, and its purpose is to minimise some of the limitations of the wheel, and also to deal with dynamic problems in order to improve locomotion capacity as a result. Tyres represent then, a highly significant component in transportation, and their construction influences considerably some important attributes of a vehicle, such as load capacity, steering, spring effect and noise suppression.

In simple terms, the pneumatic tyre is a flexible rubber device attached to the wheel, which acts as an air spring, reducing the effects of vibration and in addition mitigating the uncomfortable noise caused by not only vibration but also by the contact between the wheels and the road. However, the current level of tyre technology is astonishing, certified by thousands of patents ranging from chemical improvements in rubber and its compounds to structural solutions combining its level of performance with a broad range of applications. This means that the level of research and development related to the tyre has been as significant as vehicle development itself, even though the most important achievements remain unpublished and are kept as an industrial secret by each tyre manufacturer. This makes any attempt to conduct more comprehensive research in this field a difficult task.

Because of this high level of development in tyre technology, much has been achieved in terms of motion resistance reduction for commercial vehicles, but engine output, however, is still mainly used to overcome such resistance. According to Popov (2003), about one third of the energy produced by the engine of a heavy goods vehicle is used to overcome motion resistance, explaining why vertical tyre force is typically 200 times higher than longitudinal force. Inevitably, this is directly linked with fuel consumption. Annual expenditure on fuel for heavy goods vehicles in the United Kingdom was approximately £4 billion in 1992/93.

Depending on mud moisture levels and soil strength profiles, different ground contact areas and ground pressures are required. In dealing with very wet mud or very soft soil, tyres with a bigger diameter in relation to their width present a slight advantage (see Figure 67). In contrast, in mud with a low level of moisture, as well as frictional sand, wheels/tyres with a larger width in relation to their diameter present a slight advantage (see Figure 68). In the former, one of the most important functions of the tyre is to be able to achieve traction through a harder layer of soil underneath the mud, whereas in the latter, one of the most important functions of the wheel/tyre is to be able to manage flotation, avoiding sinkage as a result.

Figure 67: Example of very narrow wheel / tyres.
© Talltires

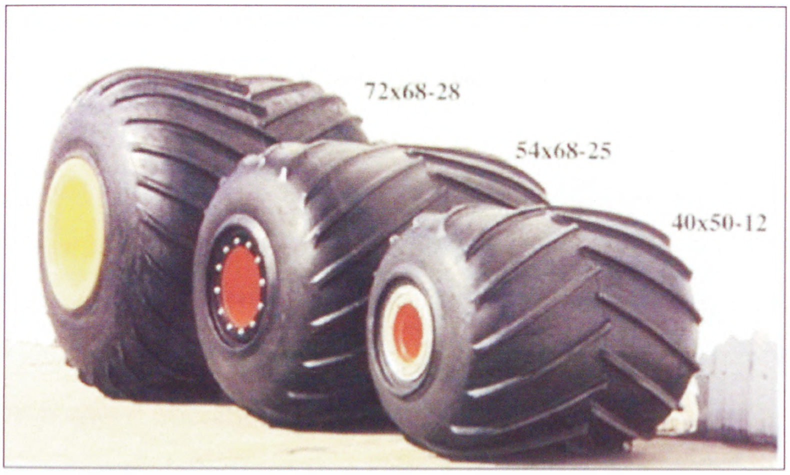



Figure 68: Example of very wide wheel / tyres.
© Rolligon tyres

In this context, the aim for the development of a particular tyre is to improve performance, not only to offer better ride conditions during a given journey, but also to ensure predictable journey times, maintaining the vehicle's optimum condition in terms of physical integrity. As the adhesion capacity of current tyres has been increased by 200%, according to French (1989), this has allowed the production of tyres with minimal side wall stiffness and wider tread/ground contact, improving adhesion, braking and steering, which leads to an improvement in controllability and safety.

Despite their vulnerability, tyres with thinner side walls are able to provide a higher level of deflection, and consequently extra shock and vibration absorption. The literature review shows the importance of tyres for the vehicle's comfort factor because the lower the vertical stiffness of the tyre the higher its capacity for shock absorption. However, the same thinner side wall of a tyre that allows better adhesion and controllability is vulnerable to impact and damage from cuts, which demands extra care. This is a problem for the vehicles transporting sugar cane cutters in Brazil, which are mainly equipped with thin-walled radial tyres.

Even though the absorption of the effects of an uneven surface provided by tyres in a vertical direction is very important from the vibration point of view, it is lower than the absorption provided by suspension, because the value of tyre vertical stiffness is usually 5 to 10 times higher than the spring stiffness in a suspension. Nevertheless, because vertical stiffness depends on tyre size and inflation pressure, this implies that tyre pressure improves ride, which confirms that controlling the deflection of the tyre according to terrain conditions and operation would be highly beneficial to the off-road transportation of the sugar cane cutters. Thus, as greater tyre deflection so obviously improves ride, controlling the tyre pressure, and consequently the deflection, can make a big difference.

In response to this, so-called Central Tyre Inflation (CTI) could be adopted. This is a concept based mainly on controlling the pressure of the tyres of a vehicle according to the different weights and terrain conditions involved, assuming that there is a specific appropriate tyre deflection for any load and speed. According to the manufacturers, for high speed operations tyre deflections should be in the 15% range, whereas for low speeds tyre deflections should be in the 30% range. As a decrease in tyre vertical stiffness accompanies a slight reduction in the predominant vibration of suspended mass, this consequently reduces the vibration of the whole system. This means that a controlled deflection of the tyre according to both terrain and operation conditions, must be recommended for the vehicle which is the subject of this research.

The tyres equipping the vehicles transporting sugar cane cutters in Brazil have to deal with loose, soft soils. In this situation, rut formation may be the most significant obstacle, and its magnitude depends on the moisture levels of the mud. Taking into consideration the importance of the control of tyre pressure, and consequently deflection, when dealing with conditions like this, calculations from Maclaurin (2007), using a Quarter Car model, show that the level of vibration acceleration could drop from 1.14$m/s^2$ on paved roads to 0.98$m/s^2$ on unpaved roads and 0.76$m/s^2$ on mud (with speed limited to 20km/h). This means that the simple adoption of a CTI system would provide a much better ride on tracks, much less damage to unpaved roads, and a much better performance on soft soil.

Therefore, based on information presented above concerning tyres, it is clear that the current radial tyres are inappropriate to equip the vehicles transporting sugar cane cutters. Although these tyres' side walls are unquestionably thinner than the previous cross-ply tyres, they are unable to provide the high level of deflection required to deal with different soil strength profiles revealed by the field research with the vehicles operating in off-road conditions.

### 4.3.8 Steering Capacity

The field research revealed interest from some companies in being able to transport a larger number of cutters in the same vehicle. Such a solution would end up saving both energy and money, and would be more environmentally friendly. However, the combination of the terrain conditions and the layout of the corridors through the plantations make this solution unfeasible. The limitations in terms of manoeuvrability imposed by the conditions above limit the adoption of a vehicle longer than 12 or 13m, which is the current length of a bus. According to the bus drivers, even the current 12m long buses face difficulties in terms of manoeuvrability when travelling through the plantations, due to the narrowness of the corridors (see Figure 69), particularly in areas occupied by mature plantation (high plants). As the sugar cane grows, it invades part of the corridors, reducing their original width of 3.5m substantially. According to the drivers, under such circumstances the combination of a steering limitation, in conjunction with the size of the vehicle, compromise the driving and damage the vehicles, in particular the side walls and external mirrors which inevitably, are hit by the plants.

Figure 69: Narrow corridors through plantations.

This problem may be solved by dividing the vehicle into two parts, joined by a pivotal yoke inspired by the system that equipped the 'Twister' military vehicle discussed earlier. However, as the Twister had a CG height considerably lower than a bus, and the system allows each part of the vehicle to follow the angles and unevenness of the terrain, the chances of a bus transporting sugar cane workers turning over would increase significantly, not to mention the discomfort of the cutters now seated in a platform based on a short wheel base distance, tackling all kinds of surfaces and obstacles.

Another system already available on the market designed to improve the manoeuvrability of long vehicles is universal flat articulation, combined with accordion-like joiners, adopted extensively by so-called 'bendy' buses. The problem is that because in this case the vehicle would be divided into two parts, the limitations discussed in the last paragraph regarding safety and comfort would be present here as well. In addition, there are two other main limitations that have to be considered here: First, this system is designed to deal with flat movements (vertical and horizontal), not torsion movements, which is one of the problems when operating in off-road conditions. Second, the cost of the system for this transportation purpose is very high.

I note here another system which is able to improve manoeuvrability, not as quite effectively as any of the articulation systems presented above, improving the turning ratio of the vehicle by approximately 30%. This is on account of the inclusion of a third steering axle, working in conjunction with the front steering axle. An example of this concept can be seen in the Scania chassis K270 for urban buses, as we can see in Figure 70.

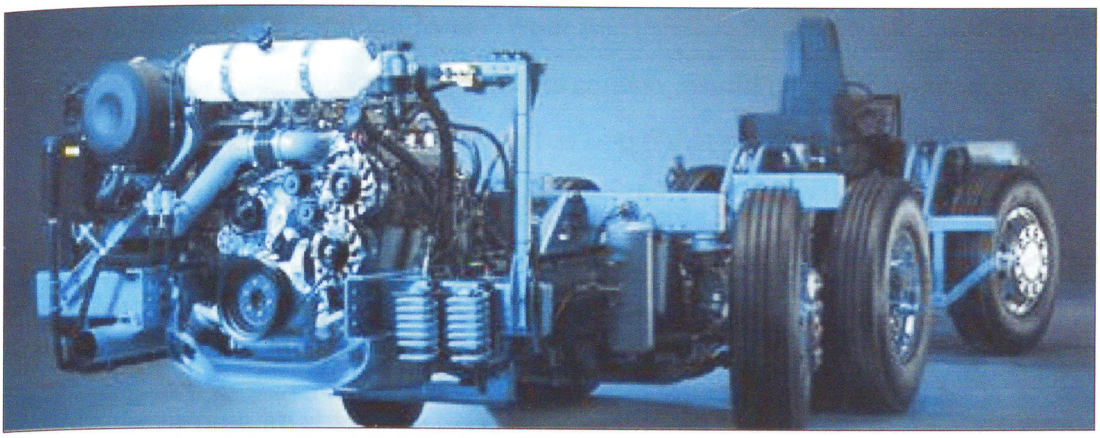


Figure 70: Urban bus chassis with steering back axle.
©: Scania

Despite the importance of the third axle in this off-road context of transportation, it will increase the turning circle of the vehicle compared to the traditional urban bus layout, which is based on one single rear axle. This results from the turning process, the tyres on the rear tend to slip (scrub) causing side forces to develop in the tyres, which tend to lead the vehicle away from the vehicle's turning direction, and increase the turning circle. Therefore, as suggested above, one solution to this is to use a driven steering third axle. However, another, potentially cheaper solution is simply to use the CTI system to reduce the pressure in the air springs of the third axle, and thus reduce the tyre loading. This will increase the tyre loading on the second axle, move the turning centre forward and reduce the turning circle.

To conclude, looking now at the vehicle as a whole, having analyzed the field research data and its mechanical parts, it is clear that a normal urban bus used in public transportation is not totally appropriate for this transportation. This is despite the advantages pointed out before, which are also the reasons why currently this kind of vehicle has been extensively adopted in Brazil for this kind of transportation, particularly in Sao Paulo State. Despite all its strengths compared to the other vehicles under discussion, such as excellent ease of maintenance, good start-up investment, operational cost, reliability and also better environmental friendliness than all the other vehicles, it presents a poor performance in terms of shock and vibration absorption, and only a fair degree of controllability and comfort when operating in off-road conditions.

A potential economy could be obtained with the reduction in cutters' travelling times, as well as with the reduction in journeys interrupted by rain, if a vehicle more suitable for dealing with the terrain conditions and types was used. A better vehicle, presenting a better performance in such a transportation context, would provide the company with more efficient use of time. This research has noted that currently the production of sugar cane cut manually depends directly on how well the time of the cutters on the plantation is managed. This is because the sugar cane companies comply with labour law related to this activity, which imposes an 8-hour shift. This means that any reduction in travel time is directly beneficial to the cutters, who will have more time flexibility when on plantation, because they would be able to increase their income by producing more.

## 4.4 Technical Implications of Vibration

Chapter 3 analysed vibration, focusing on its health and comfort implications, stating that shock and vibration absorption is one of the weaknesses of the vehicles transporting sugar cane workers. It has been proven that this issue is very important to this transportation one in this context and is consequently a crucial element to be considered in the achievement of the objective of this research. For this reason, in this chapter, the technical implications of vibration are analysed, based mainly on an analysis of the mechanical parts of the vehicle presented earlier in this chapter.

The study of vibration in the automotive industry involves two complex systems, that of the vehicle and that of the users. The first is a complex dynamic system able to transform a simple excitement signal from different sources (terrain, ride, power train, wheels/tyres, etc) into other vibration signals, whereas the second is another complex physical system which reacts very differently according to these vibrations generated by the vehicle. The engine is usually one of the most important on-board sources of vibration, mainly because of its reciprocating imbalance in each of its cylinders caused by the fluctuating inertia force associated with the mass of its rotating parts. Thus, according to Zamberlan (1988), the highest effect of vibration on the user's body, in particular the vertebral column, occurs when it vibrates at its natural frequency, which is the case here. This might be the reason why in some situations when bus drivers work in public transportation longer than the recommended number of hours, they may become stressed and aggressive.

This is thus one more reason why trucks and buses equipped with diesel engines normally present higher levels of vibration in shorter exposure times when travelling over roads with poor surfaces, as we can see in Table 10. In this table, trucks and buses are represented by the numbers 14 and 15 respectively whereas roads 1 and 3 present fairly good surfaces and roads 2 and 4 present poor surfaces.

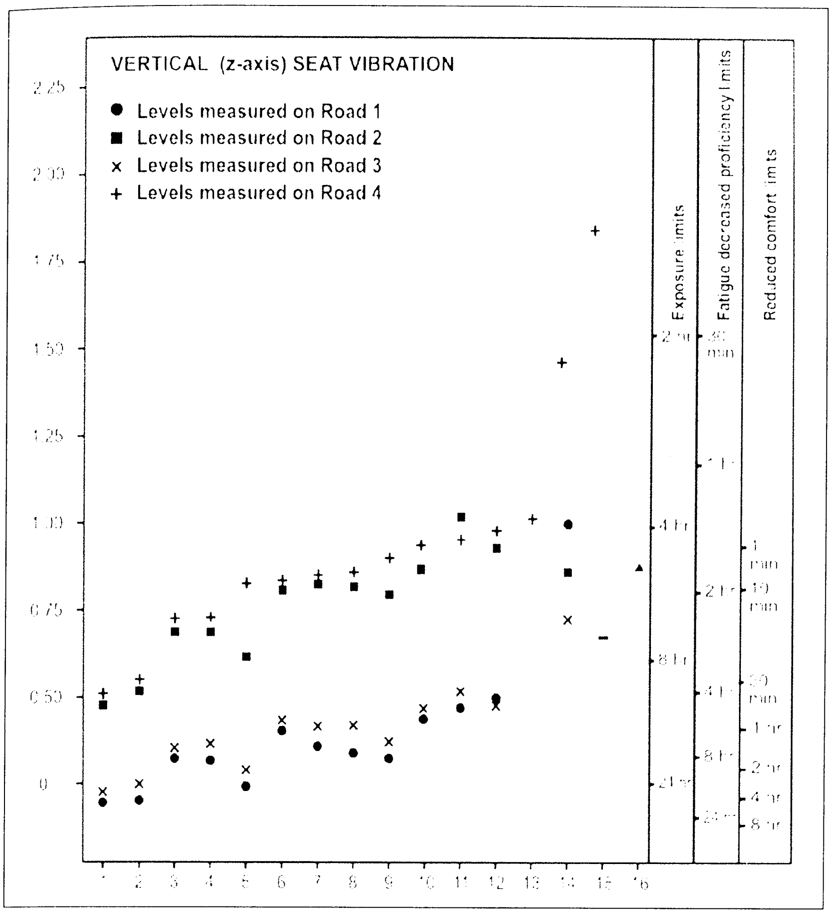



Table 10: Whole-body vibration according to vehicle and road types: Cars and vans (1-11); light bus (12); double deck bus (13); truck (14); single deck Bus (15) and passenger train (16).
Source: Michael Griffin (1996) in accordance with ISO 2631

As we can see, looking at a single decker bus similar to those used to transport cutters travelling over roads with poor surfaces, the exposure limit is less than 1½ hours. Fatigue begins without registering any discomfort at all. As the cutters' journey may last for 2 hours, with 50% of it taking place in off-road conditions, the data presented above confirms how serious this issue is in this particular kind of transportation.

The challenge of designing a vehicle to transport cutters is to achieve an optimum speed on rough terrain, minimising the effects of the consequent acceleration on the users. As Maclaurin (2006) states: *"For most vehicles, acceleration level increases fairly linearly with speed on a given terrain up to the limit that the suspension starts to contact the limit stops".* This means that the higher the speed, the worse the effects of acceleration. This confirms why the average speed of the vehicles documented during the field research when operating in off-road conditions was approximately 30km/h.

On account of this, as we can see in Figure 71, according to Maclaurin's calculations (Maclaurin, 2006), considering the Vibration Dose Value (VDV), which is considered the amount of vibration that a person should be subjected to in a 24 hour period, a softer suspension is considerably more advantageous. However, the major disadvantage of soft mechanical suspension is the tendency of the vehicle to roll. This, of course, can be controlled by anti-roll bars, although these will turn the suspension stiffer, tending to compromise the ride.

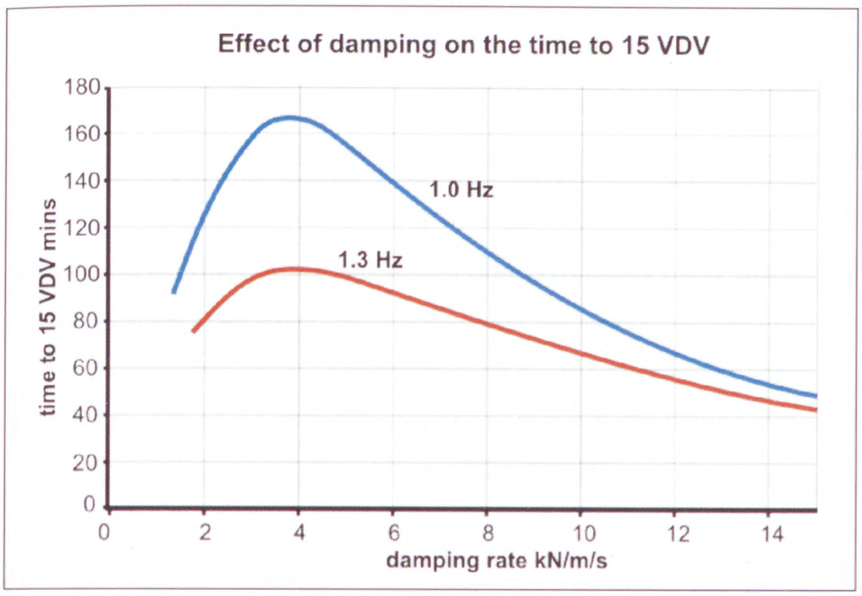



Figure 71: Effect of damping on the time to 15 VDV.
Source: Bruce Maclaurin

Heavier, truck-based, platforms in buses transporting cutters demand a higher vertical stiffness of the tyres, which also compromises the level of comfort for the users. The frequency level resulting from the stiffness of the tyres, combined with the vibration of engine and the transmission on the chassis, result in the generation of vertical vibrations with values reflecting the lower vibration tolerance for human beings, which ranges from 4 to 16Hz. This type of chassis generates a lot of lateral movement, particularly when dealing with rough terrain, and the higher CG of the vehicle and a multi-leaf spring suspension increases the amplitude of these movements. The problem is that human tolerance to these kind of movements is four times lower than its tolerance to vibration.

Looking at a design strategy and approach to minimize vibration, as well as ensuring better ride and comfort, this research shows that there is not unified approach shared by professionals responsible for suspension design and by those responsible for body design, a situation which could significantly compromise the development of the vehicle as a whole. While vehicle suspension designers are usually much more focused on mechanical issues, vehicle body designers are usually much more interested in ergonomics and usability. The former group thus believes that any suspension design improvement will inevitably ensure a better ride and better user comfort as a consequence, which is not actually true. I suggest that any vehicle platform development, in particular involving the chassis and suspension, should consider the nature of the vehicle body and vice-versa, in conjunction, of course, with the specifics of the transport activity. However, the Brazilian market for buses is based on two distinct industries: truck manufacturers supplying the platform and bus manufacturers producing the bus body to be mounted on this platform. It is clear that different results in terms of performance, dynamic behaviour and most importantly the variation in terms of vibration effects end up depending on the combination of a platform and a body produced independently by two different manufacturers.

Therefore, based on information about the vehicle during the field research, and particularly from the analysis of its mechanical parts, the whole platform of the current vehicle transporting sugar cane workers is also evidently inadequate for this transportation purpose, particularly from the point of view of shock and vibration.

## 4.5 Field Research

Although the transportation aim of a vehicle such as an urban bus is to serve a considerable number of people, unfortunately user experience and usability are not a priority. The views of the bus designers interviewed during the field research sessions confirm that in the design of an urban bus in Brazil functionality comes first, focusing more on issues that are important to the transport company (buyer) rather then the passengers (users). This reinforces a common problem faced by designers whenever they are involved in a project in which the people who pay for the product are not the people who use it. For the buyer, in this case, some of the important aspects to be considered in this vehicle are:

- Low acquisition cost
- Ease of parts replacement
- Simple maintenance
- Durability

As we can see, putting aside their importance, these priorities are related much more to the function of the vehicle as a machine than as a means of transporting people. These aspects inevitably end up matching some of those currently considered important to bus manufacturers, such as ease of production and low technology cost. The adoption of these priorities as part of the concept and manufacturing structure and philosophy of the company is acceptable as long as the result fulfils the needs of both the buyer and the users. However, the sugar cane workers' priorities, seem to be very different, listed below:

- Comfort
- Safety
- Support on the plantation

### 4.5.1 Vehicle Adaptations

Even though much has still to be observed and undertaken in terms of technical improvements in agriculture, Regulation NR-31 is the latest and the most comprehensive regulation concerning agricultural policy ever published in Brazil. As one of its elements relates to the transportation of rural workers, it worthwhile to note the most important points, as follows:

- To provide permanent or mobile shelter for the workers in bad weather
- To provide permanent or mobile toilets (one toilet for every 40 worker)
- To provide a specific compartment for the tools, separate from the workers
- To provide enough structural resistance for the vehicle in case of rollover and crash
- To provide communication between the driver and the workers
- To minimise the impact on the workers' health and safety when travelling over rough terrain
- To provide foam seats with backrests, equipped with seat belts

- To transport all the workers seated

As urban buses need many adaptations to comply with the requirements of the NR-31, bus manufacturers in Brazil, and more recently specialized garages, have provided such adaptations. The main motivation is the potential market, which involves not only the sugar cane industry, but also other agricultural industries such as coffee, orange and forestry production. However, it is also important to state that such adaptations have also to take into account the bus manufacturing issued in 1993 by the Conselho Nacional de Metrologia, Normatizacao e Qualidade Industrial (CONMETRO). This specified a number of measurements to be adopted, as follows:

- Maximum vehicle length 13,200mm
- Maximum vehicle width 2,600mm
- Maximum vehicle height 3,500mm
- Minimum approach and departure angle 8 degrees
- Minimum number of emergency windows three
- Minimum aisle width 650mm
- Maximum number of people per $m^2$ five
- Minimum distance between the seats 300mm

The Brazilian bus manufacturer Induscar-Caio was one of the first to provide some modifications to urban buses for the transportation of sugar cane workers according to particular specifications. Currently, the company has adapted an urban bus for 60 people, with a compartment in the rear for long-handled tools, such as hoes, and a compartment for short-handled tools, such as machetes, positioned at the bottom and at the sides of the vehicle. Some of the other modifications incorporated into buses for this particular transportation purpose are as follows:

- A washable material on the interior, such as aluminium on the floor and panels with a layer of plastic used as a covering of the internal walls
- A special box to accommodate all the 5-litre drinking water containers of the cutters
- A drinking water tank with a 12-litre capacity and another one for non-drinking water with a 200-litre capacity, used mainly for washing purposes

Nevertheless, despite the achievements by the regulation NR-31, according to Maturana (2007) problems still exist. He states that agricultural companies are concerned about complying with legislation merely in order not to be fined or even sued not because they wish to offer better working conditions to their cutters, saying that: *"there is no concern to serve the man. The concern is to serve the inspection".* The point here is the fact that the NR-31 does not mention a specific type of vehicle for this kind of transportation, but rather an 'adapted vehicle'; this does not necessarily have to be a bus, and has made decisions about the vehicle's adaptations quite challenging. Moreover, for the Brazilian traffic authorities a vehicle for the transport of rural workers also has to comply with the normal traffic legislation, multiplying the number of achievements to be met before the vehicle can obtain a licence.

Because 91% of the roads are under the jurisdiction of the municipalities (local governments), 8% under responsibility of the State Government and only 1% under the responsibility of the Federal Government, this represents a problem in terms of vehicle inspection. As the authority of the road patrol is limited to paved roads, this means that the majority of the roads, unpaved roads in particular are outside their sphere of authority. On account of this, the transportation of sugar cane cutters on unpaved roads or on plantations depends on local police who are often not prepared to carry out inspections. As a result, it facilitates the use of vehicles which do not comply with the regulation, and are even without authorization for the work, travelling on roads in conditions far below the requirements.

Finally, Maturana (2007), notes the age of vehicles explaining that it has been quite common for contractors to acquire second-hand urban buses that were already falling apart, having come to the end of their useful life after working regularly as part of a public transport company fleet. If this vehicle has been disposed of because it has accomplished its maximum working time in the city, it should neither to be allowed to undertake the task of transporting sugar cane cutters, nor operate in off-road conditions. This is not only because of the rigour and the particularities of this transportation, but also because of the rapid mechanical deterioration likely when operating in such conditions.

### 4.5.2 Toilets on board

Among other requirements, toilets have been the most demanding vehicle adaptation in this context. They became part of the rural workers' transportation just 3 years ago, when the NR-31 was published. Since then, any agricultural industry that depends on rural workers' transportation has to comply with this regulation. This regulation requires a toilet in good hygienic conditions, and it is mandatory to have one toilet for each gender if there are female and male workers in the same place (Maturana, 2007). However, according to Sacomani (2007), the only available double toilet for buses is very expensive, at £9,000. Thus, cost and lack of options, in conjunction with a misinterpretation of the regulation, have driven the investment in different directions from company to company. The adapted sanitary canvas on plantations (see Figure 72) is an example of this.

Figure 72: Sanitary canvas as an example of improvised toilets on plantations.

As the sanitary canvas has to be assembled and disassembled every day on the plantation, and it is still not as hygienic as it should be, the installation of toilets on buses was an obvious decision after the realisation that alternatives, such as a sanitary canvas, are not practical. This research shows that the vast majority (94%) of the sugar cane cutters agree that a toilet on the plantation is essential. However, many of the vehicles transporting cutters are still not equipped with an on-board toilet because sugar cane companies are still in the process of updating their equipment to comply with the NR-31, since this regulation is relatively new.

The usual solution in terms of an on-board toilet on buses has been the installation of the Dixie-type toilets normally used on construction sites (see Figures 73 and 74). The latest version of these adapted on-board toilets is based on chemical waste treatment, and has a tank supplying water whenever the flush is activated. The waste is cleaned once a week, when its tank is filled again with fresh water and a dose of chemical additive is added. However, despite the chemical treatment available in the latest versions seen during the field research, they still generate bad smells and a visually unattractive user interface. As far as this research is concerned, there are two ways to deal with the problem of portable toilets for vehicles in this situation: either to acquire a complete toilet produced by an independent supplier, or to create a compartment on board, equipping it with ready-made toilet components.

Figure 73: Latest toilets seen in some of the buses transporting sugar cane cutters.
Figure 74: Example of early toilets on buses transporting sugar cane cutters.

The field research shows that, even though 30% of the cutters' population consists of women, there is just one toilet on board, and in many cases it customarily ends up being reserved for women while the sanitary canvas assembled on the plantation is used by men. In addition, as it is always installed in the rear of the vehicle, this research found that the cutters felt embarrassed about using the on-board toilet because inevitably there are always people in the vehicle, eating or resting, for example. In the end, even though the cutters would really like to use the on-board toilet, in order to avoid embarrassment the majority end up using the sanitary canvas instead.

The problem is that a simple bus toilet currently seen in the cutters' buses costs about £2,000 per unit, representing 8% of the body cost; and, in contrast to the situation in Europe, there is no independent manufacturer in Brazil producing toilets for bus manufacturers. This means that currently each Brazilian bus manufacturer has to design, develop and produce its own toilet for its own buses. It is than clear that the preference for acquiring a vehicle already equipped not only with a toilet, but also with all the necessary accessories to comply with the law, was confirmed by 100% of the sugar cane companies, from question number 26 of their survey (see Appendix 4.3).

Therefore, despite the undoubted progress of having toilets on board, considering that there were none until recently, an adapted Dixie-type toilet is inappropriate as a toilet for the vehicles transporting sugar cane cutters. However, as the NR-31 does not specify what kind of toilet should be adopted, unfortunately any toilet would theoretically comply with the regulation.

### 4.5.3 Seats on board

As the part of the bus interior in direct contact with the users' bodies, seats work as a frontier between the movement, shock and vibration inputs and the users' bodies. For this reason, seats constitute a very important element in this transportation context. Thus, this means that comfortable seats are directly associated not only with the characteristics of the human body, but also with the long-term effects of sitting, as they should aim to reduce postural stress and optimize muscular efforts. This means that besides comfort, the health and safety of the users are also affected by seat design.

When sitting, 65% of body's weight is supported by two very small bones (ischial tuberosities) measuring approximately $4cm^2$ ($2cm^2$ each) and then distributed over approximately $25cm^2$ of skin on the seat cushion, as we can see in Figure 75. This means that a flatter seat surface raises the pressure under the ischial tuberosities, but a contoured surface distributes the pressure under the users' soft tissues better. However, the stiffness in this case is far more important. Peacock and Karwowiski (1993) state that a slight seat cushion deflection better distributes the pressure under the soft tissues provided by a firmer surface, on which the users' position can be changed. As a higher level of deflection as a result of a softer material on the seat cushion makes changing position more difficult, increasing muscular effort to change to the new position, this means that a seat cushion with a slight deflection is far more appropriate, not only for long journeys, but particularly for any transportation in off-road conditions.

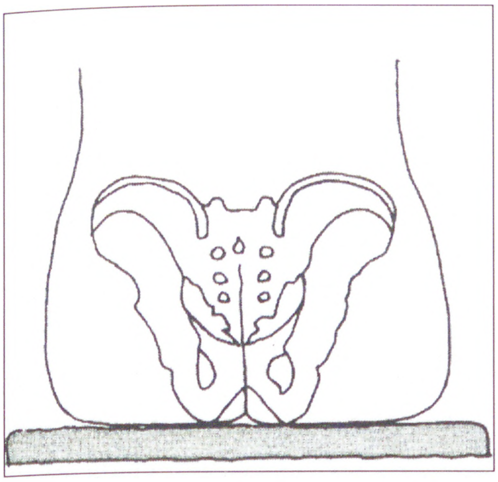


Figure 75: Ischial tuberosities and the pressure distribution on seat.
© Itiro Iida

Most of the current urban buses are equipped with hard, vacuum-formed plastic seats, previously designed to be used on short trips on urban streets in public transport many years ago. So, without doubt, they are neither appropriate for long journeys nor off-road conditions, generating visible discomfort and fatigue after 30 minutes, forcing the cutters to try and improvise improvements, such as the use of pillows (see Figure 76), in order to minimise the effects of shock.

Figure 76: Thermoformed plastic seats with pillows to minimise the effects of shock and vibration.

Even the normal extra amount of fat under women's skin ends up being a disadvantage in terms of comfort when using a seat. This is because it collaborates to increase the pressure upon the veins, reducing the time before a seat becomes uncomfortable. This explains why the women in the vehicle observed during the field research constituted the majority of those using a pillow on the seat. As women currently constitute 33% of the population of sugar cane cutters, this solution should be taken seriously when establishing design solutions.

Because of their extreme simplicity in terms of concept, material and production, the average cost of a plastic moulded seat is only £21, according to Barduco (2006), which means £1,260 for a bus with 60 seats, or 5% of the bus body cost (£25,000). However, the proportion of its weight in comparison with the vehicle's weight is quite significant. Each of these seats weighs 24kg, totalling 1,440kg for a bus with 60 seats, or an astonishing 30% of the total body weight of the bus, which is 4,700kg.

Therefore, despite the low cost and simplicity, and also for the reasons presented above, seats without a foam layer, such as the plastic vacuum-formed seats found during the observations, are definitely not suitable for use in a vehicle transporting sugar cane cutters. Furthermore, this kind of seat does not comply with the NR-31 Regulation, because this specifies the use of foam seats.

The urban buses are not normally equipped with seat belts, and consequently none of the analysed vehicles were equipped with them. However, the majority of serious injuries and fatalities in accidents involving buses are due to the non-use of seat belts, so the adoption of such a restraint system would be an important necessity. According to Barrios (2005), impacts with rigid interior parts of the buses followed by passengers' projection or ejection from the seats represent 86% of fatalities and 18% of serious injury cases. Since 1999, Article 167 of the Brazilian Traffic Code (Código de Transito Brasileiro – CTB) requires the use of seat belts by all users of buses and minibuses, but there is no such specification for the transportation of sugar cane cutters included in the NR-31.

Nevertheless, despite the fact that the seat belts have effected a substantial overall reduction in injury, Mackay et al. (1995), quoted by Happian-Smith (2002), points out that even using seat belts the contact of the passenger's head and face with objects immediately in front of the passenger, such as back of the seat in front, is almost certain to occur in collisions of about 50km/h. This confirms that the adoption of seat belts in the current bus, with its traditional seat positions would substantially reduce the number of fatalities among the cutters, but also that there will be a risk of injury due to the imminent projection of passengers' bodies to the seat in the front of them in an accident unless another seating arrangement is considered.

### 4.5.4 Windows

Another important result of the observations, when travelling with the cutters during their journey from home to the plantation, was the cutters' enjoyment of contemplating the landscape through the windows, particularly when on the plantation. This might be due to their strong relationship with nature as their workplace, and also to a consistently high level of interest in the condition of the sugar cane that is about to be cut. This is because the condition of the plants is directly connected to the level of production and, as a result, to the cutters' income. However, unfortunately the relationship between user vision and comfort has scarcely been considered. This is confirmed by Haslegrave (1993) quoted by Peacock & Karwowski (1993), who states that the most extensive studies related to this issue were made 20 years ago, and only investigated drivers, not users.

It was also confirmed that the adapted buses have wider windows in comparison with those which equipped the adapted trucks used earlier. According to Rodrigues (1993), they were not only fewer in quantity, but also approximately 30% smaller in size, measuring on average 0.7m x 0.3m. On account of this, even though there is a significant improvement in terms of the size of the windows with the adoption of buses (see Table 11), it would be better to have a bigger glazed area if the body structure, in conjunction with a possible replacement of glass by plastic, allowed.

| Urban buses' window size | | | | |
|---|---|---|---|---|
| Window types | | Busscar Urbanuss | Caio Millenium | Regulation Conmetro 1/93 |
| Lateral window | Height | 1.04m | 0.90 / 1.20m | 0.80m |
| | Width | 1.38m | 1.20m | 1.20m |

Table 11: Size of lateral windows of two different Brazilian urban buses.
Source: Alda Paulina dos Santos.

### 4.5.5 Interior Lighting

The lighting system currently in use in the interior of Brazilian urban buses is based on 10 normal 60W 600mm to 800mm long Cold Cathode Fluorescent Lamps (CCFL), protected by plastic (acrylic) lenses attached to both corners of the ceiling immediately above the lateral windows, as we can see in Figure 77. Even though they offer a convenient option for short journeys in a public transport context on paved roads, this kind of lamp is quite sensitive to shock and vibration, and they are also easily disconnected on rough terrain. This is an obvious limitation in the context of transporting cutters to the plantations.

Figure 77: Current urban bus lighting.

Also, although the NR-31 does not include lighting specifications, the large surface area of these fluorescent lamps results in a diffused and less directional light, making them more suitable for lighting large open areas such as offices, commercial, industrial and public buildings than the cutters' buses, on which a number of activities are taking place.

### 4.5.6 Interior Temperature

The conditions of the seats in the vehicles, combined with the effect of all the movement, shock and vibration, results in an increase in cutters' breating rates, producing a higher level of $H^{2}O$ steam, $CO^{2}$ and a higher body heat, which is distributed into the interior of the vehicle. The same problem was also confirmed by Rodrigues (1993), noting that the internal temperature of 22°C measured in an adapted body truck in winter was acceptable, even though the level of ventilation was not sufficient for 60 people on board. However, as we can see in Table 12, the temperature of 37°C in the summer was 60% above the maximum limit stated by Regulation NR-17, and 26% above the recommended limit of 29°C after which the adoption of air conditioning is absolutely necessary.

| Internal temperature of an adapted truck | | |
|---|---|---|
| Season | Temperature (measured) | Temperature (Regulation NR-17) |
| Winter | 22°C | 20 to 23°C |
| Summer | 37°C | 20 to 23°C |

Table 12: Internal temperature of an adapted body truck measured in different seasons.

As this research analysed the current urban buses used for the transportation of sugar cane cutters, a better result in terms of internal temperature was expected. However, as we can see in Table 13, according to Santos (2004), the measurement of the internal temperature in two different types of urban buses in operation in summer was even higher (40°C) in comparison with data from adapted trucks in 1993. This might be due the fact that the buses are better insulated than the adapted trucks.

| Internal temperature of an urban bus | | |
|---|---|---|
| Bus types | Temperature (measured) | Temperature (Regulation NR-17) |
| Busscar Urbanuss | 40°C | 20 to 23°C |
| Caio Millenium | 40°C | 20 to 23°C |

Table 13: Internal temperature measured in two different types of urban buses.
Source: Alda Paulina dos Santos (2004)

The temperature level inside the buses currently transporting cutters is therefore not acceptable. Such conditions increase the temperature of the cutters' bodies compromising not only their thermal comfort, but also their breathing, generating extra amounts of $H^2O$ and $CO^2$ in the environment, and multiplying the effects exponentially. This means that the longer the trip and the warmer the weather, the higher the internal temperature of the vehicle and the worse the thermal comfort of the cutters. This confirms that the problem related to the internal temperature of vehicles transporting cutters still demands as much attention as it did in the early 1990s.

### 4.5.7 Drinking Water Storage

The results of the field research indicate that in the mobile facility centre offered by the buses on the plantation, drinking water is the first priority. It is the most important facility because it is a vital resource, particularly due to the conditions of the environment and work - the amount of water consumed by each cutter is approximately five litres/shift. Also, this research reveals that, even though the drinking water containers are brought full from home, all the cutters refill their drinking water container during the shift, because of the need for cool water.

The current solution for providing cold drinking water on the plantation for the cutters has been to cool the water at night in a big tank and then to fill the adapted stainless steel tank installed on the buses (see Figure 78), which has been demonstrated to be impractical, and not an ideal solution. One of the problems noted by the agricultural companies is the inconvenient noise caused by the movement of water inside the tank. Therefore, despite being a simple and straightforward solution, the adapted metal fuel tank is inadequate for the storage of drinking water in the transportation of sugar cane cutters. Even though drinking water is vital in this context, there is no mention of it in the NR-31, thus a solution needs to be found. According to Sacomani (2006), the only refrigerator on the market is too small and expensive for these purposes, at £750.

Figure 78: Adapted drinking water tank on board.

### 4.5.8 Non-drinking Water Storage

Despite the essential need for drinking water, there is also a need for non-drinking water, to be used for cleaning and washing purposes (see Figure 79). However, even though this need seems to be obvious, the photo below is one of the first experimental use of sinks attached to the side wall of the bus, as part of the range of adaptations. Before this, it was not unusual to see cutters using drinking water from their container to wash themselves and their tools.

Figure 79: Non-drinking water in use for washing purpose.

Water storage is one aspect worth considering in detail, as the amount of water necessary for the toilet, for the sinks and for drinking would amount to around 600kg. This is undesirable extra weight on the vehicle, even though water is vital for the cutters. Despite the importance of water to the cutters' activities around the vehicle, some of this later ends up on the ground from the drain of the sinks. Thus, there is no point in wasting this amount, given the extra toilet on board requiring more water in the tank.

Although non-drinking water is also important, the vehicles are not equipped with a system allowing water to be re-used, thus increasing wastage and requiring bigger tanks for water storage. Therefore, the current system for the storage of non-drinking water evidently is not adequate to the transportation of sugar cane cutters. This issue is not included in the NR-31, either.

### 4.5.9 Compartment for the Tools

Even though there is now a specific compartment for tools on the buses, one of the adaptations demanded by the NR-31, it was observed that its use is not completely safe. As we can see in Figures 80 and 81, the way the machetes are currently accommodated in the compartments means that they are all spread out all in the available space, in contact with one another during the journey. After the journey, the compartment is a mess, and this ends up being a potential source of injury to the cutters when searching for their own tool in awkward positions (see Figure 82).

Figure 80: Machetes spread out all over the compartment.
Figure 81: Hoe compartment on a bus transporting sugar cane cutters.

Figure 82: Tools handled with difficulty in the compartment.

Despite the undoubted achievement of having the tools transported in compartments separate from the cutters (until recently tools and cutters were transported together), the tool compartment used currently is still inadequate for the vehicle in this transportation situation. However, taking into account the fact that the NR-31 does not offer a specification, having the compartment separate from the cutters is enough to comply with the law.

### 4.5.10 Awnings

Shelter is another requirement of the NR-31, and thus the installation of an improvised awning in one of the side walls of the vehicle was demonstrated during the field research as one the necessary adaptations in the buses. Although an awning constitutes a very simple component, it is a very important achievement, considering that the buses remain as a facility on plantations all day. The harsh natural weather conditions in sugar cane plantations, in particular the sun, make the interior of these vehicles uncomfortably warm for use as a resting place during the lunch break, due to the 'greenhouse effect' inside the vehicles.

The structure of the awnings should be easy to handle; however, field research observed that this was not the case. Not only are the awnings difficult to release from the side walls of the buses, but they also take too long (from 15 to 20 minutes) to assemble, requiring at least two people for the task (see Figure 83). The preparation and assembly of awnings in all analysed vehicles was demanding, particularly because of improvisation of parts and components.

Figure 83: Assembling the awnings on plantation.

Moreover, as we can see in Figure 84, another common problem related to this is the competition for space between the awning when in use and the plants (the higher the plants greater the problem). This is due the angle of the awnings when opened and the narrowness of the corridors through the plantations.



Figure 84: Awning and sugar cane competing for space.

Therefore, despite being another unquestionable achievement, thanks to the NR-31, for the reasons presented above an improvised awning is inappropriate for providing shelter to the cutters. However, again, because the NR-31 merely requires a permanent or mobile shelter, not specifying which kind, this solution theoretically complies with the regulation.

## 4.6 Conclusions

The analysis of the existing off-road vehicles as potential alternatives reveals that none of them are suitable for the specific requirements associated with the transportation of sugar cane cutters. The analysis of the vehicle currently transporting sugar cane cutters, including its mechanical parts, shows that a normal urban bus is not entirely appropriate for this purpose, either. This is because of two main reasons: first, the urban bus was not designed to meet the needs of either the rural context or the transportation of this occupational group. Second, the truck-based ladder chassis and the mechanical parts of the platform are clearly inappropriate for a vehicle involved with this type of transportation.

The results of the field research reveal that the adaptations in the vehicles are not described or technically specified by the regulation NR-31. As a result, this lack of detailed technical specifications makes the efficiency of some of these adaptations questionable. It has been thus confirmed that the majority of the adaptations are either inappropriate or wrong in the context of the vehicle transporting sugar cane cutters.

The detailed consideration of the technical implications of vibration in this transportation reveals that the cutters are subject to harmful vibration frequencies, amplified by the vehicles' movement, and constitutes the major reason for discomfort and motion sickness among the cutters. This is mainly due to the platform of the vehicle which is inadequate for this transportation purpose from the shock and vibration point of view, and even more inadequate when operating in off-road conditions. Thus, by comparing the data gathered from the literature with that from field research, Hypothesis 3 has been upheld. However, it is also important to state that, from the mechanical point of view, vibration can be considerably minimised but not completely eliminated.

In the next chapter I analyse the third parameter of this research: the terrain.

# CHAPTER 5 - TERRAIN ANALYSIS

## 5.1 Introduction

The aim of this chapter is to understand the impact of the terrain and unpaved roads on the transportation of sugar cane cutters.

This chapter focuses on the technical implications of the terrain and unpaved roads to the locomotion process and to the vehicle dynamics influencing the vehicle and its users. As a result, this chapter tests Hypothesis 4, which suggests that a better performing vehicle in off-road conditions increases mobility, ensuring a better ride and a reduction in both travel times and accidents.

Based on the opinion of the literature reviewed, combined with data from the field research, this study allows a better understanding of the technical implications of soil quality and road conditions. It also analyses the influence of climate and rain to the unpaved roads and terrain in this transportation context.

## 5.2 Terrain

Taking into consideration the country's vast dimensions, and the fact that 64% of the 8.6 million $km^2$ of its area is farmland, Brazil includes many different types of climate and soils in which the intensity of diversity varies according to regional differences. Sao Paulo State, in the Southeast region, where the field research took place, mainly consists of plateaus and highland areas, with several peaks over 2,000m. The soil consists predominantly of argissolos and latossolos types (Brazilian nomenclature) or rodhic & haplic acrisols and xandic, rodhic & haplic ferrasols (FAO nomenclature) representing 21% and 56% respectively.

As Brazil has been favoured with a good share of sun, soil and water, this has resulted in rapid plant grouwth. For example, a pine tree in a Finnish forest takes 50 years before it can be pulped and milled into paper. A eucalyptus tree in Espírito Santo State, located on the coast of Brazil, is ready in seven. Growers in Pernambuco State, in north-east of Brazil, harvest grapes twice a year, twice as often as their competitors in France (The Economist, 2007). Likewise, sugar cane has been also favoured by the Brazilian climate. Such favourable weather is a significant advantage in an environmental context due to the ease of managing agriculture during both seasons (harvest and non-harvest seasons) using natural resources not only more effectively, but also more wisely. In addition, there is a government incentive for what is called "family culture", small farms run by families which have been adopting some new agricultural programme.

As approximately two-thirds of Brazil's farmland constitutes of pasture, and occupied by about half a cow per hectare, this means that a significant part of the land is unproductive. If ranching were made more intensive, crops could expand into empty pasture, which means that Brazil need not reduce its forests to expand its arable land. As we saw before, the evolution of the sugar cane planted area in Sao Paulo State in the previous five decades has been based on the replacement of different crops by sugar cane and on the use of unproductive pasture areas. Moreover, according to the FAO (2003), 5.1 million ha are taken up by sugar cane in Brazil, which represents 9% of the country's planted area as a whole. Also, according to Beleboni (2006), sugar cane is not a threat to rainforests, particularly because the soil and climate conditions for these are unsuitable for sugar cane.

Lastly, putting aside the current international discussion about the impact of the production of bio-fuels on the environment and food production, as it is out of the scope of this research, it is evident that the sugar cane industry in Brazil has contributed extensively to the creation of millions of jobs, a reduction in vehicle emission and in pushing the limits of technology in this area beyond boundaries.

## 5.3 Off-road Transportation

Until 10,000 BC, the vast majority of the planet was covered by ice, forest or desert – and this is probably the reason why the invention of the wheel coincides with the agricultural exploratory period of mankind and its particular need for transport. Curiously, the wheel still constitutes the most important element of locomotion on land. However, it still does not have a good relationship with rough terrain, snow, sand or mud. To minimise the limitations of the wheel, roads eventually became as important as the wheel itself in the locomotion process. Nevertheless, as wheel improvement had been relatively marginal until the nineteenth century, this means that even in the context of current technology, off-road transportation still presents the same questions around the relationship between wheels and roads raised in the 1800s and 1900s.

In on-road transportation the vehicle can rely on developments and improvements in street or motorway technology, whereas in off-road transportation the vehicle depends entirely on its own improvements to progress, simply because in many cases there is no proper road to be developed or improved. For this reason, in order to be able to achieve adequate levels of performance in off-road conditions, some of the technical features of the vehicle have to be very different from street vehicles. As success in off-road transportation relies on the vehicle's capacity to deal with the terrain, the locomotion effects in this process are directly connected with the combination of vehicle and terrain. However, paradoxically, even though 90% of the roads in the world are unpaved, the proportion of research and development in vehicle design and automotive technology is overwhelmingly concentrated on on-road vehicles, rather than on off-road vehicles.

According to Bekker (1960), the ability of a medium (terrain, in this case) to support a vehicle statically or in motion, as well as providing thrust, can be assessed only by a combination of relevant physical geometrical values pertaining to both the terrain and the vehicle. Put simply, in any terrain there are conditions which allow the vehicle to utilise the properties of the ground for propelling itself, which are directly dependent on vertical forces (lift), horizontal forces (thrust) and motion resistance. The problem is that when designing aircraft or boats, operating in air and water respectively, it is possible to consider air and water in the calculations, whereas the surface roughness of the terrain or unpaved roads present random profiles which can be predicted by an average of several different measurements but not calculated with precision. This means that the consideration of terrain as a medium involved in transportation is not possible in the same straightforward way as in the design of an aircraft or a boat. This is particularly due to the diversity of soil types and also the even greater diversity in terms of their physical composition, multiplying the number of variables to be considered and making an accurate analysis extremely difficult.

On account of this, the ideal situation for a vehicle in operation would be that the ground presents enough strength to support the vehicle's weight without much motion resistance, providing the required thrust for propulsion for the vehicle, resulting in locomotion. However, whist motion resistance exerts an influence on transportation, it is not as high on paved roads as it is in off-road conditions.

The particular problem is that different soil types require different designs to maximize the vehicle's performance. As an example, Machado et al. (1997) says that research undertaken in Africa and in the United States shows that a damaged unpaved road is able to offer motion resistance varying from 90 to 180kg per tonne of gross weight of a vehicle. On the same road, once it has been graded with an extra layer of gravel, the level of motion resistance of the same vehicle can be easily reduced to 30 to 45kg per tonne. The adoption of alternative design criteria combining good vehicle performance on different terrain, for different purposes in off-road transportation, should therefore be one of the most important issues for research in vehicle design.

Therefore, the road and terrain conditions and performance in transportation are directly connected with the motion resistance of the vehicle, which in its turn interferes with vehicle speed. Also, such conditions are directly connected with shock absorption and vibration, which in its turn interferes with comfort, and as these are also directly connected with the dynamics of the vehicle, they end up compromising safety. As a result, the better the road surface conditions the better the vehicle performance, and consequently, the better the road surface conditions the better the fuel consumption of the vehicle. Thus, as 50% of the cutters' transportation takes place in off-road conditions, these conditions constitute an important component, compromising not only motion resistance, but also the cutters' safety and comfort.

### 5.3.1 Unpaved Roads

According to Alfelor & McNeil (1989), the proportion of unpaved roads in developed countries in 1978 varied from 5% to 63%, whereas in developing countries the proportion varied from 70% to 97% of the total network. The World Bank (1981) supported by Viviani (1998), states that the total length of unpaved roads in developing countries was approximately six million kilometres. However, as transportation demands roads, and unfortunately their construction results in a certain level of destruction and disturbance to the environment, there is currently a dilemma between the urgent need for more roads and their environmental impact.

Like any other country, agricultural areas in Brazil consist mainly of unpaved roads, and they are absolutely essential for the economy, being the primary source of moving agricultural produce. For this reason, unpaved roads are important in the Brazilian transportation system not only because of economic and social issues, but also because of their connection to the majority of other primary and secondary roads which in their turn allow access to the main paved roads and highways. This means that the unpaved roads will continue to be part of the Brazilian agricultural context for many years to come.

Despite the interest and effort of many international financial institutions associated with road construction, they currently are stricter about new projects, for two main reasons: first, because of the cost of construction, taking into account the fact that, according to Beenhakker (1983), a simple track can cost up to £10,000/km, whereas the construction of a gravel road can easily cost up to £100,000/km (see Table 14). Second, and most important, because of the difficulties of many countries to maintain their existing road infrastructure. As the World Bank (1981) reported, 85% of developing countries needed US$ 41 billion for existing road maintenance alone. As this research also reveals, after analysing financial data from sugar cane companies, the average cost of the maintenance of unpaved roads crossing sugar plantations (see Figure 85) is £0.18 per ton of harvested sugar cane or £758/km.

| 1 | 2 |
|---|---|
| Unpaved Road Types | Construction Costs per km* in 1981 |
| Track | £7,000 - £10,000 |
| Unpaved Road Without Drainage | £8,000 - £18,000 |
| Gravelled Road | £50,000 - £100,000 |

Table 14: Typical rural road construction costs.
Source: Henri Beenhakker (1983)

Figure 85: Unpaved road maintenance on sugar cane plantations.


In Brazil, according to the Brazilian Ministry of Transport (2000), just 11% of all its roads are paved (see Table 15). Rural unpaved roads are a major part of the country's everyday transport system, and in many cases people must travel long distances on them, taking into account the size of the country.

| 2000 | |
|---|---|
| Brazilian General Transport Data | |
| Unpaved roads | 1,559,941km |
| Paved roads | 164,988km |

Table 15: Brazilian general transport data in 2000.
Source: Brazilian Ministry of Transport

For this reason, rain is one of the biggest problems relating to road maintenance in Brazil as heavy rainfall can easily destroy an unpaved road. Of course this is a problem that affects the sugar cane companies considerably, particularly due to the frequency of rain during the year (see Figure 86). Financially speaking, one day without production because of rain costs £240,000/company, because access to plantation areas on such days is practically impossible. Even though agricultural activities could take place normally on the plantation on rainy days, the problem is it affects transportation, particularly the transportation of cutters, who cannot reach a particular location on the plantation to carry out their work. A vehicle able to reach the sugar cane plantation even on rainy days would thus be economically beneficial.

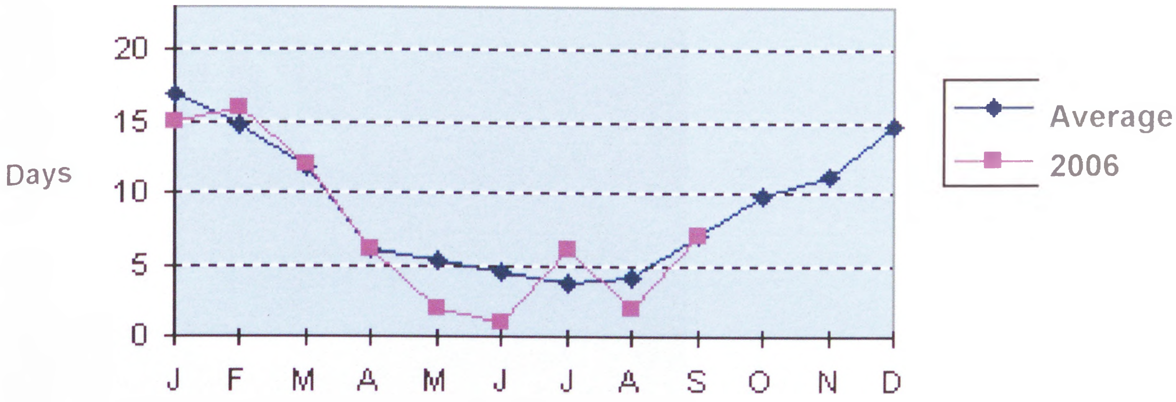



Figure 86: Rainy days in central area of SP State in Brazil.
© Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ

Visser & Hudson (1983), quoted by Viviani (1998), confirmed that a damaged unpaved surface in the rainy season should be removed and a new layer of soil added in order to reduce the damage caused by the traffic and rain, in particular when the quality of the soil is weak and the drainage is insufficient. As this research notes, the organic material (bagasse) resulting from the remains of sugar cane that drops from the trucks along the unpaved roads contributes to the deterioration in the quality of the road surfaces. Ribeiro (2006) states that a practical solution to this would be to fill in the potholes along the roads instead of grading the surface to remove them. However, as this research acknowledges, the reverse has happened in the maintenance of rural unpaved roads in Brazil, including those situated in sugar cane plantation areas. Because grading of the road surface is the common way of eliminating potholes and unevenness, this operation also removes the road's compacted layer, making it even more vulnerable to the action of weather combined with traffic. Therefore, when the unpaved roads are graded regularly the road levels are reduced turning the channel for the water to collect in when it rains.

On account of the conditions of the unpaved roads and terrain on rainy days (see Figure 87), 50% of the drivers of the buses transporting sugar cane cutters identify getting stuck as one of the major problems in the transportation of cutters, followed by the problems related to slippage emphasised by 38% of them. As we saw before, this represents a considerable limitation for this industry, with substantial financial losses and scheduling problems.

Figure 87: A rainy day on sugar cane plantations.

With an area of 247,898km², Sao Paulo State alone has 170,000km of unpaved roads, and according to Pastore *et al.* (1986), most of them are in bad condition, with daily traffic not exceeding 30 vehicles/day. While currently these unpaved roads often do not survive a single season without need of proper maintenance, unfortunately the capacity to maintain them appears to be diminishing as time goes on. The obvious solution to the problem related to unpaved roads is to pave them; however, finding investment necessary to build paved roads, in association with their ongoing maintenance cost, indicates that paved roads are not an affordable solution in many cases. This explains why there are countries around the world where distant communities have difficulty in obtaining access to health care, education and other public services due to the transport infrastructure.

As agricultural production has expanded, the road network has become longer, and is thus difficult to maintain adequately. Maintenance thus becomes even more important. Liautaude & Faiz, (1994) quoted by Viviani (1998), points out that the operational cost for vehicles using unpaved roads with a good level of maintenance is from 10% to 30% higher compared with those found on paved roads. However, this would be worse; with the same operational costs increasing three or four times, if such unpaved roads were subject to negligent maintenance or suffered from a high volume of traffic. This means that the operational cost for vehicles using unpaved roads in bad conditions can be from 40% to 120% higher than costs for operation on paved road. In addition, a layer of unpaved road in sandy soil (see Figure 88) is 20 times more easily damaged than a gravelled road (see Figure 89), in the same traffic and climate conditions.

Figure 88: Example of unpaved road without gravel.
Figure 89: Example of gravelled unpaved road.

Related to this, Machado *et al.* (1997) give an example of the effect of an unpaved road on motion resistance in Brazil. He considers a 12-ton truck equipped with 130hp engine travelling over an unpaved road without any maintenance, which has been damaged by traffic action and rain. Having a motion resistance of 90kg/ton of the gross weight of that truck, its fuel consumption is of roughly 0.87litres/km. The same exercise was then carried out after the road was graded and gravelled, resulting in a reduced maximum motion resistance for the same truck of 45kg/ton. In these unpaved conditions, the truck was also able to generate a reasonable average operational speed of 42.87km/h and a fuel consumption of 0.44 litres/km. The cost savings generated from such road improvement results in a fuel saving of 0.43 litres/km. Taking into consideration the size of the Brazilian unpaved road network (1.2 million km), and the traffic of 20 vehicles per day, it would result in a saving of 10,464,000 litres/day or £4,839,600/day, based on cost of diesel in Brazil (£0.47/litre) in September 2007.

It is also confirmed by a research undertaken by Crossley (1987) in which is clear that, the needed extra power required to overcome higher motion resistance results in higher fuel consumption. His study shows that there is a change of 28% in costs from low to medium levels of resistance and another 28% from medium to high.

Furthermore, unpaved road damage is also caused mainly by heavy goods vehicles. The American Association of State Highway Officials (AASHO) undertook a large-scale experiment involving different axle loads, revealing that a truck with 13 tonnes of load on one of its axles is nearly three times as damaging as a truck with 10 tonnes of load. This means that the increase of axle load by 30% increases damage on the road by 300%.

Another important aspect to be considered here relates to the safety of the corridors crossing the sugar plantations consisting of a single carriageway. It is often argued that since single carriageways are inherently dangerous, wider roads should be built for safety reasons, even with low traffic levels. However, according to Ellis and Hine (1994) supported by Lebo & Schelling (2001), a vehicle at a speed of 40km/h (the same speed of a bus transporting sugar cane cutters) operating on unpaved roads with a single carriageway and traffic of 10 vehicles per day has the possibility of 0.05 accidents/day. Taking into account the fact that the majority of the corridors on the plantation are used only for short periods during the year, and the low level of traffic (from 20 to 30 vehicles per day), even in busiest times during the harvest season, it would not be necessary to double the width of the current corridors. Nevertheless, it would be desirable to enlarge the current width by 1m, offering more flexibility for manoeuvre to the vehicles travelling on the plantation.

Therefore, considering the dimension of the sugar cane plantations, in association with its necessary division into smaller areas, results in a requirement for a gigantic network of unpaved roads surrounding such areas. As this research found at one of the 40 farms in Tecnocana where the field research took place, there is a total of over 190km of unpaved roads, which means that the limitations regarding unpaved roads presented above become even more problematic and challenging. Part of the solution of course includes a vehicle better capable of dealing with off-road conditions, with consequently reduced travelling times and fuel consumption.

### 5.3.2 Soil Compaction

In agriculture, there is a direct connection between soil compaction and transportation. As this research reveals, soil compaction is a serious issue, particularly on plantation areas combining soft soil and rain, which characterises sugar cane plantations in Brazil during specific periods of the year. Thus, this constitutes another reason for the aim of reducing the weight of the vehicle transporting cutters. Ironically, in this case the shorter part of the journey (10%) in which the vehicle travels over plantation areas or other rough terrain can become the most demanding, not only for the vehicle and its performance, but also for the cutters.

The intense use of agricultural machinery on plantations is not cost-effective for the agricultural industry, productively or environmentally. One of the main reasons for this is the soil compaction (see Figure 90) caused by the activity of agricultural vehicles, such as trucks, tractors, trailers and harvesting machines.

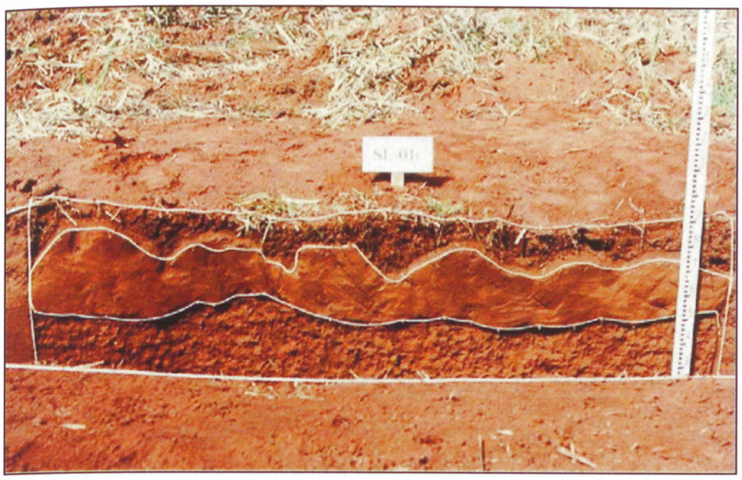


Figure 90: A layer of compacted soil underneath the surface.
© Rubismar Stolf

Soil compaction is also directly related to the properties of the soil, including its moisture level and composition. The lower the moisture level the lower the compaction, no matter what the soil type might be (clay or sandy, for instance). Figure 91 shows the difference in soil compaction caused by the same vehicle and tyre according to the moisture level in the soil, showing that the higher the moisture levels in the soil, the more compacted it becomes after traffic use.

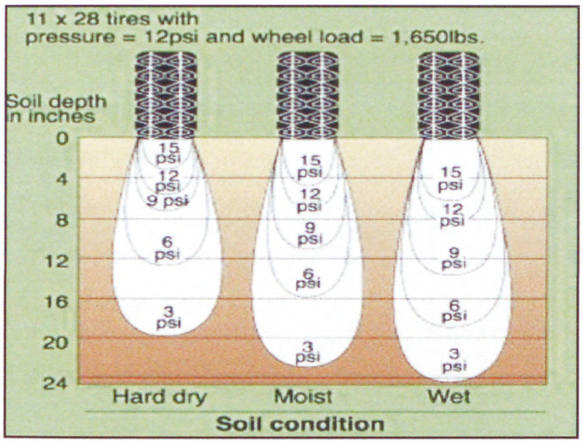



Figure 91: The effect of weight of vehicles on different soil conditions.

As compacted soil has a much lower level of oxygen, it develops a natural barrier to the plant's root penetration, sometimes making growth impossible. As we can see in Table 16, according to Mazza (2004), an increase of 39% (1.04 to 1.44 g/cm$^3$) in soil density can reduce the growth of plant roots by 91.5% (20 to 1.7 mm/day), which is a severe agricultural limitation. For this reason, soil compaction is classified as a major problem affecting sugar cane production, proving that any investment able to minimise this problem must be seriously considered, given that up to 20% of the harvest of an entire plantation may be lost in this way.

| Plants Roots Growing | |
|---|---|
| Soil Density (g/cm$^3$) | Root Growing (mm/day) |
| 1.04 | 20 |
| 1.12 | 16.6 |
| 1.2 | 16.5 |
| 1.28 | 13.5 |
| 1.36 | 7.5 |
| 1.44 | 1.7 |

Table 16: Relationship between soil compaction and sugar cane root growing.
Source: Jairo Mazza

As a result, a Brazilian sugar cane company could lose on average £3.6 million/year if its production were reduced by 20% (see Table 17). Projecting this figure nationally, 92 million tonnes of sugar cane, or £920 million would be lost (see Table 18). Thus soil compaction is a technical and financial issue, rather than a purely environmental one. Paradoxically, like heavy goods vehicles, agricultural machinery has become bigger, more powerful and in many cases heavier.

| Potential Production Loss per Company (average) | |
|---|---|
| Total Annual Production | 1.8 million Tonnes |
| Soil Compaction Loss | 20% |
| Total Annual Production Loss | 360,000 Tonnes |
| Price of the Sugar Cane per Ton | £10 |
| Annual Cost of this Loss | £3.6 million |

Table 17: Potential production loss (on average) per sugar cane company due to soil compaction.

| Potential Production National Loss (soil compaction) | |
|---|---|
| Number of Production Units | 248 |
| Total Annual Production | 460 million Tonnes |
| Soil Compaction Loss | 20% |
| Total Annual Production Loss | 92 million Tonnes |
| Price of the Sugar Cane per Ton | £10 |
| Annual Cost of this Loss | £920 million |

Table 18: Potential Brazilian sugar cane production loss due to soil compaction.

Another important issue related to soil compaction shown by this research is the risk of erosion on the plantation caused by the effect created between the compacted soil of the corridors through plantations used by the vehicles, and the softer soil along the plantation. Taking into account the fact that the rain water is unlikely to penetrate the compacted soil, all the water tends to run towards the softer soil on the plantation, creating ditches that may turn into areas of excessive erosions. Consequently, soil compaction is also problematic for agricultural production, both in terms of direct effect of compaction itself, and indirect effects created by consequent soil erosion.

Although compared to agricultural machinery the passage of vehicles transporting sugar cane cutters is not unduly harmful to the soil in terms of compaction, it is worth taking into account soil compaction,  because the lighter the vehicle the better its performance in soft soil, and the lower the soil compaction.

## 5.4 Field Research

The conditions of the unpaved roads and terrain on sugar plantations over which the vehicles transporting sugar cane cutters travel was also part of the field research sessions in Brazil, and farm number 40 in Borebi SP was once again used as reference for this analysis.

Regarding the proportion of paved and unpaved roads used by the vehicles in this transportation study, as we can see in Table 19, it confirmed that actually there is not much difference in this proportion, if compared to data presented by Rodrigues (1993).

| Types of Roads in Rural Transport | 1993 | 2006 |
|---|---|---|
| Paved Roads | 47% | 50% |
| Unpaved Roads | 40% | 40% |
| Rough Terrain | 13% | 10% |

Table 19: Road types used for the transportation of sugar cane cutters in SP in 1993 and 2006.

After leaving the paved roads, vehicles transporting the cutters have to travel on kinds of unpaved road and terrain. Whether travelling on loose and soft terrain or travelling on hard and rough surfaces, the vehicle operates at low speeds because of having either to deal with a higher motion resistance or to minimise the undesirable effects of shock and vibration.

The investigation also reveals that, as shown in Figures 92, 93 and 94, because of the size of the plantations, it is common to have different types of soil (e.g. clay or sand or a combination of both) in the same region. This confirms the hypothesis that in off-road transportation what is suitable for one vehicle may not be for another.

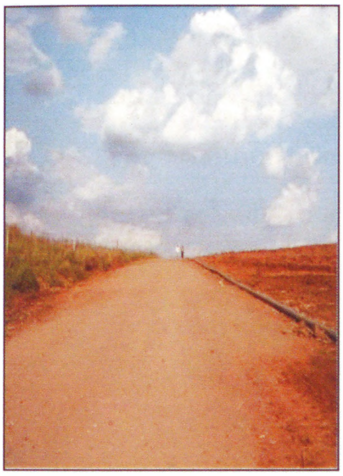
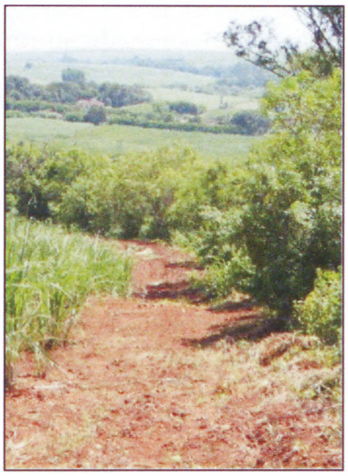




Figure 92: Gravelled road surrounding sugar cane plantations.
Figure 93: Narrow corridors throughout plantations.
Figure 94: Terrain conditions on plantations in harvest seasons.

Also, the conditions of the unpaved roads observed during the field research sessions confirm the position of Pastore (1997), who states that lack of appropriate drainage is the most common problem of unpaved roads under the authority of municipalities and sugar cane companies. This absence of appropriate drainage includes:

- Lack of transversal convexity, allowing a rapid escape of the rain water to the side gutters
- Lack of side gutters
- Lack of water exits alongside the road in order to offer an appropriate direction for the water on both sides of the roads

The research indicates that where the proportion of clay is higher than sand, the conditions are, as follows:

- In rainy seasons, if the surface layers of an unpaved road is not robust enough to cope with heavy traffic conditions, it becomes damaged, making the road impassable for traffic for some time
- In rainy seasons, if the quality of soil is weak and the drainage is insufficient, the base of the unpaved road gets damaged and it becomes necessary to add an extra layer of better soil in order to reduce the damaging effects of traffic, which, incidentally is not usually done as part of the maintenance
- In the dry seasons, excessive generation of dust was noted and confirmed by footage recorded from a vehicle immediately behind a bus transporting the cutters
- Many surfaces present a crocodile-skin appearance during the dry season causing vehicles to shake a lot and produce excessive dust, whereas in rainy seasons the same roads become smooth and slippery
- The accumulation of soil in the centre and at the sides of the unpaved roads forming tracks due to the action of weight of the vehicles concentrated on its wheels was also noted. In this case, a complete deficiency of drainage was also observed, allowing the water to remain on parallel ditches on the road, normally called 'W' format, instead of the water being guided out of the road

In regions where the opposite was noted, (e.g. a higher proportion of sand than clay), the conditions are as follows:

- Surfaces of the roads and/or corridors throughout the plantations showed an excessive loss of granular material
- During the dry season, the formation of a layer of fine sand on the surface was noted due to traffic, generating unevenness and potholes as a result
- The more sandy the soil the more easily damaged the road surface, particularly potholes and depressions caused by surface material disintegration

Furthermore, as the majority of these unpaved roads are in bad condition, they become even worse between October and December when the level of rain is high and coincides with the end of the sugar cane harvest season that usually occurs from April to December. As this research shows, this is the period in which the technical capabilities of the vehicles are really tested, facing all kinds of locomotion limitations. The field research indicates that flooding, combined with natural road surface wear caused by traffic, normally results in big potholes on unpaved roads. This happens when the water is able to travel across the surface layers without appropriate protection or drainage, and some kinds of clay soil in arid areas can form cracks on the surface due to the contraction caused in the dry season, making the formation of potholes even easier. Gravelling the unpaved roads would be a suitable and affordable solution, particularly because Brazil has abundance of gravel that could easily be used for this purpose. However, the distance between the source of the material and the working point on the road to be repaired needs to be considered, taking into account the fact that if this distance is longer than 10km it ceases to be economically viable. Most importantly, as gravel is a finite natural resource, this option is not environmentally sound.

This research found that the unpaved roads under the responsibility of municipality were in a worse condition than those belonging to the sugar cane companies. This suggests that these companies have tried hard to keep their roads in acceptable condition. However, the size of the whole unpaved road network, combined with the effects of traffic and weather, make the maintenance task very challenging indeed. This means that unpaved roads, with different conditions and surfaces, conspire to increase the task of the vehicle transporting sugar cane cutters from one place to another safely, quickly and comfortably. The combination of these limitations and the difficulty of paving the unpaved roads on plantations makes the investment in a more appropriate and specific designed vehicle for this transportation purpose not only a more economic option, but also a very sensible one.

## 5.5 Conclusions

The analysis of the types of unpaved roads and terrain indicates that a vehicle more capable of coping with these conditions is required. Despite the best maintenance efforts, a single rainfall, combined with the traffic of heavy trucks, is enough to ruin the road surfaces, becoming in some cases impassable. The combination of rain with the softness of the terrain on the plantation during the planting season results in the vehicles getting stuck in the mud easily.

It was found that in order to be able to achieve satisfactory performance levels, the vehicle must have some technical features appropriate to the task. The level of motion resistance of the vehicle travelling over unpaved roads can be reduced by 3 to 4 times, comparing a road without maintenance to a graveled road. However, the literature shows that constant maintenance of unpaved roads is not economically viable. Moreover, the field research pointed out that the unpaved roads and terrain conditions are not favourable for the type of vehicle currently in use, increasing the accidents exponentially. Therefore, Hypothesis 4 is confirmed.

In the next chapter, I compare the costs of other transportation alternatives as the last step to confirm whether or not a bus-type vehicle is the best alternative for the transportation of sugar cane cutters.

# CHAPTER 6 - ECONOMIC ANALYSIS

## 6.1 Introduction

The aim of this chapter is to analyse the costs of other transport alternatives in relation to the problem of the sugar cane cutters' commuting in comparison with the current solution.

This chapter tests Hypothesis 5, which suggests that, land transportation using a bus-type vehicle remain the only viable option that should be explored for this matter. Like the user, vehicle and terrain analysis, the economic analysis was also based on data gathered from the field research.

Several alternatives were considered in this analysis, from the suggestion of paving the roads to the construction of a railway network to the adoption of an aircraft. The comparative analysis, based on productivity, demonstrates what would be the best solution from the economic point of view.

## 6.2 Methods

This study considers not only the start-up investment and the operational cost of each option, but also the impact of such investments amortised over 10 years. In order to provide a more accurate and comprehensive result, data relating to the transportation of sugar cane cutters as well as sugar cane is considered. Moreover, the current system for the transportation of sugar cane cutters using urban buses has been adopted as a reference to be compared to the other alternatives, which include:

- A new paved road infrastructure to be used by the existing fleet
- A new railway infrastructure, including trains
- An aerial alternative using high load capacity helicopters

The method used was to take one of the farms (see Figure 9.5) from Tecnocana (Macatuba SP Brazil) as a reference. The black lines on the map represent the paved roads, whereas the green lines represent the unpaved roads surrounding the plantation and the grey ones represent the corridors throughout the plantation. Travelling with the vehicles transporting the cutters it was also possible to determine travel times and distances. Such information, in conjunction with financial figures presented by the company above, enabled the calculations about costs related to the current transportation system. Besides the map and the field research the calculations have also been based on data supplied by the administrative and agricultural department of this company.

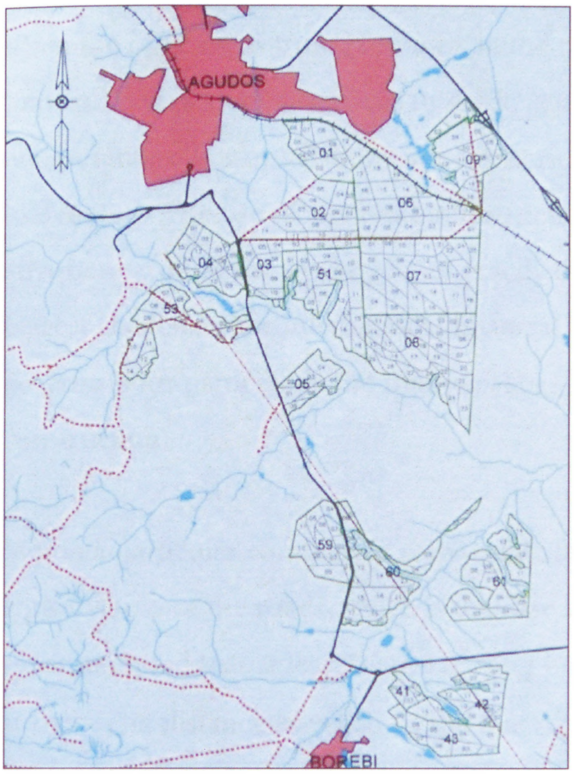



Figure 9.5: Tecnocana Farm Number 40.
Source: Tecnocana

To obtain details of the costs related to paved road and railway construction, and also the adoption of a helicopter, the calculations were also based on specific information gathered from experts in each particular field of knowledge. From four distinct kinds of cutters' journeys from their homes to plantations, three different conditions were considered: paved road, unpaved road and corridors through the plantation. These journeys were also measured, and recorded, and their condition analysed.

The next step of this investigation is based on the approach of the agricultural companies when setting up a business plan in which they try to maximize the use of the resource and optimizing the start-up investments and their consequent amortizing costs. For this reason, this study considers not only the costs of transporting the cutters, but also the sugar cane itself.

The transportation cost is analysed in the light of literature relating concepts based on traditional micro-economic theory. Thus, transportation costs are considered as similar to any other consumer goods production costs. This analogy is acceptable up to a point. In companies that produce consumer goods, for example, it is possible to plan production observing only average demand. In this case, the manufacturing process can be constant, so that when supply is higher than demand the goods are put in stock, and are delivered when the opposite is true. However, in the case of services, this approach fails, due to the impossibility of putting services in stock, generating as a result an under-usage of equipment and/or installations in peak periods when the company tries to match supply to demand. The use of any road infrastructure, including unpaved ones, as a service anywhere around the world, , faces exactly the same problem, remaining one of the biggest challenges for international financial institutions such as the World Bank and governments, particularly the municipalities involved with road maintenance and construction.

When a particular company is responsible for the implementation, maintenance and conservation of the roads, which is the case with many sugar cane companies, it is recommended that at least three variables be considered, as follows:

- The distance travelled by the fleet
- The operation time of the fleet
- The length of the road

Thus, this part of the study adopts concepts and calculation guidance from Kawamoto (1993), who uses 'function production' as a base for cost determination in transportation, including rail transport. According to this method, a unit reflects the quantity or amount transported as well as the distance and also includes aspects related to vehicles, roads and terminals. The cost of railway implementation, in particular, depends basically on topography and project speed, considering each type of surface condition translated into costs per kilometre, materials, quality of soil and so on.

In order to keep the same level of accuracy for the railway analysis, Queiroz (2006) and Barbieri (2006) were consulted, and through their expertise it was possible to identify the suitable alternative for this particular case. Thus, having looked at the problem from a Brazilian point of view, the construction of a wider gauge (1.6m) railway has been considered for analysis. It would cross the main plantation areas as directly as possible, with the position of the rails in accordance with standard railway design requirements. However, it is important to address the fact that in terms of payment in instalments (amortising), it would not be possible to imagine the use of the railway by anyone other than rural workers, simply because there are scarcely any people living on sugar cane plantations in Brazil at the moment. The majority are currently living in towns surrounding the plantations.

Another alternative for moving cutters from their homes to the plantations considered in this analysis is by air, using a Chinook helicopter, which has a capacity of 45 seats.

While the cost of each alternative is presented in percentage terms in relation to the daily production of sugar cane on the reference farm (345 tonnes x £11.12/ton £3,834.68/day), for the amortising of the start-up investments the lifespan of each alternative is considered instead. Thus, as underlined by Salgado (2006), a calculation amortising the start-up costs for over ten years was undertaken, as we can see in Table 21, and it is based on the Equivalent Annual Cost (EAC) method (Samanez, 2001), which is the cost per year of owning and operating an asset over its entire lifespan. This is particularly appropriate when comparing investments of unequal lifespans, which is the case of the comparison here, considering the expected lifespan of each option (80% for buses, 50% for paved roads and railways and 70% for helicopters). Also, two different Brazilian annual interest rates were used in this case, due to the considerable difference between them: the Brazilian Economical and Social National Development Bank (BNDES) with an annual rate of 7%, and the treasury bonds (TiT) with a rate of 13%.

## 6.3 Comparative Cost Analysis of Alternative Solutions

With a view to catching up with more developed countries, some decades ago the Brazilian government decided to invest massively in road construction. For this reason road transportation became by far the most common mode of transportation, as opposed to rail and shipping. However, as this unfortunately led to high transportation costs, some questions have been raised since this research began. Instead of urban buses, why not simply pave the unpaved road network on the plantation, or why not build a new railway throughout the sugar field, or even why not adopt an aerial solution, making this transportation problem completely redundant? This chapter has been written in order to answer these questions.

The first stage of this analysis involves travel distances and travel times, and took place during the same sessions of field research used for the previous analysis involving the cutters, the vehicle and the terrain. The results are presented below as follows:

Journey 1 – Bela Vista plantation area:

- Picking the cutters up in town 9km (25 minutes) 18%
- On paved roads 32km (35 minutes) 63%
- On unpaved roads 8km (20 minutes) 16%
- On plantation corridors 2km (5 minutes) 4%

Total 51km (85minutes)

Journey 2 – Limoeiro plantation area:

- Picking the cutters up in town 9km (25 minutes) 14%
- On paved roads 32km (35 minutes) 50%
- On unpaved roads 10km (25 minutes) 16%
- On plantation corridors 13km (15 minutes) 20%

Total 64km (100minutes)

The second stage includes all necessary information for the calculations, including also the resources (assets) to operate in the analysed farm, as follows:

- Farm area: 1,793.40ha
- Daily sugar cane production: 345 tonnes
- Sugar cane cutters: 450
- Drivers, machine operators and supporters: 176
- Adapted urban buses for sugar cane cutters' transportation: 10
- Minibus for drivers', machine operators' and supporters' transportation: 1

- Heavy duty trucks: 10
- Paved roads: 8.3km
- Unpaved roads: 79.6km
- Corridors: 112.1km
- Unpaved roads + corridors through plantations: 191.7km
- Travel distance (average): 52.3km
- Travel time (average): 85 minutes

The third stage is based on data presented above, calculating the current cost of transporting the cutters from their home to the plantation using the current adapted urban buses, as follows:

10 buses with capacity for 45 to 60 people = £450,000 (start-up)
The operational and maintenance cost is £0.33/ton of sugar cane, which means:
345 tonnes/day x £0.33 = £113.85/day or £35,521.20/year
104.6km (return trip) x 10 buses = 1,046km/day
£113.85 ÷ 1,046km = £0.11/km

The cost of transporting the sugar cane itself from the plantation to the mill using heavy-duty trucks (tractor + 3 semi-trailers) is calculated as follow:

10 trucks with capacity for 45 tonnes = £2,500,000 (start-up)
The operational and maintenance cost is £0.81/ton of sugar cane, which means:
345 tonnes/day x £0.81 = £280.31/day or £87,456.72/year
805.4km (return trip) x 10 trucks = 8,054km/day
£280.31 ÷ 8,054 = £0.03/km.

### 6.3.1 Paved Road System

To begin with, in order to obtain accurate road cost calculations, with reference to the Brazilian situation, Macedo (2006), was consulted, and with his support and advice it was possible to determine the most appropriate kind of paved road with the minimum cost. Taking into account the conditions of the terrain and the activity, serving not only cutters but also sugar cane transportation, a compacted lower layer is proposed, followed by

300mm of stable soil with rocks, 25mm of asphalt, superficial treatment plus finishing, costing £100,000/km (start-up) with a maintenance cost approximately 1% per year.

#### 6.3.1.1 Journey A

With reference to the map presented earlier, 79.6km of unpaved road around the plantation areas would need to be paved. This means a total start-up cost of £10,910,000 (79.6km of paved road (£7,960,000) + 10 buses (£450,000) + 10 trucks (£2,500,000). In addition, the total operational and maintenance cost of £202,577.92/year or £649.29/day (road maintenance cost (£79,600) + operational and maintenance cost of buses (£35,521.20) + operational and maintenance cost of trucks (£87,456.72), calculations include six days/week, or 312 days/year).

#### 6.3.1.2 Journey B

Taking into account in this case not only pave the main unpaved roads around the plantation areas (the green lines on the map), but also all the corridors through them (grey lines on the map), 191.7km of paved road would be necessary. As we can see in Table 20, this means a total start-up cost of £20,120,000 (191.7km of pavement (£19,170,000) + 10 buses (£450,000) + 10 trucks (£2,500,000). In addition, the total operational and maintenance cost of £314,677.92/year or £1,008.58/day (road maintenance cost (£191,700) + operational and maintenance cost of buses (£35,521.20) + operational and maintenance cost of trucks (£87,456.72). Calculations also include six days/week, or 312 days/year.

### 6.3.2 Railway System

Rail transport has been used for many years on sugar cane plantations in Australia (see Figure 96), where, according to James & Ruhle (2006) 36 million tonnes (95%) of the sugar cane harvested in 1999 was transported by rail, with over 4,300km of track. Putting aside the fact that the topography of the majority of sugar cane plantations in Brazil is not favourable to a railway, a system adopting the TR-50 rail type without electrical infrastructure, to be operated with diesel locomotives, would cost £174,223.35/km and the maintenance cost would be 0.34 %/year.

Figure 96: Australian sugar cane railway.
© Chris Hart

As we can see in Table 20, taking into account 76km of railway including the areas for manoeuvres and cargo terminal, a total start-up cost of £15,365,974.60 or £174,223.35/km would be necessary. This means (76km of railway (£13,240,974.60) + 2 used diesel locomotives (£625,000) + 6 used passenger carriages for the cutters' transportation (£300,000) + 30 cargo wagons for sugar cane transportation (£1,200,000). In addition, the maintenance cost for such a railway would be £52,244.31/year (0.34% of the start-up cost) or £167.50/day ÷ 152km (return trip) = £1.10/km.

According to Kawamoto (1993), the operational cost for the train would be 4.7 litres of diesel/1,000 tonnes transported. This means 2 diesel locomotives weighing 240 tonnes + 6 passenger carriages weighing 240 tonnes + 30 cargo wagons weighing 600 tonnes = 1,080 tonnes (without cargo) + 345 tonnes of sugar cane = 1,425 tonnes (with cargo) totalling 2,505 tonnes (1,080 + 1,425).

2,505 tonnes ÷ 1,000 tonnes = 2.51 x 4.7 litres of diesel = 11.77 litres x £0.50/litre = £5.89/km x 152km (return trip) = £894.79/day x 182 days (harvest time) = £162,851.78/ year (cargo included) or,

2,160 tonnes ÷ 1,000 tonnes = 2.16 x 4.7 litres of diesel = 10.15 litres x £0.50/litre =

£5.08/km x 152km (return trip) = £771.55/day x 130 days (out of season activities) = £100,301.50/year (cargo excluded). Grouping this data, we have:

- Total cost per year = £315,397.59 (£52,244.31 + £162,851.78 + £100,301.50)
- Total cost per day = £1,010.89 (£315,397.59 ÷ 312 days)
- Total cost per km = £6.65 (£ 1,010.89 ÷ 152 km)

### 6.3.3 Aerial Solution

According to sources in the US Army (2006), the adoption of a Chinook helicopter (see Figure 97) would require a start-up investment of £9,775,000, and according to The British Royal Air Force (2006), its operational cost, including maintenance, would be £5,000/flight hour.

Figure 97: CH-47 Chinook Helicopter in operation.
©: Mini Helicopter

Looking at the Chinook helicopter to transport 450 cutters, we have:
450 cutters/45 cutters per trip (its cabin capacity according to US Army (2006) = 10 different trips to three different distances (3 x 35km; 4 x 15km and 3 x 6km) and three different travel times for each situation (3 x 10 minutes; 4 x 8 minutes and 3 x 7 minutes). This means 166 minutes (return trip) or 2.77 flight hours/day which means £13,850/day or £4,321,200/year.

Including the transportation of the sugar cane itself, although other sources have mentioned a different payload capacity, such as US Army (2006), which gives 12 tonnes for one of its hooks and 7.5 tonnes for the other two totalling 27 tonnes, this study has considered data from the aircraft manufacturer Boeing (2006), which recommends 12 tonnes as the weight capacity for this helicopter. Thus, taking into consideration the Chinook helicopter transporting all 450 cutters plus 345 tonnes of sugar cane (daily production), we have:

345 tonnes of sugar cane ÷ 12 tonnes/trip would require 29 trips with three different distances (11 x 35km; 10 x 15km and 8 x 6km) and three different travelling times for each situation (11 x 10 minutes; 10 x 8 minutes and 8 x 7 minutes). This means 492 minutes (return trip) or 8.2 flight hours/day which means £41,000/day or £12,792,000/year. Table 20 below presents all the results, as follows:

| Sugar cane + cutters transportation comparative cost table (Farm Number 40) | | | | | | |
|---|---|---|---|---|---|---|
| Alternatives | Distance | Time | Start-up | Operational + Maintenance | Daily Cost | % Prod. |
| Current System (10 adapted urban buses transporting 450 cutters) | 52,3km average (one way) | 10 trips x 85min. Average (one way) | R$ 1.800.000,00 or £ 450,000 | R$ 0,44 (£ 0,11)/km or R$ 142.084,80 (£ 35,521,20 )/year | R$ 455,40 or £ 113,85 | 4% |
| Current System (10 big lorries transporting 345 tonnes of sugar cane) | 52,3km average (one way) | 77 trips x 140min. Average (one way) | R$ 10.000.000,00 or £ 2,500,000 | R$ 0,14 (£ 0,03)/km or R$ 329.826,88 (£ 87,456,72)/year | R$ 1.121,25 or £ 280,31 | 7% |
| Paving Road (compacted lower layer, stable soil with rocks, asphalt superficial treatment plus finishing) + 10 buses for the cutters + 10 lorries for sugar cane | Journey A 79,6km paving (main roads) | 70,9min. Average (one way) | R$ 43.640.000,00 or £ 7,960,000 | R$ 0,58 (£ 0,14)/km or R$ 810.311,68 (£ 202,577,92)/year | R$ 2.597,15 or £ 649,29 | 17% |
| | Journey B 191,7km paving (main roads + corridors) | 59,6min. average (one way) | R$ 88.480.000,00 or £ 22,120,000 | R$ 0,58 (£ 0,14)/km or R$ 1.258.711,68 (£ 314,677,92)/year | R$ 4.034,33 or £ 1,008,58 | 26% |
| New Railway (railroads, 2 locomotives, 6 carriages for the cutters, 30 wagons for sugar cane ) | 76km average (one way) | 2 trips x 51,7min. Average (one way) | R$ 61.463.898,40 or £ 15,365,974,60 | R$ 26,60 (£ 6,65)/km or R$ 1.261,590,36 (£ 315,397,59 )/year | R$ 4.043,56 or £ 1,010,89 | 26% |
| Aerial Solution (1 helicopter Chinook transporting 450 cutters) | 3 x 35km 4 x 15km 3 x 6km average (one way) | 3 x 10min. 4 x 8min. 3 x 7min. average (one way) | R$ 39.100.000,00 or £ 9,775,000 | R$ 20.000,00 (£ 5,000)/flight hour or R$ 17.284.800,00 (£ 4,321,200)/year | R$ 55.400,00 or £ 13,850 | 361% |
| Aerial Solution (1 helicopter Chinook transporting 450 cutters +345 tonnes of sugar cane) | 11 x 35km 10 x 15km 8 x 6km average (one way) | 11 x 10min. 10 x 8min. 8 x 7min. Average (one way) | R$ 39.100.000,00 or £ 9,775,000 | R$ 20.000,00 (£ 5,000)/flight hour or R$ 51.168.000,00 (£ 12,792,000)/year | R$ 164.000,00 or £ 41,000 | 1 069% |

Table 20: Sugar cane + cutters transportation comparative costs

| Life time cost of the alternatives | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Options | Start-up | Years | | | | | | | | | | After 10 Years | EAC | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | BNDES (7%) | TiT (13%) |
| | | | | | | | | | | | | | | |
| Current System | 450,000 | 32,789 | " | " | " | " | " | " | " | " | 32,789 | 90,000 (20%) | 90,345.80 | 110,833.40 |
| New Road System A | 10,910,000 | 193,119 | " | " | " | " | " | " | " | " | 193,119 | 5,455,000 (50%) | 1,351,651.90 | 1,907,570.95 |
| New Road System B | 22,145,000 | 305,469 | " | " | " | " | " | " | " | " | 305,469 | 11,072,500 (50%) | 2,657,046.55 | 3,785,445.03 |
| New Road System | 16,915,974 | 257,579 | " | " | " | " | " | " | " | " | 257,579 | 8,457,987 (50%) | 2,053,886.28 | 2,915,839.73 |
| Aerial Solution | 9,775,000 | 10,055,999 | " | " | " | " | " | " | " | " | 10,055,999 | 2,932,500 (30%) | 11,235,509.15 | 11,698,228.33 |
| | | | | | | | | | | | | | | |
| Current System (buses) | 450,000 | 32,789 | " | " | " | " | " | " | " | " | 32,789 | 90,000 (20%) | 90,345.80 | 110,833.40 |
| Current System (Lorries) | 2,500,000 | 80,924 | " | " | " | " | " | " | " | " | 80,924 | 500,000 (20%) | 400,684.00 | 514,504.00 |
| | | | | | | | | | | | Total | 590,000 (20%) | 491,029.80 | 625,337.40 |

Table 21: Life time cost of the alternatives

As we can see, the results show that in paving the entire unpaved road network on the plantation it would be necessary to consider the cost of the paved roads (26%) plus 4% related to the vehicle, costing 30% of one day of production. In paving the narrow corridors (single-lane roads 3.5m wide maximum) it would be necessary to create two other parallel lanes of approximately the same width along each side of the corridor. As the agricultural machines have to manoeuvre (turning round, for example), these extra unpaved lanes would allow the machinery to do so over them and not over the new paved road, so avoiding destroying it. Based on the data from Table 14 regarding the cheapest cost (£8,000) of construction of 159.2km of unpaved roads without drainage, approximately £1.3 million would be necessary as start-up investment. Furthermore, it would mean tripling the area currently used for corridors, swapping the current figure of

5% for 15% of the whole plantation area used for roads. Considering the current plantation area of 1,793ha from the farm adopted as a reference here, it means an approximate reduction of 179ha in its plantation area, and consequently:

- 34 tonnes of sugar cane less in its daily production ( 5,712 tonnes per year ) or,
- £408 less per day ( £68,544 per year ) in just one single farm

Building a new railway would cost also 26% of the daily production, but this solution would not offer the necessary level of flexibility, as it is unable to reach all parts of the plantation. This means that if a railway system were adopted as a solution for transportation on sugar cane plantations, it would still be necessary to keep part of the current fleet of trucks and buses in operation in order to move the cutters and sugar cane from different parts of the field to the terminals. For this reason, it would be necessary to include the extra cost for this additional activity.

The adoption of an aircraft (the Chinook helicopter, in this case) would be completely out of question. Even though it would be a much more up-to-date way to tackle the problem, it would cost 120 times more to transport the cutters and 360 times more to transport sugar cane.

Lastly, if a more accurate and comprehensive economic analysis is required, and if there is a prototype to be tested, the PABAC computer program, developed by Crossley (1987), could be used. This program can processes motion resistance factors, gradient resistance and wheel loads, enabling the generation of cost outcomes in conjunction with vehicle performance. Because the variables considered in this chapter have been formulated to the way in which they may be used according to the PABAC procedure, it will thus be a suitable program for this context.

## 6.4 Other Transportation Costs

Shifting the focus of the research from the technical and social to a business context, according to Zanetti, 2004 supported by Idea News (2004), from 62 to 65% of the costs in the sugar and ethanol industry are related to its agricultural aspect, meaning that after the quality of soil, and the rainy season, transportation represents the remainder of those costs. Some further consideration regarding the transport structure adopted by most of the sugar cane companies in Brazil must be taken into account. This structure is basically divided into four major groups, as follows:

- The transportation of cutters
- The transportation related to support for machinery operation
- The transportation of supervisors
- The transportation related to road construction and maintenance

Table 22 presents an analysis of how many kilometres have been travelled monthly by the entire fleet of one of the Brazilian sugar cane companies. As we can see, out of the total 261,920km, 84,000km, or 32%, are related to the transportation of cutters only. Moreover, it is important to state that these figures would be higher if the analysed company had not started to use the service of contractors for some of its agricultural activities some years ago.

| Transport Activity | Distance |
|---|---|
| Supervision | 16,000km |
| Support for Machinery Operation | 51,200km |
| Transport of Cutters | 84,000km |
| Road Construction and Maintenance | 67,520km |
| Total | 261,920km |

Table 22: Distances travelled monthly by one of the sugar cane company's fleet in 2004.

Also, as confirmed in Table 23, the total cost for the same company in terms of operational and fleet maintenance cost is £687,500 per month, of which £258,100 or 38% alone, is spent on transportation of cutters - which means a total of £3,097,200 a year in just one company. This means that if an agricultural company like this used a more appropriate vehicle, able to deal with the transport conditions more effectively and efficiently, it would be able, as a result, to reduce the travelling times, as well as saving a significant amount in operational and fleet maintenance costs.

| Transport Activity | Cost |
|---|---|
| Supervision | £3,200 |
| Support for Machinery Operation | £128,000 |
| Transport of Cutters | £258,100 |
| Road Construction and Maintenance | £298,200 |
| Total | £687,500 |

Table 23: Monthly operational and fleet maintenance cost of one of the sugar cane company in Brazil.

For the reasons presented above, the transportation of sugar cane workers currently represents an important niche of opportunity for the bus industry. This research reveals that the current level of interest of this transportation is much higher than it was four years ago when this research started. Sacomani (2007) confirms this potential market and new business opportunity, stating that currently important changes are occurring in the transportation industry as a result of the NR-31. As an example, he cites the recent high level of interest of several transport companies (important clients of bus manufacturers) in investing in new fleets (around 200 vehicles) in order to serve the sugar cane companies transporting their sugar cane workers, as contractors. There might be two reasons for this: first, the possible realization of the bus industry that actually there is a potential market of 10,000 units/year (a conservative figure) for this type of vehicle in Brazil alone, which is indeed a very attractive prospect for this industry. Second, the rush of the sugar cane companies to comply with the NR-31.

In terms of an example of a service like this already in operation and in a position to confirm this new business opportunity, Rios (2007) presents a specific report. According to the report, the bus company Raca Fretamentos is already serving five different sugar cane companies in three different states in Brazil with a fleet of 180 buses acquired exclusively for this particular transportation purpose, all modified to comply with the regulation. This merely confirms this new tendency of service as a new niche in the transportation business in Brazil. In addition to this, another new business opportunity that has arisen with this new market is that of technical assistance (repairing or replacement of parts). However, if the current adapted buses are neither suitable for this transportation purpose nor entirely beneficial to the companies, then the way the vehicle has been used based on further adaptations is still not bridging the gap between the law and transportation needs. Consequently, it does not represent a good strategy even from the market point of view.

This research confirms therefore that despite all the limitations, the current solution (adapted urban buses), remains by far the cheapest option for sugar cane cutters' transportation, costing 4% (on average) of the daily production cost of the company. As a result, despite the fact that the current buses are inappropriate for this purpose, the development of a new concept based on a bus-type vehicle structure appropriately and specifically designed for the transportation of sugar cane workers is a sensible, viable and affordable solution.

## 6.5 Conclusions

The comparative cost analysis of other alternatives to solve the research problem reveals that all of them present serious limitations. The analysis shows that neither paving the roads, nor constructing a railway system, nor using helicopters is the most suitable and economical solution.

The field research reveals that the transportation of cutters represents 32% of the total transportation costs of a sugar cane company. As a result, this might be the reason why many transport companies are offering a transport service for cutters, spotting a good business opportunity. Thus, it has been confirmed that any improvement in these transportation conditions is also economically beneficial to the sugar cane companies as well to the bus industry.

The significance of this issue is argued by the following examples:

- A single farm of sugar cane demands on average 1.3 million $m^2$ of asphalt. If we consider that the sugar cane company involved in this study has over 40 farms, if each company decide to pave the entire road network in all of its farms, would be necessary to invest around £900 million each.
- Even though the investment reaches a point where it would be feasible, paving the unpaved roads would be solving the problem only partially, as the vehicle would still inadequate to the demand.

- The unsuitability of a new railway system is mainly because it would be necessary to keep the current road infrastructure and fleet to compensate the lack of flexibility of this alternative in terms of mobility.
- Costing 120 times more than the current investment, the cost of adopting a cargo helicopter is out of question in this case.

Therefore, by comparing the data gathered from the comparative cost analysis and the data from the field research, Hypothesis 5 is supported.

In the next chapter I present design solutions for a more appropriate vehicle to transport sugar cane cutters.

# CHAPTER 7 - VEHICLE DESIGN

## 7.1 Introduction

According to Camara et al. (2001), a vehicle constitutes a systems with one of the most significant numbers of social factors. In this context, this chapter aims to present design solutions for a vehicle to transport sugar cane cutters safely, healthily and comfortably, at a reasonable cost.

These solutions are provided in the light of ergonomic issues involved in vehicle design technology, particularly for bus manufacture. Furthermore, Hypotheses 6 and 7 are tested through a combination of up-to-date technology and existing off-the-shelf components and parts, produced originally for different purposes but suitable for achieving the necessary level of usability. Hypothesis 6 suggests that a holistic analysis is needed, involving all stakeholders, but with a particular focus on users' needs, whereas Hypothesis 7 suggests that a more appropriate vehicle designed for this purpose will improve not only the conditions of the workers' everyday life, but also productivity in sugar cane industry.

To achieve this, the chapter starts by outlining important issues relating to ergonomics, materials and production processes. As the cutters' vehicle operates as a source of transportation, as well as a mobile facility centre, the establishment of design solutions are based on principles of usability. Following the same structure as the vehicle analysis field research, this chapter presents the design solutions firstly from the point of view of the parts and systems of the vehicle's platform, and secondly from the point of view of the parts and systems of its body. The result is a vehicle which fulfils the initial objectives of this research while at the same time proposing a new design language for agricultural vehicles.

## 7.2 Vehicle Design Analysis

Successful vehicle design has much to do with imposed constraints and the achievement of optimum compromises where necessary. At present, in a more competitive arena than ever before, vehicle manufacturers are striving to produce better designed and more reliable vehicles by focusing not only on the technology, but also on designs based on user experience. For instance, the vehicle under discussion should be considered as something much more than a mere means of transportation, and as part of the users' everyday life. However, agricultural and industrial vehicles generally are still considered primarily as tools. According to Tovey (1992), quoted by Happian-Smith (2002), even today traditional procedures adopted by many manufacturers in the development of new commercial vehicles are still sequential, and may be described as examples of an 'outside-in' design, with development moving from the exterior to the interior of the vehicle. This is definitely the case for the vehicles transporting sugar cane workers.

For this reason, this project was based on 'inside-out' design, in which the cellular concept of development moves from the interior to the exterior, focusing, in this case, on user needs inside the vehicle. Through this approach, the definition of the volume of the vehicle's interior and its layout was based on variables such as users' body dimensions (anthropometrics), age, postures, space required for possessions, interaction with the vehicle and interpersonal behaviour.

Despite the importance of the interior design of this vehicle that communicates so intimately with the users inside, the exterior, through its developed design language, communicates and interacts with the outside world. The question here is: what is the general design language of the cutters' vehicle? Or even further, what is the design language of agricultural vehicles generally? Unlike car design, which has changed throughout history, with consequent design issues around brand and identity, agricultural vehicles, have not developed in the same way. Vehicles transporting cutters have traditionally always been based on adaptations, and the basic structure of most agricultural vehicles has remained unchanged since their early stages. In the same way that it is accepted in engineering that the relationship between the form, weight and size of a vehicle is directly connected with its performance, and in design the same relationship is directly connected with its design language, I argue that for both types of vehicle there has been no opportunity to develop a specific design language, answering the question raised above. Thus, this project is also an opportunity to introduce an example of what may be the beginning of a design language for agricultural vehicles following on from actual agricultural transportation needs.

### 7.2.1 Methods

In design, the combination of either unidentified or identified needs and either undefined or defined solutions can help the choice of appropriate research approach (either qualitative or quantitative), according to each particular situation. Based on data previously presented in Chapters 2 to 6, it is possible for this research to unpack important points contributing to the establishment of suitable vehicle design solutions. In order to do so, a method is needed.

In design, process and method are discussed as interchangeable. However, even though they co-exist, they are different. As the word 'process' means movement, it is therefore related to a sequence of activities when designing, whereas a method concerns the systematic way of carrying out these activities. This means that a design method is within the design process, adopted consciously or unconsciously as a tool by the designer. There are a large number of published design models, and the majority of them are based on a more straightforward structure, when the pioneers wanted to break with an unimaginative and static technical society, and combine exploration and collaboration. On account of this, design process generally was divided into four basic phases:

- Feasibility
- Preliminary design
- Detailed design
- Planning

As the users constitute an essential part of this investigation, it is important to refer to some author who's the design work and approach has been profoundly relating to user needs. Dreyfuss (1955, was responsible for a method focused on the user in product design and transportation design. In his 'Designing for People', it is possible to see clearly the influence and exploration of ergonomics in his design. The industrial designer Jay Doblin, professor at the Illinois Institute of Technology (IIT) in Chicago who worked for

Raymond Loewy from 1942 to 1955, was one of the strongest supporters of specialization in design, and his methods involved critical and at the same time synthetic skills, defending principles which have similarities in relation to my research approach, as follows:

- Investigation of human circumstances to draw out impressions
- Involvement by both client and end-user in the design process
- Articulation of the multiple disciplines explored by design

Although these principles were well established and widely acknowledged, it is also important to note the later development of the approach. However, as in the examples above the user-centered approach was incorporated to the basic four stages structure presented above, other authors started question this. For example, Herbert Simon (1969), professor at the Carnegie Mellon University, established the foundations for 'a science of design'. In his work 'The Sciences of the Artificial', he proposes the use of scientific methods for man-made products, emphasising the combination of behavioural observation, making and user-experience in order to include the users in the process. However, in 1970s it still was not the case as the design writer Christopher Jones advocated ergonomics and user-centered issues was not part of design and engineering practices at the time.

The point is that despite the fact that all the approach discussed above have been used resulting in many examples of successful products in design history, even the use of ergonomic approach was related more to physical and measurable aspects than behavioural ones. Although functionality is a crucial issue in this project, in this case it is necessary to break the legal, social, technical and commercial aspects down into manageable parts in order to execute it. The format of this investigation therefore should be based on end-users without neglecting the buyer, for instance. On account of this, like the method proposed by Julius Lengert (Bürdek, 1994), the design method of my research could be defined as 'man-machine system designing', which aims to achieve internal compatibility between the human and machine elements and the external compatibility between the system and the environment in which it operates.

At present there is an ongoing debate about research in design, and the design writer Nigel Cross has recently discussed methods not only for design practice, but also for design research. His view is that the discussions of the 1960s regarding design methods is a path towards the integration of rational methods to design, defending, the view, however, that design is not a science, but is an area that is searching for *intellectual independence.*

In the context of putting together design and production in the automotive industry, according to Leaney (1995), quoted by Happian-Smith (2002), in Europe and in the US there has been a shift from product development practices to integrated systems engineering. Due to the high requirement for flexibility, the bus industry in Brazil is mostly based on Integrated Product Process Development (the IPPD model), which integrates all the essential activities, through the use of multidisciplinary teams, to optimize the design and manufacturing processes. According to Happian-Smith (2002), some of the key factors of this model are:

- Customer focus
- Concurrent development of processes and products
- Maximization of the flexible optimization process in manufacturing, including the suppliers

However, the same advantage of the IPPD model – its flexible manufacturing method based on its ability to cope with changes in products and in production volumes – in the case of bus development paradoxically turns into a disadvantage when the power and influence of the buyer on this flexibility ends up being detrimental to the needs of the other sectors involved. This has also happened with design models in which their structure indicates a consideration of the user and the client, but not necessary an interaction.

For this reason, a specific design model is being proposed here, and it is termed BLUM – Buyer, Legislator, User and Manufacturer. As we can see in Figure 98, the main vertical axis of this model is constituted by the key elements of the given design process, strategically intersected by horizontal axes representing the strategic communication between the other elements with the main vertical axis. In this model, the analysis of the design problem therefore focuses on the system instead of focusing on the object or product; the user and the buyer are not studied as independent factors but as an interface. However, fulfilling the needs of the users and the expectations of the buyers is not enough if the legislation does not allow the implementation of the project, or if the manufacturer is not capable of converting legal requirements into feasible technical parameters, firstly, and into design solutions, secondly. Furthermore, as we can see in this design model, phases which are normally called 'design detail' and 'design for manufacture' in traditional methods, are not part of it. In this model, detailed design production must be undertaken by a given manufacturer, who is specifically involved with the implementation of the design solutions, according to the its own technology and infrastructure available.

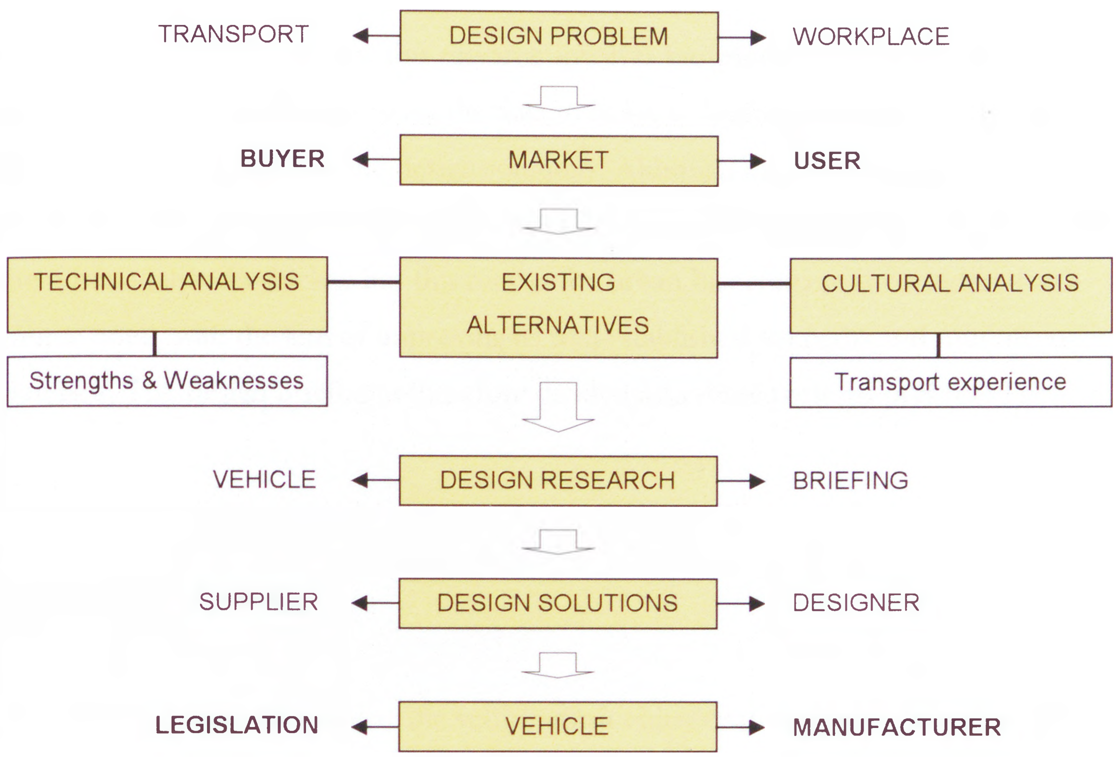



Figure 98: BLUM Design model.

Lastly, user trials with full-size mock-ups are undoubtedly useful when formal ergonomic evaluation of the solutions is required, as in the case of this specific vehicle. Based on criteria which define acceptable and unacceptable design conditions, a sample of the occupational group studied could be involved in the simulation of actual transportation activities. However, given the context of this project, rather than a mock-up only, a small scale model and a prototype are also required. A scale model will be made in order to physically represent and confirm important aspects such as the arrangement of the seats in the interior and the design language communicated by the exterior. It will be presented in the RCA Vehicle Design Show 2009. In the meantime, negotiations will begin between sugar cane companies willing to finance both the mock-up and the prototype and a bus manufacturer willing to make them. While the former will allow a full size ergonomic evaluation, the latter will allow a full evaluation of all aspects analysed in this investigation – vibration in particular – as the reliability of this method would depend on the vehicle's performance as a whole.

## 7.3 Design Briefing

Taking into account the fact that this research involves knowledge from different fields, extra care was taken when processing the data in order to build up a solid base for the briefing and consequently for the design solutions. Although the current adapted urban buses do not fully serve the needs of the cutters, it remains the best option compared with all the other analysed vehicles. For this reason the urban bus concept is considered as a reference point, with the aim of improving its well-established strengths and minimising its weaknesses. The design briefing is therefore divided into three parts, as presented below:

### 7.3.1 Ergonomic Aspects

- As a mobile facility centre, the vehicle must enhance the support offered to the users on the plantation
- It must take into account the cutters' everyday life, on board as well as on the plantation
- It must provide a homely feeling as much as possible
- It must improve the level of comfort, safety and satisfaction for the users
- It must facilitate socialization among users on board
- Its interior must be based on a living room-like layout
- It must provide two toilets (male and female)
- It must maintain both natural and artificial lighting, as well as a noise level in accordance with the limits addressed by specific standards
- It must provide a wider glazed area
- It must be equipped with awning(s)
- It must offer accommodation for the users' belongings
- It must be able to minimise the harmful effects of shock and vibration

- As one of the most important parts of this vehicle, its seats must be designed as a multi-functional system rather than as a mere component
- Using and interacting with the vehicle must be easy to learn
- Its interior and its emergency exits must be easily accessed by the users
- It must have specific compartments for tools and tanks for drinking and non-drinking water
- It must be easy to clean
- It must be able to provide a sufficient number of tables and chairs to accommodate the whole group of users

### 7.3.2 Technical Aspects

- It must comply with the NR-31, NR-17 and CONMETRO standards
- It must be able to be operated in both on- and off-road conditions, dealing with all kinds of terrain as part of its transportation context
- When travelling off-road it must provide a satisfactory performance without, however, causing damage to the unpaved roads or to plantation soils
- Its body structure and chassis must be formed by one single integrated unit
- It must be able to improve its own manoeuvring capacity
- It must offer good controllability in both on-road and off-road situations
- Its weight must not superior to 13 tonnes
- It must adopt not only off-the-shelf components as much as possible, but also ready-made parts from different industries
- As well as being appropriate for the sugar cane cutters, it must be suitable for use by different categories of rural workers, and be able to offer a vehicle with different capacities
- Its parts must be easy to replace

### 7.3.3 Economic Aspects

- Its final price must be compatible with the price of a current urban bus plus 20% extra for adaptations.
- It must have a competitive cost when taking in consideration all items above requested.
- It must have a life-cycle of 10 years (minimum) for technical reasons.

## 7.4 Ergonomics

The importance of ergonomics to this research, is to offer the possibility of providing a preventative approach to the design solutions instead of a more complex and difficult corrective one. This means that solutions can be established from the beginning without the inevitable clumsy adaptations adopted in existing products, which constitute the main current problems of the adapted vehicles for sugar cane cutters. However, the preventative approach in ergonomics usually demands a higher level of knowledge, not only because it ends up involving an interdisciplinary approach, but also because some of the solutions tend to be new. This justifies the reason why this research has been as comprehensive as possible in all areas of its data-gathering.

The ergonomic model is as important as the ergonomic approach. Traditionally, there are two types of ergonomic models, normative and descriptive. In the normative model it is assumed that there is a normal behaviour pattern involved, which works perfectly according to standardized parameters. This means that it is established deterministically, presuming that the effects can be predicted and then modelled. In contrast, the descriptive model considers changes in behaviour due to variations of variables which are often used for simulation, representing actual behaviour conditions. Thus, considering the characteristics of the transportation of sugar cane cutters, the descriptive model is obviously the most suitable. As the behaviour of the sugar cane cutters is not based on linear and predictable human behaviour response, the adoption of a normative model would be a mistake in this case.

However, as the normative model is more deterministic, and consequently more straightforward to work with, the vast majority of the new generation of human-machine interface software has been based on a normative model. COMBIMAN, CSERIAC, CAR and SAMMIE are examples. Despite the unquestionable advantages in this field, determining some of the characteristics involved and allowing an interaction with other CAD/CAM platforms, they fail to predict the dynamic aspects of anthropometry and biomechanics. In addition, the effects of stress, fatigue and environment are still not adequately quantified, and hence not able to be modelled. This position is also stated by Kroemer (1993), supported by Peacock & Karwowski (1993). For this reason, instead of computer-aided design procedures, the ergonomic analysis here relies more on data gathered from observations. The ethnography and user-experience studies provide dynamic geometry, whereas the anthropometric data from the occupational group involved, and already available, provides static geometry.

### 7.4.1 Safety

The potentially harmful and risky interface between the users and the vehicle during a crash has been another big challenge for design, ergonomics and engineering. This is mainly because of the limitations of the human body when submitted to rapid deceleration lasting in many cases one tenth of a second. Thus, among other measures, the adoption of crumple zones to dissipate energy while maintaining the structural integrity of the passenger compartment constitutes an important factor to be considered in vehicle design from the safety perspective.

Existing safety approaches fall into two general categories: active and passive. An active system, such as brakes and traction control, act directly to prevent an accident taking place, and most of them do not depend on the action of the user; a passive system, on the other hand, such as air bags and seat belts, has the function of maintaining the physical integraty of the occupants, providing protection, in some cases, without any action on the part of the users. The United States has one of the highest levels of non-use of active vehicle safety systems in the world, and efforts to encourage the use of such systems have been ineffective. In Brazil, however, in the last 15 years the use of seat belts, for example, has became a habit by force of the law and by means of massive public and government campaigns showing the benefits of its use. However, based on users' behaviour on board through ethnographic study, the adoption of seat belts by the cutters will not be simple and straightforward, due to the fact that they will need some time to adjust to using a device such as this.

The concept of the 'friendly interior' is an example of a passive safety approach. This approach focuses on appropriate materials and careful design of surfaces and shapes that, once damaged by a crash, are less harmful to the users. Although such measures have not proved effective in protecting unrestrained passengers in crashes at 30mph or higher, this approach has clearly reduced the risk of injury caused by contacting solid protruding objects in the interior.

An essential finding of the field research focusing on the vehicle's interior is the fact that even though most of the sugar cane cutters do not know much about their rights, they are aware of issues such as safety, comfort and health. Thus, basic ergonomic issues, such as the adoption of efficient and more appropriate postures for the users in this particular kind of transportation, need to be resolved at a very early stage, as there is limited scope for modifications later in the process without financial consequences. The most common problem is the design of seats, in which the body size and proportions of potential users may not have been accurately envisaged. The quality of the accommodation provided by a vehicle is an extremely important issue, in particular in the case of cutters' transportation, in which long journeys in off-road conditions are involved.

### 7.4.2 Anthropometrics

Anthropometrics is one of the disciplines which support ergonomics, defined as the measurement of human body dimensions. For many years, the expression 'average man' (a hypothetical human figure at the centre of a given anthropometric spectrum) has been common writing in ergonomics. The 'average man' represents a mathematical standard for human body weight and dimensions, harmonically correlated with each other in order to be adopted as a design reference. In engineering, when developing universal engine components, a 100% success rate is expected for fitting a particular component into the engine because they are all made to an identical specification. However, this standard approach does not work when human beings are involved, and, as time goes on, it has become clearer that even though this has been the basis for most product design focusing on 90% of the population, the 'average man' concept simply does not exist.

The most important reason for this is the fact that it is almost impossible to find a human body which exactly conforms to this type, combining perfectly the huge number of variables involved. This means that in the automotive industry, if the variability of human body is not acknowledged, it leads to poor design. Thus the use of percentiles (the percent of observations in a sample that have a value below a given score) to assess human dimensions has to be considered carefully, as the people of the same stature have different arm lengths, leg lengths and so on. For this reason, new up-to-date technologies, such as the 3D scanner, have currently allowed not only a completely new approach to anthropometric data-gathering, but have also made the interaction of this data with virtual modelling systems much easier.

This was amply demonstrated in the research project 'Anthropometric Analysis of Rural Workers in Sao Paulo State', undertaken by Rodrigues (1992). In this study, the dimensions of 243 sugar cane cutters from Sao Paulo and three other States (Minas Gerais, Bahia and Paraná), working on plantations in Sao Paulo, were measured (see Appendix 5) and each average category was calculated. The analysis showed that of the 10 dimensions measured, none of them was 'average' . Therefore, taking into account the fact that this anthropometric study is the only one specifically dedicated to this occupational group and its ethnic origin, instead of adopting one of the sources of anthropometric data available in the literature, it has been decided to use the data from the analysis above for the first stage of the development of the design solutions of this current research.

An example that may illustrate the importance of a specific anthropometric study of the occupational group under discussion is the design of seats. While studies undertaken by Grandjean (1980) and Gordon et al. (1989), both quoted by Peacock and Karwowiski (1993), show the distance from the buttock to popliteal region as approximately 440mm for the 5th percentile female, the measurement of the same variable and percentile obtained in the anthropometric study involving the population of sugar cane cutters shows a distance of 428mm. Although the difference seems to be small, ergonomically speaking, 12mm difference in the seat's length would be more than enough to compromise the users' comfort in relation to the considered percentile.

Therefore, as this research has progressed, it is clear that after further developments in algorithms, animation is the key issue in improving the latest human-machine interface software. This would enable the presentation of the algorithmically processed results of some functions to be more biodynamically realistic. However, it is important to state here that even a higher level of computer-based data processing and advanced animation resources will not be enough to compensate for the current lack of knowledge about the cognitive process. This means that besides the need for research related to more sophisticated tools, little is still known about basic functions, due to the complexity of the human body.

## 7.5 Materials and Production Processes

At present, good design is partly a matter of the right choice of materials, which also includes the combination of a more efficient structure and the exploitation of multiple functions through more complex and sophisticated material properties, which naturally results in the consideration of compounds. Despite current advances in the development of steel, metals and polymers in terms of composition as well in terms of production processes, according to Hodkinson & Fenton (2001) the future may lie in the wider meaning of composite construction, with a combination of metals and polymer compounds fulfilling complementary roles. In this context, a new advance developed by Bayer allows the bonding of metal and plastic in an injection moulding process. In this innovation, the use of reinforced plastics combined with metals heralds a new era in the production of parts with thinner walls and much lighter structures.

However, such approaches and advances are unfortunately out of the scope of the bus industry, due to the lower production scale of the bus in comparison with a normal car. This has been the major reason motivating this industry in the development of its own solutions in the area of improvements in technology, materials and production processes. As this research reveals, the lower level of accuracy in bus production, as a result of the flexibility necessary to produce variations of the same model serving different briefings and client specifications, makes clear that materials selection inevitably ends up being dominated by those which are more suitable to this lower level of precision. This means that materials with reduced contraction and thermal stresses, such as fiberglass reinforced plastics, are suitable, explaining the wide-ranging adoption of this material in this industry.

Another important process suitable for bus manufacturing is vacuum-forming, due to the low cost of tooling for small-scale production, combined with the possibility of producing large parts. However, even though this industry already uses this process extensively, it is clear that it is not currently exploring all the opportunities already available in terms of either process or material. For example, advances in the production of plastic sheets by means of the co-extrusion process have made it possible to extrude up to 16 different materials in the same sheet. This means a significant reduction in cost, using only the required amount of material for each application, and, most importantly, the possibility of combining different characteristics and specifications in one single sheet. As an example, in order to provide extra protection against harmful UV rays and at the same time to ensure a glossy surface finish for the component, a thin layer of acrylic could be added over a layer of Acrylonitrile, Butadiene and Styrene (ABS) on the external surface of the part. To provide extra protection against oil and grease, a layer of Polyvinyl Chloride (PVC) could provide a facing for the parts' interior surface. Lastly, in the middle, because of the need for a high level of mouldability and low cost, a thicker layer of High Density Polystyrene (HDPS) could be used.

Urethanes have also established new paradigms in this industry by enabling interior parts and components to be produced from injected polyurethane, through the Reaction Injection Moulding (RIM) process. Like vacuum-forming, this process allows the production of large and complex parts without high investment in tooling, as it works under low pressure. Although the use of this material and process is growing fast in the bus industry compared to vacuum-forming, it is still not exploited appropriately in terms of diversity, as only a small number of components and parts have been produced by this process in the bus industry.

Resin Transfer Moulding (RTM) is another very useful process for this industry. This process relies on a closed mould being filled with fiberglass also receiving the injected resin under low pressure. The process and conjunction of qualities of polyester or epoxy resins provide dimensionally stable parts with low volume shrinkage of between 1- 3%, together with good mechanical properties, which can even be painted at temperatures up to 150°C if necessary. However, the production of most of the reinforced plastic parts still relies on manual and toxic processes based on open moulds, such as hand-lay-up or spray-up. Because in these traditional processes the control of the glass or resin depends on operators' ability, this means that it is impossible to have the same thickness all over the part and normally a higher amount of material is needed. Thus, with the current reduction of tooling costs, in particular for low pressure applications, an economic viability study should be carried out, considering the impact of the economy of material, reduction of production time and the high quality provided by RTM for some parts, in comparison with traditional processes.

Another important aspect to be considered here is related to metalwork. This research could not determine whether or not the steel used in the body structure of the existing buses is based on the Ultra Light Steel Auto Body (ULSAB) project (Happian-Smith, 2002). However, this project, a result of the concerned efforts of major steel industries worldwide, has been able to develop lightweight steel which is more ductile and stronger, giving thinner sheets and channel sections, reducing body weight by 25%, which in the case of an urban bus would mean a reduction of approximately 1,200kg.

Thus, considering the size, weight and height of the body structure of a bus, balancing the use of some materials and processes is unquestionably crucial to dynamics of the vehicle, and even more crucial when operating in off-road conditions. The result of this balance would improve controllability, and consequently safety, and it would minimise undesirable effects resulting from movements of the body structure to the users.

Lastly, in terms of manufacture, there are two basic principles that have guided the developments of products: 'Sustainable Innovation' and 'Disruptive Technology'. With sustainable innovation, development is based on the product or service, improving the quality of either as a result. The use of disruptive technology – a concept developed by Professor Clayton Christensen from Harvard Business School (Larica, 2003) – enables development to be based on different ways of adding new attributes, to provide a better service through conventional products. I argue that the development of any product for new commercial markets depends on the combination of both principles, and the design solutions in this study were developed with this combination.

## 7.6 Design Solutions

After all these considerations, the conclusion is that for this kind of transportation, the vehicle must be designed as an integrated product. It has to bring together the right dynamic and shock absorption capabilities for the chassis and the right human-interface concept for the body, combining both design and engineering. In this thesis I therefore explore the integration of the areas above towards better design solutions. From previous analyses about the impact of both platform and body of the vehicle on the users, design solutions are proposed and conclusions are drawn. In this section, all the findings of this research are translated into solutions for the vehicle involved with the transportation of sugar cane cutters. As a result, the design solutions presented here are not only relevant to the needs of all stakeholders, but are also feasible. Thus, the whole range of solutions can be implemented immediately by any bus manufacturer in Brazil or abroad.
In providing design solutions for this transportation, the first question was raised in relation to the use of the vehicle when not transporting cutters. Why not use the vehicle for other transport purposes instead of it being stationary on the plantation all day? This is unfortunately impossible, because of two important reasons: first, because the mobile facility centre that the vehicle offers is as important as the transportation role itself, the vehicle has to be available to the cutters all day on the plantation. Second, even if a more complex and expensive multi-functional vehicle allowed the body structure to be detached from the platform whenever necessary, it would be necessary to go back to the current system of having a chassis independent of the body, which has been proved wrong for this transportation purpose. Furthermore, it has been confirmed by the sugar cane company survey that none of the companies are currently considering any alternative use for the buses when they are not transporting the cutters.

Therefore, as it was confirmed in Chapters 5 and 6 that an urban bus could reasonably be used as a reference, or starting point, for the development of the vehicle design proposed here, this chapter presents design solutions which take into account this point of reference for both the product and its production.

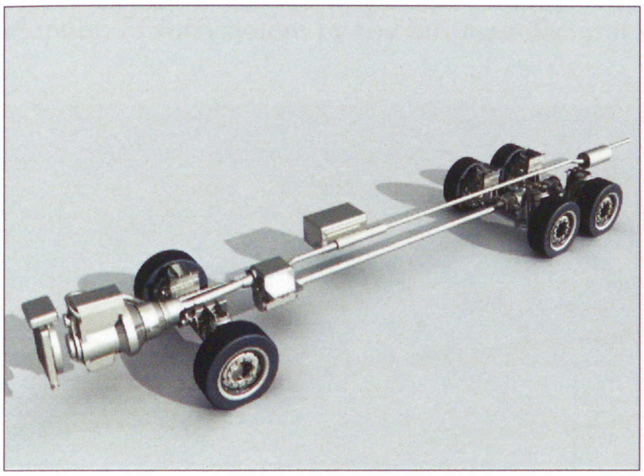
### 7.6.1 Power Train

As the platform of the buses currently in use is supplied by another separate manufacturer (from the truck industry, in this case), more so than in any other vehicle, the choice of a power train is heavily influenced by what is available on the market. As the power train is constituted by the engine and the driveline together, it consequently affects the layout and the weight distribution of the vehicle. The driveline includes all of the assembly between the output of the engine and the wheel hubs. It obviously includes the transmission, which essentially transfers the power from the engine to the wheels – thus ensuring the main objective of any transportation process: mobility. However, another important aspect of the power train for this transportation purpose is the stiffness of its assembly which is important to the integrity of the vehicle in accidents, as well as determining the magnitude and frequency of the vibration from the engine.

With regard to the position of the engine, this proposal considers the front engine rear wheel arrangement, as seen in the normal layout adopted by trucks and buses currently in production in Brazil. In this layout, the engine and the transmission are aligned and mounted longitudinally, with a propeller shaft connecting to a separate rear mounted final drive. Although a front engine is not the best solution for the design of the interior of the vehicle, it is a much cheaper, simpler and more straightforward solution. This factor becomes very important indeed from the maintenance point of view, once 100% of the analysed vehicles are equipped with a manual transmission. The advantage of providing more weight on the rear axles and consequently more traction for the vehicle by having the engine positioned in the rear can be easily obtained by other solutions, such as by redistributing the weight of the vehicle on the axles or by changing the position of the axles, for instance. This advantage thus does not compensate for the disadvantage of having a more complicated and not straightforward connection between the rear engine and the transmission, and a more difficult and expensive maintenance as well.

In addition, the position of the engine is also important from the commercial point of view. One of the main reasons why the vast majority of urban buses in Brazil are equipped with a front engine is because it is a better choice for the buyer, on two counts: firstly, due to the lower acquisition cost of a new vehicle with this configuration, and secondly due to its higher resale value. This means that the front engine position is thus better economically, rather than technically.

Besides the requirements related to vibration and structural physical integrity, the power train of the vehicle transporting the cutters must also enable the vehicle to be less vulnerable to getting stuck in muddy conditions and soft soil on rainy days. For this reason, the design of the power train is a combination of three factors: first, the adoption of three axles instead of the current two provides a better weight distribution, a higher ground contact area, and consequently better traction. Second, the adoption of a 6x4 drive layout is able to provide power transmission to all four wheels in the rear axles (see Figure 99 and 100). Third, the engine should be based on a proven and readily available system, not only for cost reasons, but also because a more sophisticated system relying on more specialised and high-end maintenance would end up as a more or less serious problem depending on what country the vehicle operates in. Thus the design solution includes the use of the last generation of electronically-controlled diesel engines, with 220hp of power positioned in the front and capable of generating a power/weight ratio of approximately 16 instead of the current 12 or 13.



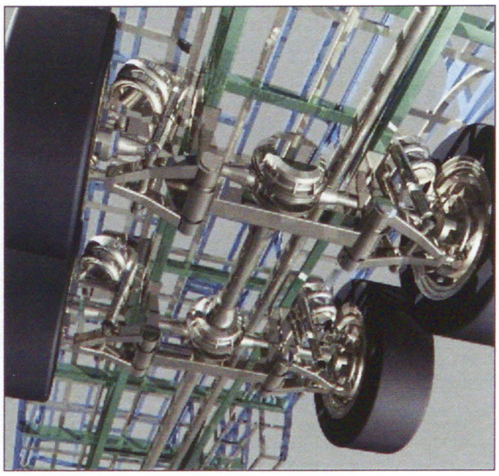


Figure 99: Design of a 6x4 drive layout for the vehicle.
Figure 100: Design of four wheel drive in the rear + suspension + tubular chassis.

As we saw previously, the diesel engine is not the best option as far as vibration is concerned, but because other options are even less suitable, the diesel engine is the only viable alternative, leaving the responsibility of minimising the effects of shock and vibration to other parts of the platform, such as the chassis and the suspension. Also, taking the aspects related to technical assistance into account, such as the warranty and maintenance of the mechanical parts provided by the platform supplier, the mechanical cluster of the current platform (except for the chassis, that must be replaced) could be supplied by the same truck manufacturer, retaining its assistance and warranty conditions.

7.6.2 Chassis

As the chassis of the vehicle, in conjunction with its body structure, are essential to dynamics, stability, safety and vibration absorption, the ladder chassis must be replaced by a lighter and stiffer tubular chassis. The design solution for the chassis offers two parallel rectangular tubes linked transversally to each other, also by tubes (see Figure 101). As the body structure is also tubular, now the chassis and body structure can form one single integrated unit. This unit would provide a much better performance in relation to the aspects mentioned above, as well as in terms of deformation when involved in an accident, distributing the energy generated by the impact more efficiently, and at the same time keeping the integrity of the structure, offering extra protection to the users. In addition, improving the safety of this new integrated structure even more, the controlled collapse system proposed by Ford (see section 4.3), should be considered. In this system, asymmetric corner divots are introduced as triggers to the front end of the tubes, being particularly suitable for this application, even though this research did not identify the adoption of such system by any bus manufacturer to date.

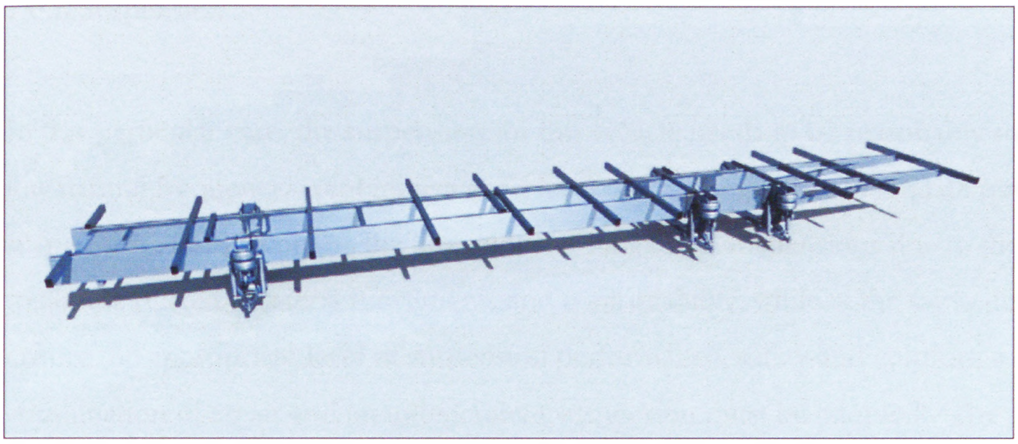


Figure 101: Design of the tubular chassis as part of the integral body structure.

This design solution for the chassis is developed based on the twin tube box-type frame, like those used in the SX MAN 8x8 truck chassis presented in Chapter 4. Based on the principle that the lighter the vehicle, the better its performance, particularly in soft soils, it is clear that the chassis in this case needs to be robust but not heavy. Moreover, as the lower the platform mass the lower the effects of vibration over the vehicle body, due to the fact that vehicle dynamics are mainly based on the weight of the vehicle and its mass distribution, this lighter solution constitutes another advantage here. However, this solution might be more expensive, taking into account the fact that, unlike the traditional ladder chassis, many parts of the tubular chassis would have to be specially manufactured.

With regard to the weight distribution and axle loadings, and taking into account the total length and weight of the vehicle, 13m and 15,000kg (fully loaded) respectively, the following configuration is proposed: One front axle and two rear axles (distance between the front axle and the mid point of the two rear axles 7.7m) and a front engine positioned forward of the front axle, and 7.7m of distance between the front axle and the middle of the second and the third axle. Research into distributed vehicle loads by Maclaurin (2008) has shown that it would be possible to distribute 35% of the total weight on the front and 65% on rear axles. An improvement compared to 40/60 ratio of the current urban buses. Part of the solution in order to obtain a more favourable ratio was based on simply moving all the axles forward in the proposed vehicle by about 0.6m. This new weight distribution will markedly increase the traction of the vehicle, which combined with other aspects, such as the proposed tyres and CTI system, will improve significantly the off-road performance of the vehicle, not only on soft soil and mud, but most importantly on slippery surfaces.

### 7.6.3 Suspension

In this particular case, the suspension for this vehicle needs to be reasonably soft, with a low natural frequency, combining a good level of damping and an adequate travel suspension. Thus, avoiding the limitations of long travel suspensions due to their weakness related to lateral movements and controllability, while at the same time trying to ensure the appropriate level of suspension performance, safety and comfort, a combination of an air and an independent suspension must be adopted. The design of the air suspension, in particular, is based on rubber bellows and shock absorbers, inspired by the model developed by Goldschmitt, presented in section 4.3. This solution would be able to reduce significantly the effects of shock and vibration, thanks to the absence of springs and its stiffness, generating a low natural frequency in association with its usual height control. In addition, it will be able to offer a travel suspension 150mm higher in comparison with the one actually presented in the urban buses.

However, despite the lower height of the air suspension compared to traditional suspensions, it is still not possible to achieve a flat floor and to eliminate completely the inconvenient protuberances in the interior caused by the wheel arches (see Figure 102).

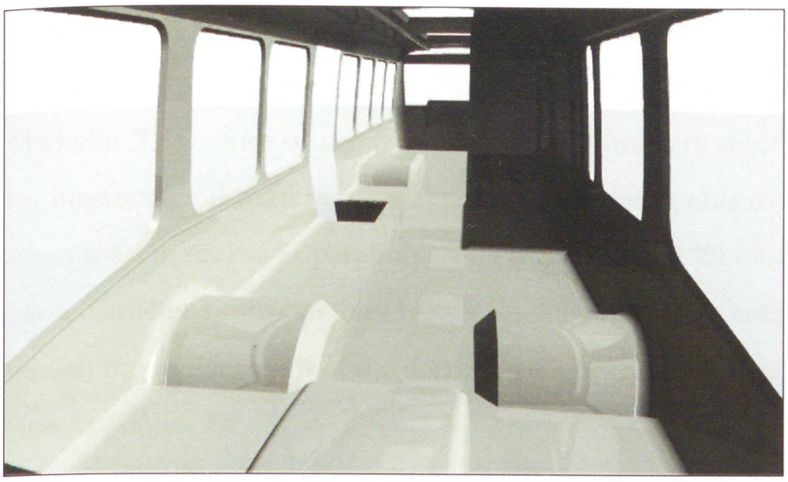
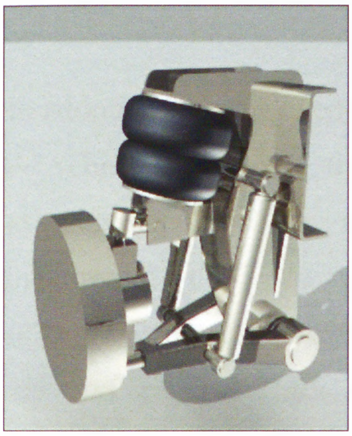


Figure 102: Protuberances on the vehicle floor caused by wheel arches.

This constitutes a major limitation related to the design of the interior layout not because of the suspension itself but because of the wheels. For this reason, as a solution to reduce the height of these protuberances, rubber bellows are positioned at 60 degrees and placed in the upper part of the suspension (see Figures 103 and 104) instead of being positioned at 90 degrees and placed in the lower part of the system, as is normally seen in traditional air suspensions using air sacs (see Figure 66).



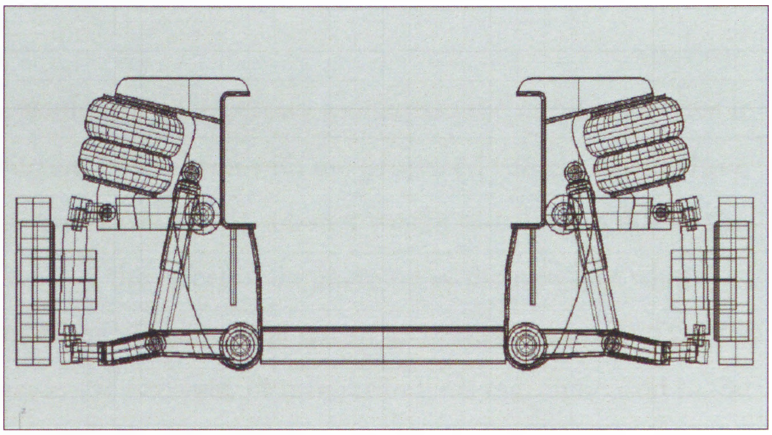


Figure 103: Design of proposed air suspension.
Figure 104: Proposed system in place.

### 7.6.4 Tyres

The tyre equipping the vehicle transporting cutters must be able to contribute to the safety and comfort of the users, ensuring an appropriate level of performance for the vehicle, no matter the surface or terrain conditions. A flotation tyre, capable of offering a high level of deflection would be one solution in this context. However, as the normal low pressure flotation tyres already used in agriculture have only limited deflection and limited and a maximum allowable speed, a suitable solution here is an on/off-road tyre such as the Michelin XZL series or similar, widely used in military vehicles. This tyre was designed for improving off-road performance, as well as being able to develop adequate speeds when used in on-road operations. The model 14.5 R 20 (365 R 20) tyre (see Figure 105) has a diameter similar to the 11.00 R 20 radial tyres currently used on the buses, even though the replacement of the current tyres by the new ones increases the cost by 34% (see Appendix 7).

Figure 105: On/off-road tyre Michelin XZL Series.

In adopting this type of tyre it would not be necessary to increase the number of tyres in the vehicle compared to the current buses, even with the proposed vehicle having three axles instead of two. This is for two reasons: first, a better weight distribution due to the inclusion of a third axle, and second, the effect of the increase of the new tyre width (370mm, compared to 290mm of the current radial tyres), increasing the ground contact area and pressure. This eliminates the necessity of using twin tyres currently used in the back of the vehicle. However, in the case of a vehicle smaller in length, serving other agricultural purposes and a smaller number of people, the vehicle could be equipped with a different model of the same kind of tyre capable of being used as a twin in the back axle, like the current system. In this case, a tyre such as a Michelin 12.00 R 20 or similar must be used. As we can see in Figure 106, in accordance with Maclaurin's calculations (MacLaurin, 2006), to make a worthwhile improvement to the vehicle, a Vehicle Limiting Cone Index (VLCI) of between 200 and 250kPa is desirable.

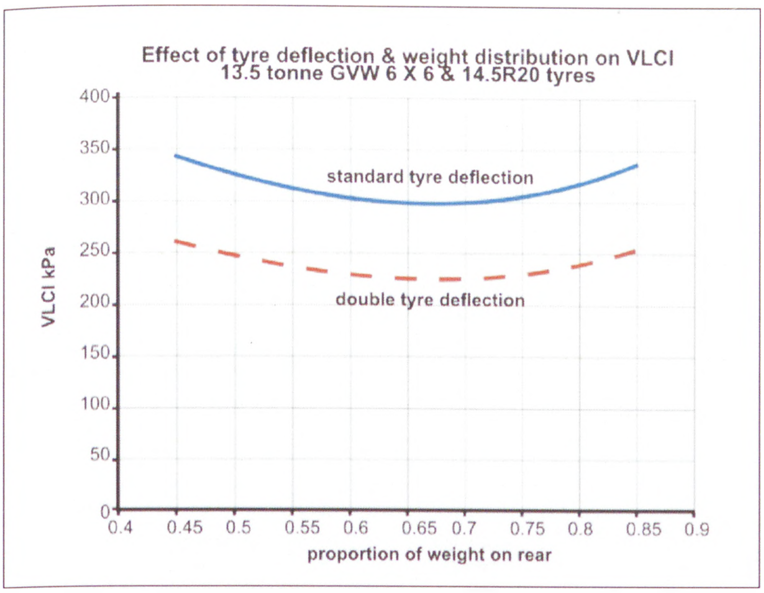



Figure 106: Effect of tyre deflection & weight distribution.
Source: Bruce Maclaurin

Regarding the effects of tyre deflection and weight distribution for the vehicle with Central Tyre Inflation (CTI), Table 24 below shows that the performance of a 6x4 layout may be acceptable, having a VLCI of 284kPa compared to 418kPa of the current vehicle. Thus, as soil strengths below 320kPa can be considered pretty soft, the figure of 284kPa indicates a good result confirming that the vehicle equipped with the proposed tyres and CTI, is undoubtedly appropriate for this transportation context, even over very soft soil or mud.

| Tyre types performance | | | | | |
|---|---|---|---|---|---|
| Vehicle | | | | Limiting Soil Strength VLCI (kPa) | |
| Tyre size | Gross Vehicle Weight tonnes | Drive layout | | Road | Mud |
| 11.00 R 20 (on-road) | 13.5 | Twin tyres on single axles | 6 x4 | 473 | |
| 12.00 R 20 (on/off-road) | 13.5 | Twin tyres on single axles | 6 x4 | 468 | 351 |
| | | | 6 x 6 | 375 | 305 |
| 14.50 R 20 (on/off-road) | 13.5 | Single tyres on twin axles | 6 X 4 | 374 | 284 |
| | | | 6 X 6 | 298 | 226 |

Table 24: The relationship of the drive layout of the vehicle and its tyre deflection.
Source: Bruce Maclaurin

Also, to better understand the performance of a CTI system operating in the vehicle transporting cutters, Figure 107 compares a vehicle not equipped with CTI with another which has it, using as a reference the 140-minute trip analysed on 17th August 2006. As we can see, the journey starts with the vehicle picking up the cutters from different stops in town and taking a paved road for a while. Once leaving the paved roads, the vehicle then spends some time on unpaved roads until it reaches obstacles and soft soil for a short time on the plantation.

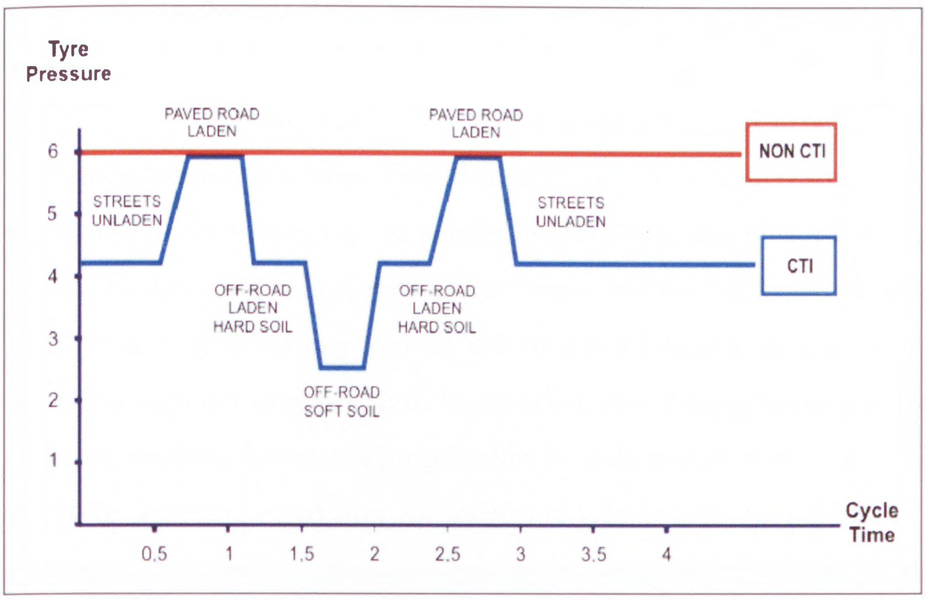



Figure 107: Simulation of a vehicle transporting cutters equipped with a CTI system.
Source: Innovative Transport Equipment

This comparison shows that it should only be necessary for the tyres to operate at full pressure for about 25% of the whole trip. Thus, the tyres currently in use are running 'over-inflated' for 75% of the journey. This means that the tyres are wearing out faster, providing less traction in many cases, and most importantly transmitting more shock on the users. Another important advantage of CTI is that, as described in section 4.3.8, it would also be possible to alter the loading between the second and third axles and thus effectively reduce the turning circle and increase the manoeuvring capacity of the vehicle.

Lastly, one point has still to be considered, that of wheel slippage when travelling over mud or any other slippery surface. To improve the performance of the vehicle in such situations, the adoption of a wheel slip control system is also recommended. This works by a combination of two different actions working together: braking the wheel individually whenever there is a difference of speed in each wheel, and reducing the engine torque. During private communication with Bruce MacLaurin (MacLaurin, 2008), it was clear that the adoption of a system developed by Bosch, using the Anti-lock Brake System, (ABS) would be suitable and viable in this case. This does not require special training by the drivers and it is cheaper than other systems.

### 7.6.5 Body Structure

As already mentioned above, when presenting the solution for the chassis, a suitable solution for the body structure of this vehicle is the adoption of a space frame structure merging the chassis and the body into one single integrated structure (Figure 108) forming a monocoque like structure. The advantages of this integrated structure are numerous. It is stiffer in bending and torsion, weighs less, and also quieter for the users. Moreover, an integrated structural concept would last longer and would provide a much better performance when turning over, or involved in a frontal collision. However, the process of producing such structure must be based on steel tubing forming polygonal looped rings, inspired by the system proposed by Honda and presented in section 4.3. The rings would be interconnected over the lengths of vehicle sides to obtain a better structural integrity, and most importantly, improving the level of stiffness due to the considerable reduction of welding and joints. As a result, this system would generate a better-looking frame and a reduction in material used.

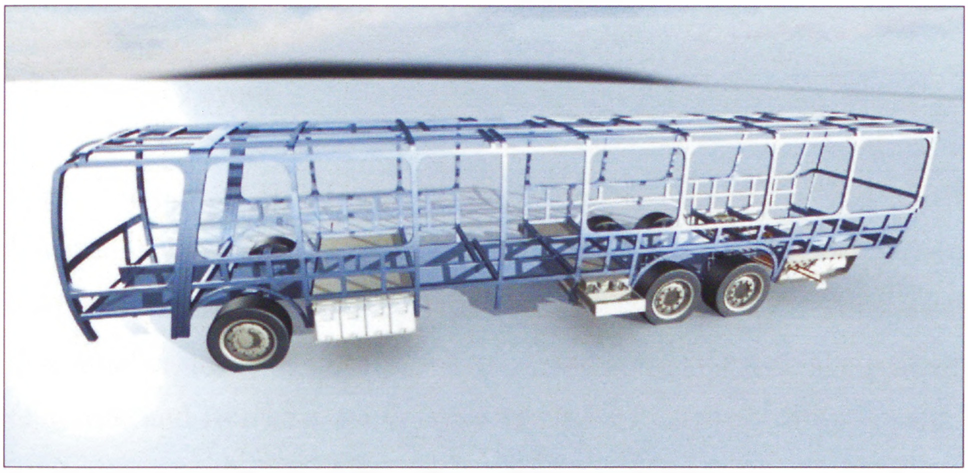


Figure 108: Design of the body structure integrated to the chassis.

As this design requires a 13m long vehicle (1m longer than the current bus) to provide a better interior layout and accommodation for the cutters, this means approximately 400kg extra for the structure, whereas the transfer case for the third axle (6x4 drive layout) would weigh approximately 200kg more, totalling 600kg extra. However, as replacing the ladder chassis by a tubular chassis integrated to the body structure would save approximately 1,800kg, this ultimately means 1,200kg less (see Appendix 7). At the end all these improvements can be translated into more safety and comfort for the cutters.

The solution to offering extra protection for the body of the vehicle comes from the design of its section, as presented in section 4.3, adopting a hexagonal section (see Figure 109) instead of a traditional square or rectangular one. Having both side walls of the vehicle formed by two plans and creating an edge at their intersection, contact with plants (sugar cane, oranges, coffee) would be minimised, consequently reducing the damage to the vehicle.

Figure 109: Design of the hexagonal section of the body structure, inspired by the Cadillac 'Commando'.

### 7.6.6 Interior Layout

The first important aspect to be considered in the design of this vehicle's interior is its dimensions. In an attempt to obtain a better ratio between the occupied area per person and the dimensions of the vehicle, a few improvements must take place with regard to the ideal number of cutters to be transported. The design solution is a body structure with 2.6m wide and 13m long, with a total capacity of 57 people, with a possible decrease in its length immediately behind the position of the toilets, suitable for different purposes. As a result, the amount of space per person would be improved by 32% in comparison with the current buses, as we can see in Table 25. Even though 0.58m$^2$ is still not the ideal 0.80m$^2$ per person, taking into account the design and mechanical limitations related to the length of the vehicle, this improvement, with only 1m increase in length, is a significant achievement.

| Type of Vehicle | Occupied Area | Number of People | Square metres per person |
|---|---|---|---|
| Mercedes 1113 (1993) | 14.26m² | 40 | 0.35m² per person |
| Urban bus (2005) | 26.56m² | 60 | 0.44m² per person |
| Proposed design | 33.00m² | 57 | 0.58m² per person |

Table 25: Area per person from 1995 to the design solution.

Also, the vehicle's interior reflects the way the cutters interact with the vehicle. On account of this, rather than create an adequate packaging, the design of the interior must be more comprehensive, including aspects of usability, particularly because the cutters' perceptions of their transportation has changed in the last few years, thanks to the replacement of the adapted trucks with buses. Consequently, as this change in perception has resulted in a change in habits and behaviour, it contributes significantly to a change in their daily transportation experience, as well as their everyday life and culture. One example that can be used here is the confirmation, by means of the ethnographic study, that because functionality is inherent to the transportation context, it means that functionality is also interpreted by the cutters as a provider of comfort and welfare.

Due to the complexity of the interior layout of the kind of vehicle studied by this research, alternative interior solutions were all physically visualised in the form of 1:10 scale experimental models (see Figure 110). This is not only the clearest way to visualise each option, but also a more effective way to apply fast changes, making this three-dimensional investigation very successful in supporting the decision-making about the interior.

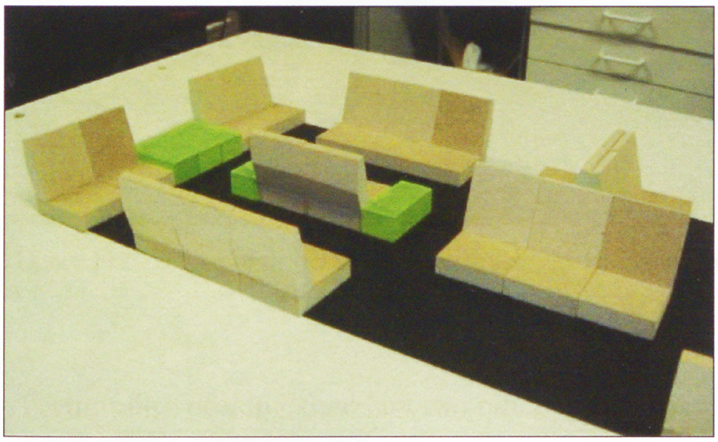


Figure 110: Scale model of a possible interior layout for 43 seats.

The position of the seats constitutes an important factor in the establishment of the interior layout of the vehicle. One of the most challenging aspects faced during this scale model investigation was to provide a distribution of the seats which either avoided or minimised the sensation of a packed space (see in Figure 111), which became evident after experimenting with traditional seat positioning arrangements in normal buses. Because the field research indicates that the interior should provide a homely feeling, encouraging social interaction amongst the users, the position of the seats must allow the majority of the users to look at each other more easily when talking. On account of this, the best design solution for the arrangement of the seats is represented by Figure 112, which shows an arrangement based on the way the cutters usually get together on the plantation during their breaks, giving them a similar psychological context.

Figure 111: Traditional seat positioning in a bus.

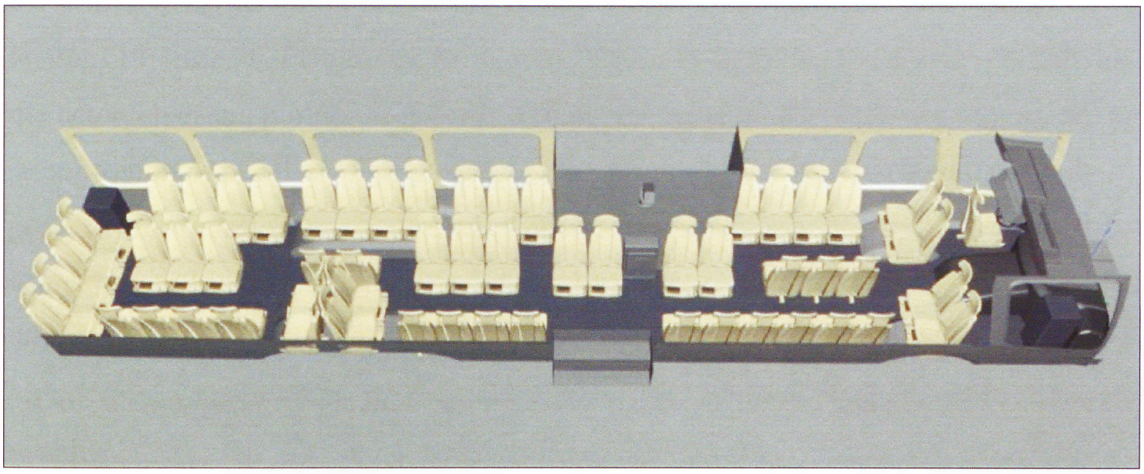


Figure 112: Design of the internal layout of the vehicle accommodating 57 people.

Technically speaking, there are two other benefits of a seating arrangement that has the vast majority of the seats arranged around the edges of the interior. First, according to a study from Vulcan (1990) quoted by Happian-Smith (2002), in general, passengers sitting on the edges of the bus interior are less frequently injured in accidents. Second, taking into account the lower tolerance of the human body in relation to lateral head movements (common in off-road situations), the proposed seat arrangement, with the seats positioned side by side longitudinally, would turn the lateral movement of the vehicle into horizontal or vertical movements for the users. Theoretically, this would provide more comfortable and healthy conditions for the cutters from a vibration point of view. This might be the reason why the majority of military trucks for transporting troops adopt a similar seating arrangement, even though there is no hard evidence to support this.

Lastly, the only limitation that applies to seating arrangement in buses is determined by the national CONMETRO standard in Brazil. This standard stipulates the transversal positioning of rear-facing seats over the wheel arch (wheel box) of the vehicle.

### 7.6.7 Seats

The practical accommodation of the workers on board the vehicle involves issues related to the dimension of the seats and their position, whereas the issue of comfort involves the shape and relative stiffness of the seats.

In accordance with the requirements of the NR-31, a feasible and appropriate solution for the trim of the seats would be the adoption of moulded self-skinned foam seats (see Figure 113) instead of laminated foam seats (Figure 114). When the seat is very soft, like the latter, changing position is difficult, making the relief of discomfort from pressure or joint position impractical. This means that the proposed seat cushion would not only provide more comfort, but would also minimise the shock and vibration effects on the users. It must use high density foam (about 40kg/m$^3$), of an appropriate thickness (about 20mm). The combination of these two would reduce the maximum pressure of the body on the seat by about 400%, making t the cutters' journey more pleasant, comfortable and healthy.

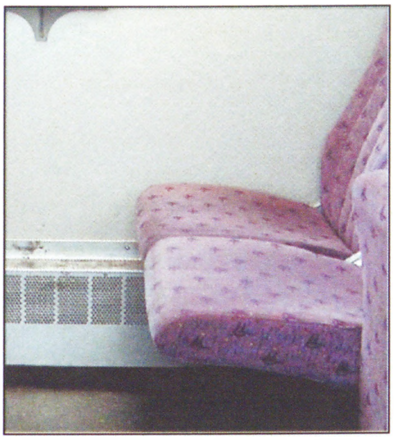


Figure 113: Design of the new moulded foam parts for the seat.
Figure 114: Example of seats with laminated foam.

The idea behind the design of the seats was based on a combination of new developments in aircraft seating and the latest solutions adopted by the automotive industry. The result of such a combination would provide a free-standing seat divided into three parts: a base and the backrest, a removable seat pan and independent self-skinned foam elements would be easily replaced when worn out. As we can see in Figure 115, the headrest would be produced by the same process and material (moulded polyurethane) used for the other self-skinned foam parts of the seats. Also, due to the fact that most of the seats would be positioned side by side, this solution includes extra volume for both sides of the foam elements on the lower part of the backrest, holding the users' body more firmly and ensuring extra safety. Also, even though the optimal porosity in seats related to the transfer of water vapour from the users' bodies still remains an important subject for investigation in vehicle design, the inherent porosity of the kind of polyurethane foam proposed here would allow a certain level of vapour permeability. This issue is very important for the transportation of sugar cane cutters, taking into account the high temperatures on the plantation and the thicker clothes worn by the cutters as a protection against the environment. Moreover, taking into account the fact that 93% of the cutters normally keep with them a 600ml plastic bottle containing coffee or juice, the design of the seat also provides a small compartment immediately in front of the seat pan for small personal belongings and a small plastic bottle, making them more easily accessible.

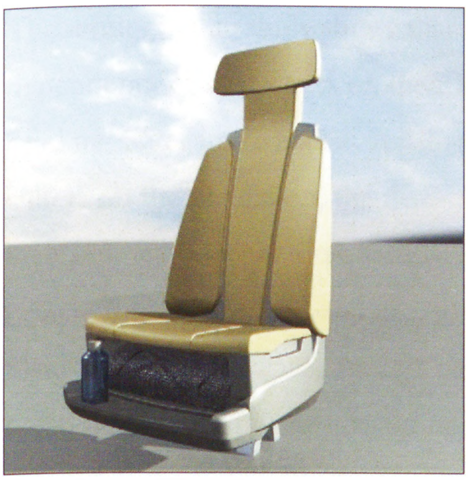


Figure 115: Design of the new seat.

As the weight of the seats makes up a significant part of the weight of the vehicle, this design eliminates the traditional tubular structure of the seat. The solution proposes that each of the seats directly anchored to the body structure through one single tube coming out from the lateral walls of the vehicle, keeping the seats suspended in relation to the floor, as we can see Figure 116. This design would also provide a neater layout, with free space underneath the seats, making the cleaning of the floor much easier, in comparison with the current system that relies on a tubular steel structure, as we can see in Figure 117.

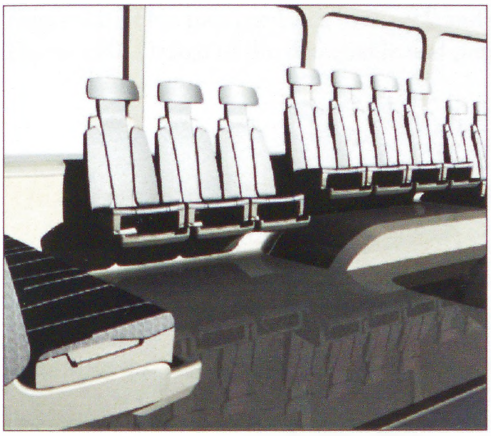
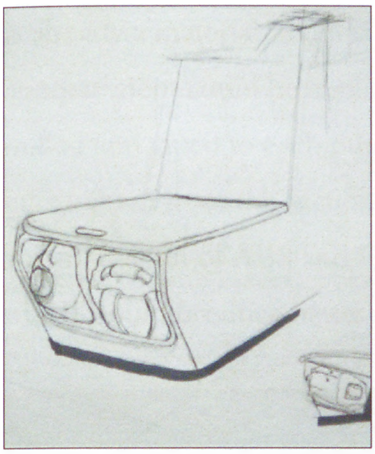


Figure 116: Design of the attachment of the seats to the body structure.
Figure 117: Traditional steel tubular structure supporting the seats.

In addition, considering the relationship between the seats and the cutters' personal belongings, their accommodation in the interior of the vehicle is quite challenging, considering the significant amount of space required to accommodate them. A natural solution would be to create a compartment for them. However, this would be a considerable change to the habits of the cutters, considering that 55% of them take all their backpacks and drinking water containers with them at all times, wherever they are.

The ethnographic study shows that this behaviour is because of the high level of dependency of the cutters on their belongings, backpacks with food and container with drinking water in particular. Adding to this to the fact that there are no seats for the cutters on the plantation, the design of the seats allows the same seat pan to accommodate their belongings when on board (see Figure 118), to carry their belongings out of the vehicle (see Figure 119) and also to be used as a portable seat on the plantation (see Figure 120). In this case, the seat pans would leave the vehicle with the cutters at the beginning of the shift and would be fixed back on to the seat when they board the bus at the end of their shift.



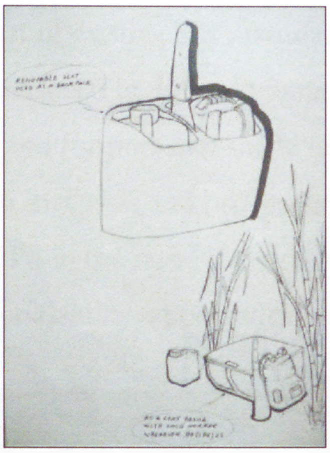


Figure 118: Design of the seat pan to accommodate a backpack and drinking water container.
Figure 119: Seat pan used as a backpack and portable seat on the plantation.
Figure 120: Design of the detachable seat pan to be taken on the plantation.

This new seat would be manufactured in plastic by the blow-moulding process using a cheap, easily mouldable and washable resin, such as High Density Polythene (HDPE). It would be equipped with the three point seat belts developed for buses which are already available on the market. Lastly, the estimated cost of this seat would be 210% higher than the cost of the seats equipping the current buses, but with a higher cost-benefit for the cutters. Moreover, besides the additional benefits offered by the new design it is estimated that its weight would be 20% lower than the weight of the current ones, generating a weight saving of about 210kg for the vehicle (see Appendix 7 for more details).

### 7.6.8 Drivers' Belongings

As the driver's and supervisor's belongings are currently spread out all over the dashboard of the buses, the design solution for this situation is a specific overhead compartment (see Figure 121), positioned right at the front of the ceiling and above the dashboard. Even though there are already a couple of small compartments like this in the interior of the Brazilian urban buses, none of them was developed for this specific purpose. This means not only that they are not in the right place, but also that they are not quite suitable in terms of size. Considering that sheets of Polypropylene (PP), reinforced with materials such as calcium carbonate to improve its mechanical properties, is already a material which is part of existing bus manufacturing processes, this compartment could be easily produced in different parts by the vacuum-forming process, milled and glued to each other and forming one single unit. However, based on the information from the section on materials and processes presented earlier in this chapter, a combination of ABS and HDPS in the same sheet must be considered in this case, which would produce better mouldability, appearance and finishing.

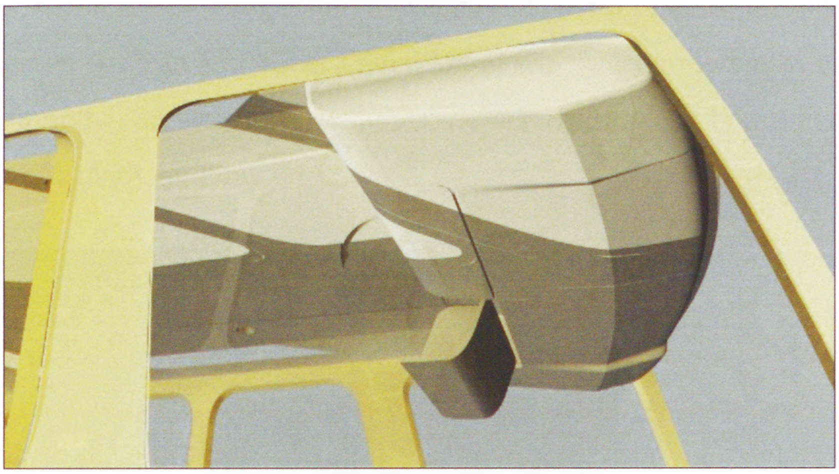


Figure 121: Design of the overhead compartment for the driver's belongings.

### 7.6.9 On-board Flooring

The material currently covering the floor of urban buses does not provide a homely feeling. The 3mm thick aluminium plates used as flooring requires a significant production cost, and it is both time-consuming to install and aesthetically unpleasant, resulting in a mosaic-like composition, formed by separate plates put together with an enormous quantity of rivets, as we can see in Figure 122.

Figure 122: Riveted aluminium floors currently in use in urban buses.

I propose that the design of the flooring should be based on a simple and resistant plastic-rubberized material similar to linoleum, which is already widely used in the interior of metro trains (see Figure 123), and for domestic applications as well. It is cheaper than the aluminium, and can cover large areas with just a single piece, which means a much lower number of divisions and is easy and quick to install. Moreover, it presents a much more aesthetically-pleasing result, with different colour options; it is rubberised, waterproof, and easier to clean and offers a safe level of grip. Most importantly, even though it has a smoother surface, it is not slippery, which constitutes a bonus in this case to the cutters, particularly on rainy days.

Figure 123: Example of the transport application of a linoleum-type flooring.
© Wikimedia

One of these specialised materials already used in the transport industry is available under the trademark TARAFLEX. Regarding costs, this solution would cost 76% less than the current system, saving around £615 per bus (see Appendix 7 for more details). As a base for the flooring, instead of plywood, the new option of MDF boards made from sugar cane bagasse could be used. They are cheap, resistant to impact, waterproof and environmentally friendly.

### 7.6.10 Windows

As revealed by the field research, besides being more welcoming to the cutters when contemplating the landscape, a broader glazed area would allow the cutters to feel that the interior of the vehicle is bigger than it actually is, improving comfort and welfare as a result. For this reason, respecting the technical and safety limits, it is possible to increase the area of the side windows of the vehicle by 250mm in a vertical direction, as we can see further in Figures 158,159 and 160. However, because keeping these windows as glass would increase the weight of the side walls by 20%, and this would increase the vehicle's dynamic problems, the glass must be replaced by plastic (Polycarbonate – PC).

Even though bus manufacturers from Europe and South America are still not as confident about the use of PC for the glazed area as car manufacturers, it has already been successfully and broadly adopted by American bus manufacturers. Among the advantages of PC some are as follows:

- Transparency of around 90%, similar to best-quality glass.
- Thermal resistance of over 100°C.
- Appropriate for harsh environments.
- Virtually unbreakable, due to the fact that its high mechanical resistance to impact. is 250 higher than glass and 30 times higher than acrylic.

As polymers have recently reached an impressive level of improvement, the use of PC for automotive application is not exception. The PC produced by SABIC Innovative Plastics, under the trade name LEXAN Margard, is an example of these specialist products, and it has been used in the automotive industry for many years. Although this material was not specifically tested in the sugar cane environment, it is already part of the agricultural context, used for equipping cabins for tractors and forestry equipment. Margard can selectively absorb rays near the infra-red part of the spectrum, thereby reducing the level of solar transmission by 60%, consequently also reducing heat inside the vehicle. Its lifetime is the same as glass, and if a different colour were required, both a version with greenish tint to it (Margard MR5IR) and a clean version with solar film protection over it are available. Moreover, when it is attached to the body structure, instead of relying on traditional frames, it can fixed by glue or by double-faced foamed acrylic tape, such as 3M's VHB, or similar.

The adoption of PC in the vehicle would cost 144% more than the cost of glass, but, it would be able to reduce the weight of the side walls of the vehicles by 165% (see Appendix 7 for more details).

### 7.6.11 Interior Lighting

The lighting design solution for this vehicle is the latest generation of lighting in the automotive industry, not only for the interior, but also for the exterior. This design is based on Light Emitting Diode (LED) technology. These lights are positioned on the ceiling, in a longitudinal relationship to the vehicle; however, they are placed not in the corners but more centrally, as we can see in Figure 124, distributing the light directly above the users. Compared with the current fluorescent lamps, they are more efficient, easier to install, easier to repair and provide a more homely ambience. They are also cheaper, costing approximately £60 to light the whole interior, whereas the current system costs £7/m or £168/vehicle.

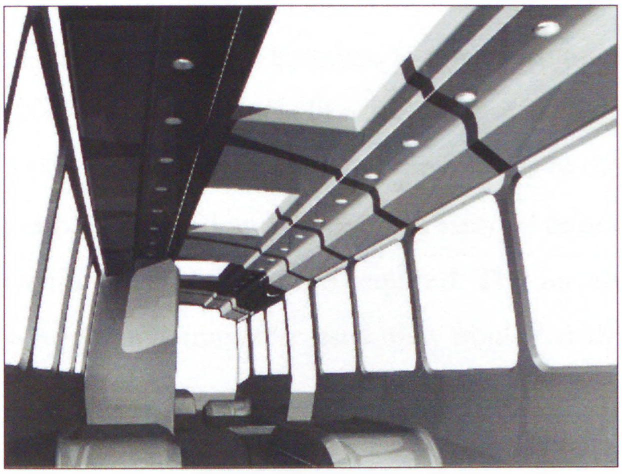


Figure 124: Lighting design solution.

This type of lighting is currently the leading long-life, low-voltage product, with an operating lifetime of 50,000 hours. In this particular case, as the new generation of LED-based interior lighting system requires 24 lamps (two parallel lines of 12 lamps each - one per metre) as part of the solution, it would generate in total 900W of light, whereas the fluorescent lamps on current vehicles generate 600W.

Lastly, the improvement of the natural light in the interior of the vehicle, due to the increase in the glazed area, means that the artificial lighting can be less diffused and more directional for the cutters' activities.

### 7.6.12 Air Conditioning

The field research showed that none of the analysed vehicles was equipped with neither air conditioning nor a ventilation system. Because the thermal conditions inside the vehicles transporting cutters during the summer far exceed the temperature of 29°C ergonomically determined as the limit when air conditioning is necessary, the installation of this system in this vehicle is mandatory. However, traditionally air conditioning units developed for buses have involved equipment with considerable dimensions, weight and cost. Equipment normally weighs up to 600kg (including insulation, attachment structure, compressor and gas), positioned on top of the vehicle, which causes a significant problem in relation to vehicle dynamics.

The compact air conditioning units currently used in caravans and motor-homes are a possible solution. They would be able to produce 10.000 Btu/h; they are cheaper, lighter (from 30 to 45kg), and based on small modules with sealed compressor units already filled with r-744 gas, harmless to the environment. The problem, according to Goedert (2007), is that a vehicle like this requires equipment capable of delivering 4,000m$^3$/h. Taking into consideration the dimensions of the vehicle, the materials, the number of people on board and the average external temperature of approximately 35°C, a thermal capacity of 75.000Btu/h is required. This means that even if three of the caravan-type air conditioning units were used, they would hardly reach 50% of the total capacity necessary.

Traditional air conditioning manufacturers have been looking for new solutions for automotive applications along the same lines as this research, and since 2003 they have been presenting new developments based on almost the same features as these models in caravans and motor-homes. One of these systems is the Carrier AC-82222 Split System (see Figure 125), based on split free-blowing, and this is the one recommended in this design. Each unit is capable of producing 40,000 Btu/h, so two units would achieve the required capacity for this vehicle. As most of the materials used in the design for the interior, such as the flooring and the glazing, are based on plastic, the thermal coefficient would be lower, which constitutes a distinct advantage. This means that more efficiency and a lower thermal capacity is required from the equipment, with consequent economic benefit, as ordinary air conditioning compressors demand between 5 to 10% of the engine power.

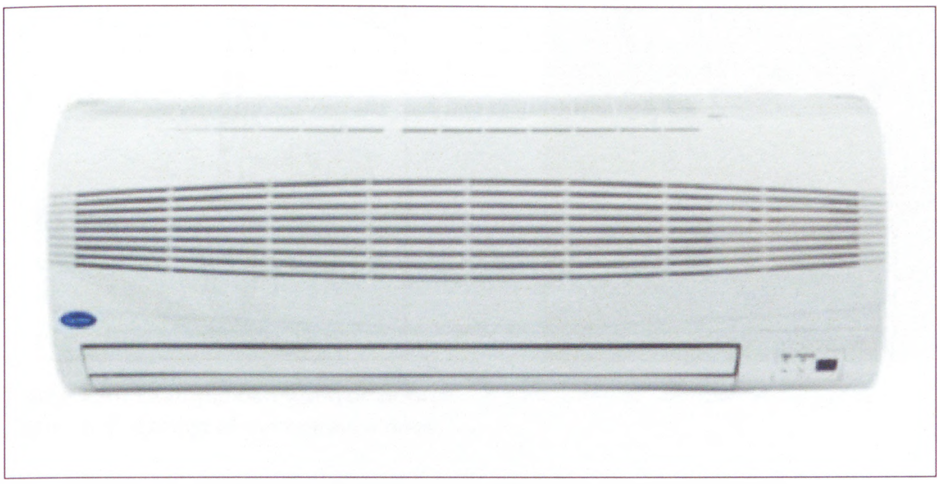
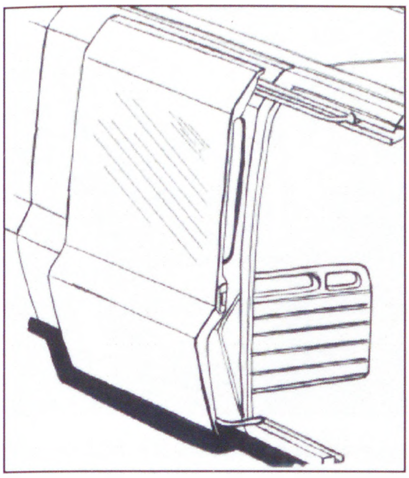


Figure 125: Carrier Split compact air conditioning unit.
© Sumaria

Lastly, despite other advantages, such as easier and simpler installation, two more aspects must be considered: cost and weight. The adoption of these two recommended air conditioning units, if compared to traditional systems, would reduce the cost of the investment by 68% which means a £6,800 saving, and would weigh 91% less (see Appendix 7 for more details).

### 7.6.13 Accessibility

As the cutters are normally carrying their belongings when getting in or out of the vehicle, accessibility is a very important issue. There are two types of door for this purpose available on the market: the door which is assembled in one single piece, similar to those used in vans (see Figure 126), and the door constituting of two folding pieces. Comparing these two, this research shows that the first option is more complex and expensive than the second. Thus, the design solution proposed is a door with two folding parts, accommodating rubbish bins vertically positioned in the lower part of its internal wall (see Figure 127). Instead of the two or three doors found normally in the traditional urban buses, the adoption of one single, wider (1,250mm) door would require only two steps to access the vehicle, reducing the costs by 67% and saving approximately 140kg in weight (see Appendix 7 for more details).



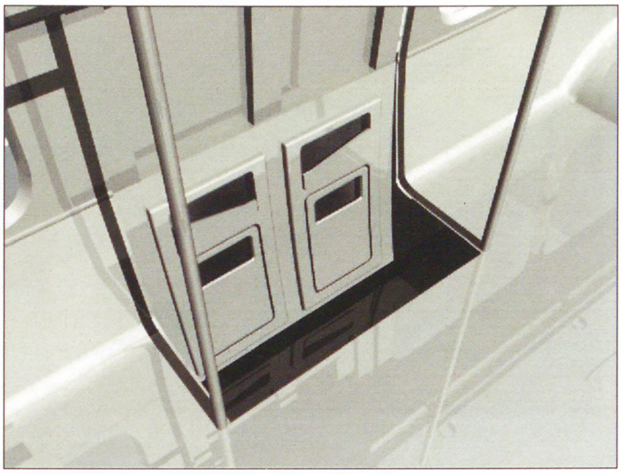
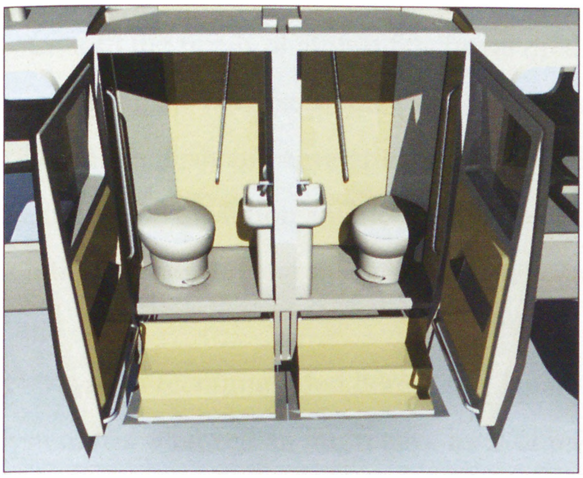


Figure 126: Example of a van-type door.
Figure 127: Design of the entrance door.

As already mentioned above, the existing position of the engine, in the front, right next to the driver, consequently compromises significantly his/her accessibility. The design solution proposed would be a door for the exclusive use of the driver, positioned on the left side of the vehicle, allowing him/her to access the vehicle easily. Although this solution is common in buses all over the world, it is not in Brazil.

### 7.6.14 Toilets

Taking into consideration the requirements of the NR-31, this vehicle must be equipped with two toilets, with access from the exterior only (see Figure 128), allowing the cutters to use them more freely and without embarrassment. The natural location for these would be at the back of the vehicle; however, this is not the best solution in this case for two reasons: First, the departure angle of the bus would mean positioning the toilets above the rear bumper, which means access is more difficult. Second, as the rear of the vehicle is quite vulnerable to shock and vibration, this positioning would damage the structure of the toilets, as well as would become uncomfortable and unsafe for the cutters. Thus, as the part of the vehicle less affected by shock and vibration is in between the axles, the proposed positioning for the toilets would be there. Even though this would mean a compromise in the internal layout, this solution would be better in terms of weight distribution and accessibility, particularly with the design of the folding stairs incorporated into the underneath of the vehicle, as we can see in Figure 129.



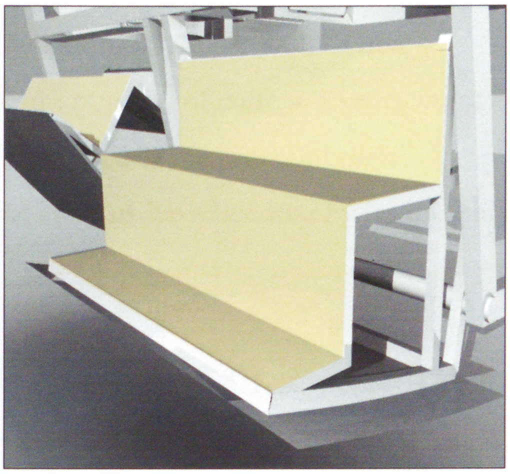


Figure 128: Design of the two separate toilets accessed externally to the vehicle.
Figure 129: Design of the folding stairs to access the toilets.

While the structural external walls of the toilets are produced in fiberglass, the panels of the interior (see Figure 130) must be vacuum-forming moulded from an ABS sheet, due to its level of resistance to chemical cleaning products. Also, by having two separate toilets accessed from the outside, the 24% of the cutters who currently like to change their clothes before and after their activities on the plantation would have more freedom and space for using the toilets for this purpose.

Figure 130: Design of the toilets' interior.

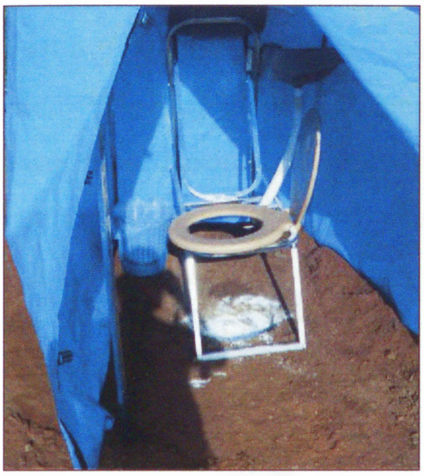
With regard to the toilet system itself, the natural solution would be the adoption of one of the systems currently in use on inter-city coaches; these, however, are complex and expensive. In looking for solutions in different fields, camping-type portable toilets were considered. They have a waste cap, they are easy to empty and clean and have far fewer components and parts, making them much simpler. However, they would not be able to cope with the needs of almost 60 cutters on the plantation on a daily basis. Thus, considering the context of toilet use, vehicle types and number of cutters, a permanent toilet with a flush and a water tank is the best solution. Taking into account their technological evolution and decrease in costs, these systems have become by far the best solution for boats, caravans and motor-homes.

The system recommended here is the Thetford Bravura (Figure 131) or similar. This system has achieved an impressive level of improvement in terms of gravity-based toilets, using little water, as gravity transports the waste. As a result, it demands only 0.3 litre of water per flush, meaning that a 150-litre water tank would allow 450 flushes, or around 8 flushes per cutter per day, which is quite reasonable. The system is low-tech, well-tested and relatively easy to maintain, demanding only the installation of a tank below the toilet. Regarding the costs, despite the fact that they offer a significant improvement, the total estimated cost of this solution including two toilets would be 19% cheaper when compared to the cost of the toilets equipping the buses currently in use (see Appendix 7 for more details).

Figure 131: Permanent toilet Thetford Bravura.
© Thetford.

One of the manufacturers in this industry has been investigating an economical solution that would separate solid and liquid waste, separating dead solids (nitrates and phosphates, for example) and allowing water to be reused for flushing. This would be an excellent environmentally friendly way to save water in toilets; however, it is currently still in the early stages of research.

As we can see, the new design solution proposed here for the toilets in the vehicle would certainly improve the cutters' comfort and hygiene, reducing the dependency on the improvised sanitary canvas (see Figure 132). However, as a last resort, in cases in which it is really necessary to provide such facilities to workers who are far away from the vehicle, a portable and more hygienic solution must be adopted. Thus, with an interest in this research, an Italian manufacturer of accessories for caravans and camping started working on the development of a specific design solution in order to tackle this particular problem. The result is the BI-POT-Maxi, by Fiamma, which is a portable toilet attached to a mobile base, as we can see in Figure 133. The system is entirely portable, with a base consisting of a 40- litre waste-tank, toilet roll, bottle with chemical treatment for the waste and a brush.



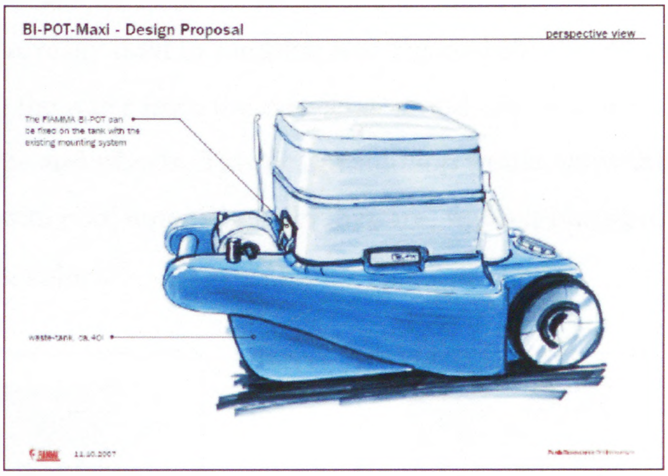



Figure 132: Sanitary canvas on plantations
Figure 133: Design of the Fiamma BI-POT-Maxi.
© Joao Marcelo Soares and Fiamma, respectively

### 7.6.1.5 Drinking Water

Considering that drinking water is vital on the plantation, keeping it properly stored and cooled has been one of the biggest challenges in this kind of transportation for many years. After the considerations resulting from this research, the design solution here is divided into three steps, as follows:

- Containing and cooling drinking water.

- Serving drinking water on board during the trip.
- Serving drinking water in different parts of the plantation.

Firstly, as a resource to contain and cool drinking water in the vehicle, a simple domestic horizontal refrigerator, with a door on the top and a 150-litre capacity (see Figure 134) must be adopted. As the interior of this type of refrigerator is vacuum-formed by means of one single plastic (HDPS) sheet, the interior becomes sealed, which means that it can be used as a proper water tank, with its own cooling system and double wall for insulation.

Secondly, as a resource for providing drinking water for the cutters on board, two normal water-cooling machines, each with 20-litre capacity, (see Figure 135) must be used. Having this resource available on board (one positioned in the front and another in the rear of the vehicle), it would be possible for the cutters to save the water within their individual water containers.

Thirdly, as a resource for serving drinking water in different parts of the plantation, at least two 40-litre mobile water tanks normally used in camping (see Figure 136) should be used. These can easily be refilled with the water from the refrigerator, and can also be easily moved around, due to the handle and wheels. This design solution would allow the cutters to refill their water containers with cool water wherever they are, without having to wait for an opportunity to return to the vehicle.



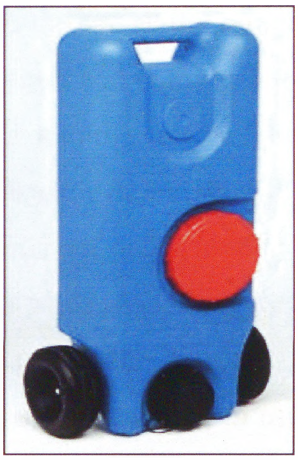


Figure 134: Example of a 150-litre refrigerator
Figure 135: Example of a water cooler machine.
Figure 136: 40-litre portable water tank.

Considering that the amount of water in the three systems is 270 litre in total, this is 35% higher than the amount of water available in the adapted water tank in the buses currently in use, being the amount needed by 58 cutters. To accommodate the portable 40-litre water tanks, a compartment utilising the space in the lower part of the vehicle (see Figure 137) could be used. Because of their upright position at a 30° angle in the compartment, the tanks would be ergonomically and easily handled. Also, as these tanks have two lids (one for filling and one for draining), this compartment can be equipped with a pipe and a valve, both connected to the refrigerator, which would make it easy to fill the tanks with fresh cool water whenever necessary.

Figure 137: Design of the compartment for portable 40-litre water tanks.

Another important issue to be considered here is how to keep the quality of the drinking water acceptable for consumption. When water is stored in a tank, despite all the hygienic precautions, the formation of bio-film in the interior of the tank, pipes and connections are inevitable, contaminating the water and representing a health risk to the cutters. The only way to counter this problem would be to put the tank out of use for more than 10 hours while being chemically treated, which inevitably ends up being not only a time-consuming operation, but also changes the flavour of the water for while. As leaving the water tanks in the vehicles without any care or treatment is unacceptable, the design solution here is the adoption of a so-called CWR System (see Figure 138) already in use on a large scale in medical and pharmaceutical technology.

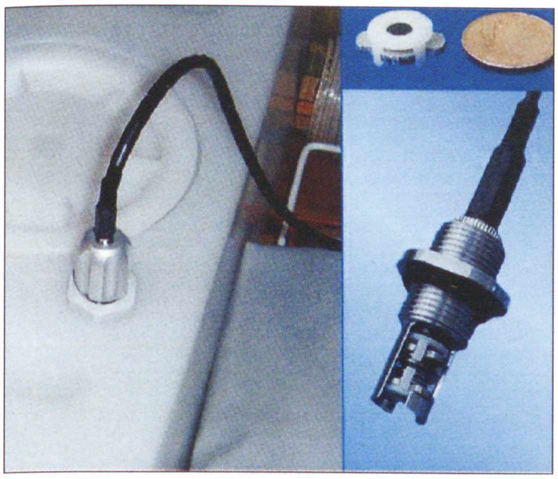


Figure 138: Water tank disinfection system based on CWR.
© Carysan.

This technology is able to reduce the proliferation of undesirable micro-organisms in the water by means of electrolytic ozone production, eliminating the need to use any additional chemical products. As a disinfectant gas, ozone works even in the most inaccessible areas of the tank: this costs approximately £200 per kit on average, and operates at a low tension, consuming a very low level of electricity.

### 7.6.16 First Aid Resources

Because safety is one of the crucial issues in this transportation context, although in cases of significant injuries the cutters can be taken quickly to the nearest hospital, first aid assistance for emergencies must be available on board at all times.

As we can see in Figure 139, the current vehicle has a plastic case used as a first aid box without a specific compartment on board to accommodate it. Thus, the design solution provides a compartment for it right in front of the door (see Figure 140), allowing direct and easy access, and ensuring that the first aid logo is easily visible. This compartment occupies the free space between the double wall dividing the two toilets which has space enough to accommodate not one but two first aid boxes. This would allow one box to be kept on board whereas another could be kept on the plantation, available to those groups of cutters working further away from the vehicle.

Figure 139: Current first aid box on buses.
Figure 140: Design of the compartment for the first aid boxes.

Like the first aid box, the stretcher is a crucial component of the first aid resources. The stretcher is used to bring back a cutter to the vehicle from a specific location on the plantation, for reasons that vary from a simple indisposition to a serious injury caused by the machete. In addition, as the bus is not fast enough to take cutters to hospital in cases of emergency, the sugar company survey confirms that cars and pick-up trucks are commonly used on such occasions. Some companies also use ambulances appropriately equipped and crewed for assistance, which travel around plantations for emergency assistance when necessary.

As we can see in Figure 141, the design solution for the stretcher uses a currently area without utilization in the vehicle body, i.e. the external rear wall. Protected by a door, the stretcher could be easily attached and detached from the compartment. When detached it could provide assistance away from the vehicle and move the injured cutter, whereas when attached it could also be turned into a bed to keep the cutter comfortable and attended to until his/her removal.

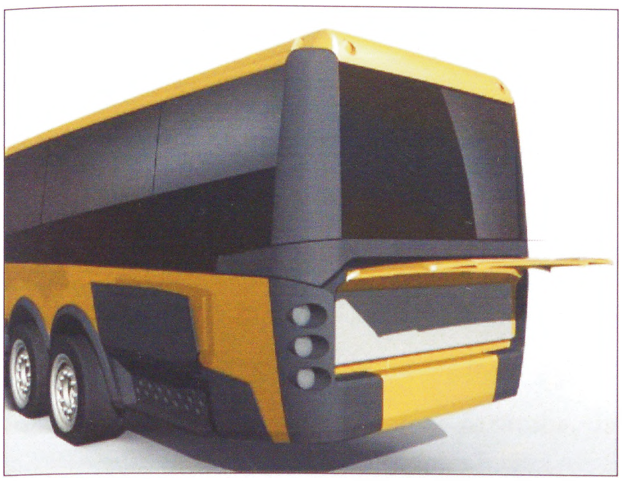


Figure 141: Design of the stretcher as part of the external rear wall of the vehicle.

### 7.6.17 Sinks

In view of the washing needs of the cutters, a source of non-drinking water for washing purposes needed to be considered. Some buses are equipped with a small detachable sink positioned on the side wall of the vehicle. However, as the water supplying the sinks is not reused and flows freely through the drain, ending up on the ground, a higher amount of water and consequently bigger tank are required.

The design solution provides two bigger sinks (see Figure 142) positioned on each side of the vehicle, and equipped with two taps each plus soap and paper towel dispensers, allowing four cutters to use them simultaneously, making washing easier and quicker. The accommodation of the sinks is based on a concept inspired by the drawers in caravans and motor-homes using two telescopic metal runners. Figure 143 shows how clearly effective this component, originally designed for furniture, would be in this case.

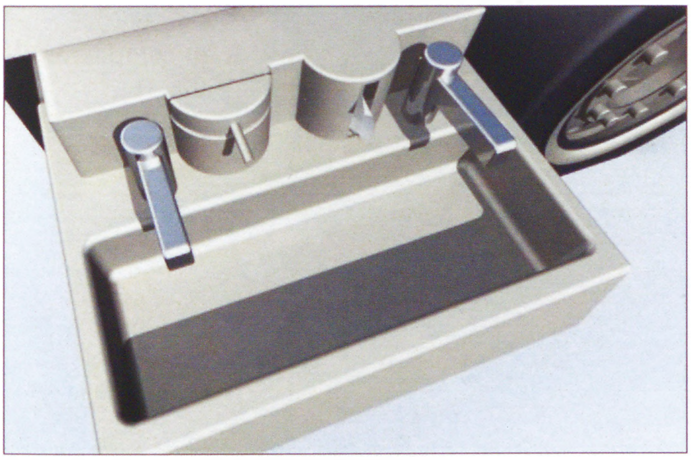


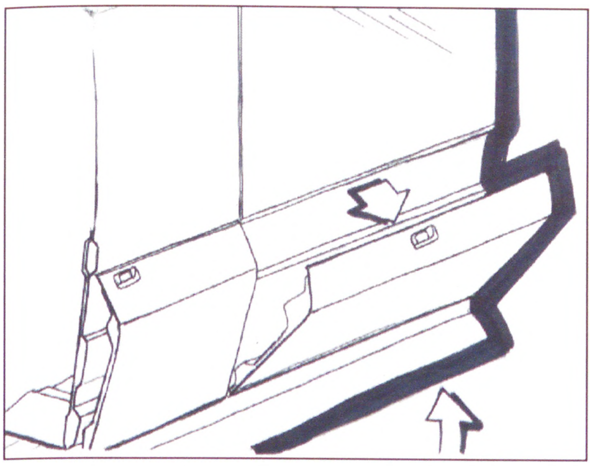
Figure 142: Design of the sinks with two taps based on drawer concept.
Figure 143: The motor home drawer which inspired the concept.

In order to save water, thus reducing the amount of water in the tank and its weight, the design solution includes shower-type taps. In addition, a small, simple water pump such as the Fiamma Aqua 8 system or similar, should be installed. As the ideal situation would be to re-use the same water again instead of having the used water simply draining out of the sinks, the design solution also includes the adoption of one of the domestic recycling systems currently available on the market. With this environmentally friendly system, it would be possible to turn the water used in the sinks to be reused again for the sinks and for the toilets. In countries such as Australia, these systems, equipped with appropriate filters, are commonly used for reusing rainwater for a number of purposes, including drinking and cooking.

Finally, another important observation relates to the position of both the drinking water and non-drinking water tanks. For dynamic reasons, they should be positioned as close as possible to the platform of the vehicle, which would not then cause problems with using the water pump, regardless the lower height of the tank.

### 7.6.18 Tool Compartment

The tool compartment in the sugar cane cutters' vehicle must accommodate the machetes properly, positioning them in such away that they are not damaged, and are easy to identify individually, enabling the cutters to get their tools and replace them quickly and easily. As it is necessary to have the compartment in a lower part of the vehicle, because of package and dynamic reasons, the initial idea was to accommodate the machetes on the inside of the compartment door, as we can see in Figures 144 and 145. Once opened, the door of the compartment would be positioned as a horizontal table-like surface, with the machetes on it.



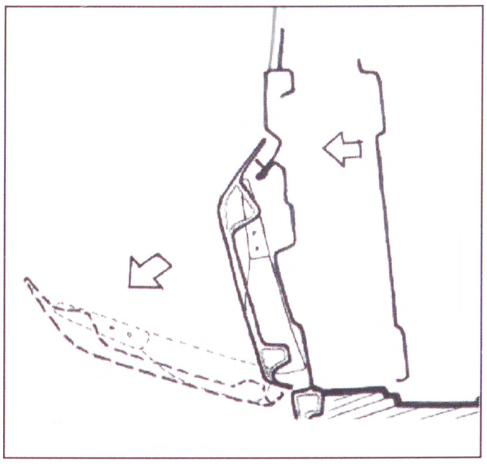


Figure 144: Using the compartment door to accommodate the machetes.
Figure 145: A possible solution for accommodating the machetes.

However, for technical reasons, such as the weight and quantity of the machetes, the idea above was then improved as part of the evolution of this compartment towards the design solution based on the concept of a drawer (see Figure 146), similar to the solution of those arrived at for the sinks.

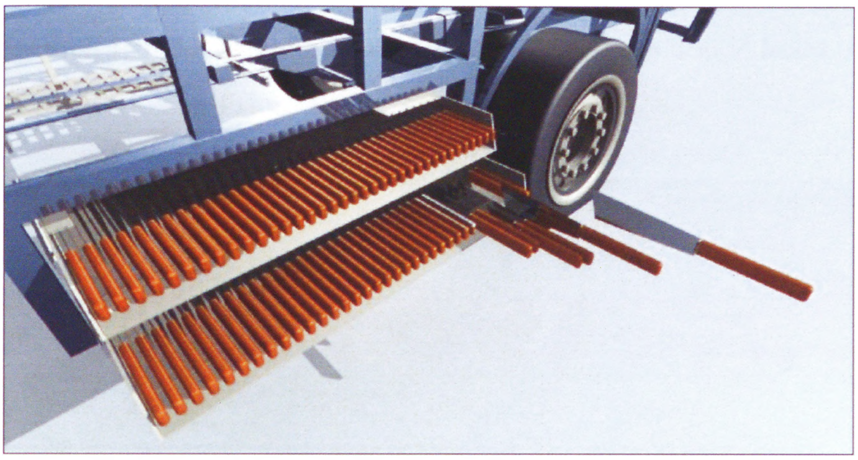


Figure 146: Design of the compartment for machetes based on the drawer concept.

As we can see in Figure 147, when the door of the compartment is opened and the drawer accommodating the machetes comes out of the compartment, the door is flipped underneath the drawer, unblocking the machetes that can be then removed from the drawer. It makes the operation of handling the tools safer, easier and more ergonomic for the cutters.

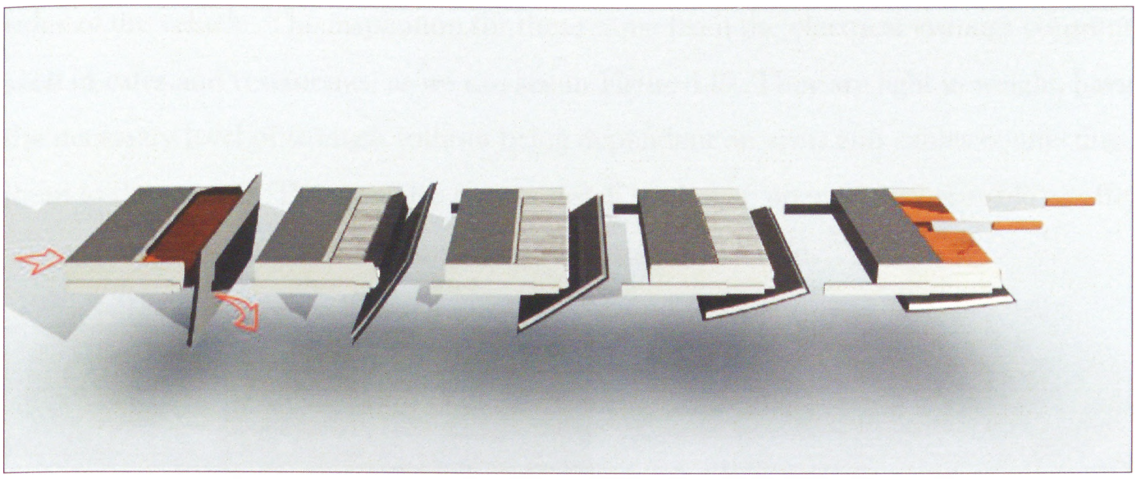


Figure 147: Design of the door pulling the drawer while being positioned underneath of it.

As the cutters' vehicle carries not only machetes, but also hoes, according to the agricultural activities taking place during different seasons, the accommodation of the hoes also needs consideration. The accommodation of the hoes, due to their size and shape, is as important as the storage of the machetes. The design solution of the compartment for the hoes is based on the idea of keeping them suspended horizontally by their handles accommodated in sequentially positioned holes inside the compartment, as we can see in Figure 148.

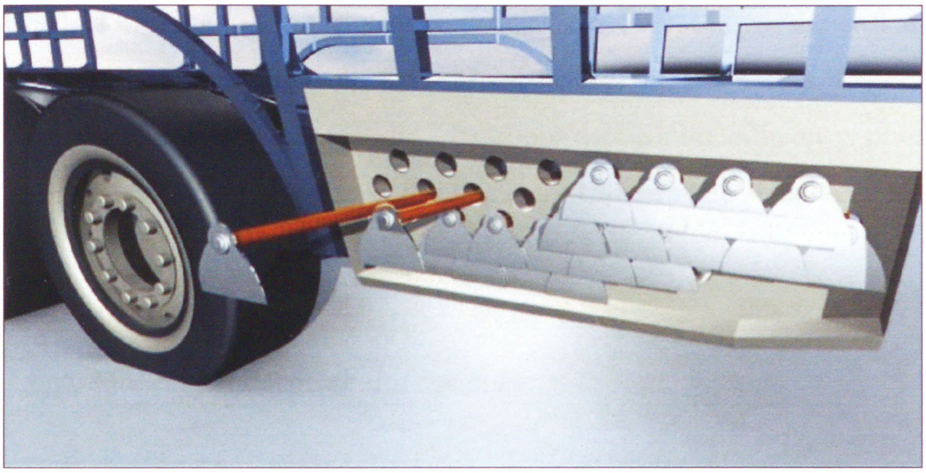


Figure 148: Design of the compartment for storing hoes.

### 7.6.19 Awnings

The cutters need protection and shelter from the sun during the day outside as inside the vehicle. In order to offer this protection on the plantation, as well as better temperature conditions on board, the design solution suggested is to install electrical awnings on both sides of the vehicle. The inspiration for these came from the electrical awnings commonly seen in cafes and restaurants, as we can see in Figure 149. They are light in weight, having the necessary level of strength without being dependent on arms and cables connecting them to the ground. They are also easy to install, and once opened they are able to offer an angle that does not interfere with the plants near the vehicle.

Figure 149: Example of electrical awning for commercial use.

Furthermore, there are lighter versions of this kind of awing designed specifically for caravans and motor-homes, such as the Twinstor model produced by Brustor or similar, which is highly suitable for using in this vehicle. Even though the cost and weight are 84% and 82% higher respectively, in comparison with the adapted awnings currently equipping the cutters' buses (see Appendix 7 for more details), the efficiency, practicability and ease of operation of this option justifies this extra expense and weight.

### 7.6.20 Flooring underneath the Awnings

As there is no paved surfaces on the plantation, tables and chairs have to be placed on the soil. Although the area underneath the awning is normally cleaned for this purpose, requiring on average 20 minutes, there is a problem when the soil is wet. The design solution for this is a portable plastic flooring system, such as the IkaRoll or similar, as we can see in Figure 150. It is made up of small flags of 400 x 100mm, snapped together according to the size required, creating a 'domestic' environment for the cutters. Most importantly, this system would keep the ground underneath the awnings in much better condition, even in wet soil or mud, supporting the tables and chairs as well as being easily washed when necessary.

Figure 150: IkaRoll flooring system.
© Ikadan.

### 7.6.21 Tables and Chairs

Accommodating tables and chairs for over 50 cutters in appropriate compartments in the vehicle is quite challenging. The design solution here is a folding table and chairs such as the Picnic model from Kofferset (see Figure 151) or similar, allowing the cutters to be grouped in a way which suits their interaction. This folding table with bench seats, folds away neatly to form its own carrying case measuring 870 x 330 x 112mm. This means that just 15 of these would be enough to provide accommodation for all the cutters under the awnings. On account of this, they could be easily accommodated in one single compartment measuring approximately 1,400 x 900 x 500mm, which is the same size as the current tool compartment.

Figure 151: A folding table and chairs in plastic and aluminium.
© Campingcomfort.

Moreover, as each of the existing tables weighs 5kg and each the chair weighs 2.8kg, whereas, the proposed system weighs 10kg, this design solution would provide a weight reduction of 39% with a increase of the cost by 7% compared to the current tables and chairs (see Appendix 7 for more details).

Lastly, more images of the design solutions, can be seen in Appendix 6.1.

### 7.6.22 Vehicle Exterior

As mentioned before, this vehicle design has been based on inside-out design, starting from the interior and progressing to the exterior. Therefore, once the interior layout, and the design solutions regarding the interior were defined and established in association with the design of the body structure, it was time to define the exterior design. Two of the most important purposes of the exterior design for this vehicle are not only to establish a communication with the interior, but most importantly, to create a design language for the vehicle. As the briefing is usually presented in a more general way in order not to limit the creative process, I argue that as a starting point of the establishment of a design language, a group of more specific requirements for parts or components of the product (the vehicle transporting cutters, in this case) should be pointed out. Therefore, for this particular vehicle, key elements of its exterior which emphasise an extra protection against off-road conditions as well as the agricultural environment were formulated, as follows:

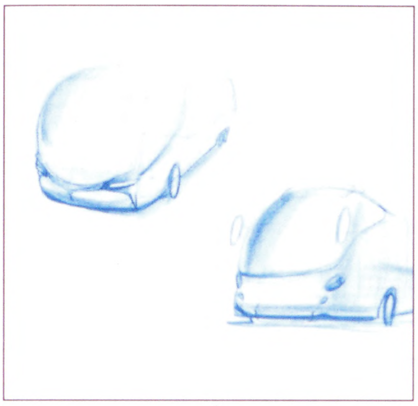
1. Hexagonal section of the body structure
2. Metal protection for the front and rear ends
3. Tubular protection for the vehicle's corners
4. Skids in the front and in the rear
5. Shields attached to the top of the front and rear
6. Side protection bumpers attached to the body

In order to confirm the impact and influence of these elements on the definition of a design language for the vehicle, three vehicle designers were invited to be part of this study. In order to give more credibility to the experiment, I decided not to play an active part in it, allowing the designers to work independently, with no contact with the work of the others, and consequently without any influence from the others' ideas.

Although all of them received the same data related to dimensions, structure and package of the vehicle, and were instructed and managed equally, they worked in different ways, in order to confirm my research position. Therefore, the three different concepts of the exterior design presented here are not mine.

The first participant was Hélio de Queiroz (a Brazilian vehicle designer from GM) whom was asked to visualize the exterior with the design briefing mentioned earlier on page 159 to base his work on. The second and third participants were Ehsan Moghaddampour (a recent graduated MA student in vehicle design from RCA) and Do Hyung Kim (a current MA student in vehicle design also from RCA). They were asked to use the same briefing, but also to incorporate all six specific elements presented above in their concepts.

In the following stage, the process was divided into three sections: first, all of them created the overall format of the vehicle, based only on the briefing and proposed package, as we can see in Figures 152, 153, 154 and 155.



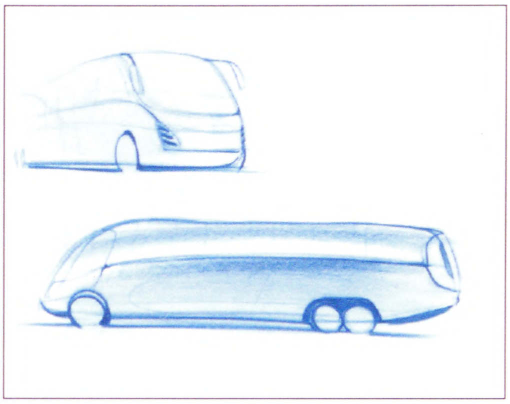
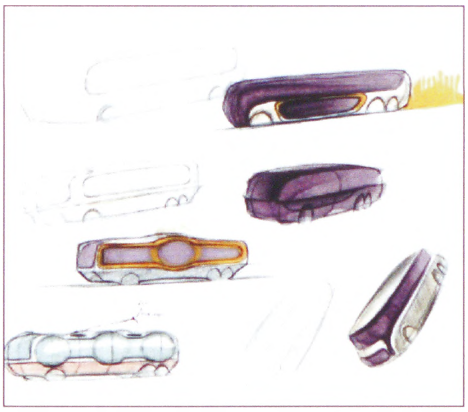


Figure 152: Sketch of the overall format of the vehicle (1).
Figure 153: Sketch of the overall format of the vehicle (2).
© Ehsan Moghaddampour



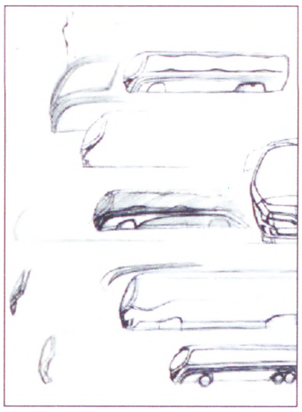


Figure 154: Sketch of the overall format of the vehicle (3).
Figure 155: Sketche of the overall format of the vehicle (4).
© Do Hyung Kim

Second, Ehsan and Do included the six elements in their concepts (see Figures 156 and 157).

Figure 156: Sketch towards the definition of a design language (1).
Figure 157: Sketch towards the definition of a design language (2).
© Ehsan Moghaddampour and Do Hyung Kim, respectively.

From the design point of view, the six elements that relate to the exterior design have much to do with the plantation scenario, as they constitute the basis of the interface between the vehicle and the off-road conditions and agricultural environment. Thus, the results of this experience also confirmed that rather than just being related to the transportation purpose or function, the consideration of the environment surrounding the vehicle is crucial for the establishment of a design language, particularly for agricultural vehicles. The difference is also clear in comparing Hélio's work, which was not inspired by agricultural or natural elements, and Ehsan's and Do's work which was inspired by animals and insects.

As Helio's work was not informed by all the six elements suggested as ways of establishing the design language for this type of vehicle, the result was very good, but still not able to communicate a specific design language for the vehicle. This can be seen in Figures 158, 159 and 160, in which is already possible to see clearly that without the presence of the six elements, even if it fulfilled the briefing, the vehicle could be easily mistaken for a normal coach.

Figure 158: Front perspective of Hélio's concept.

Figure 159: Back perspective of Hélio's concept.

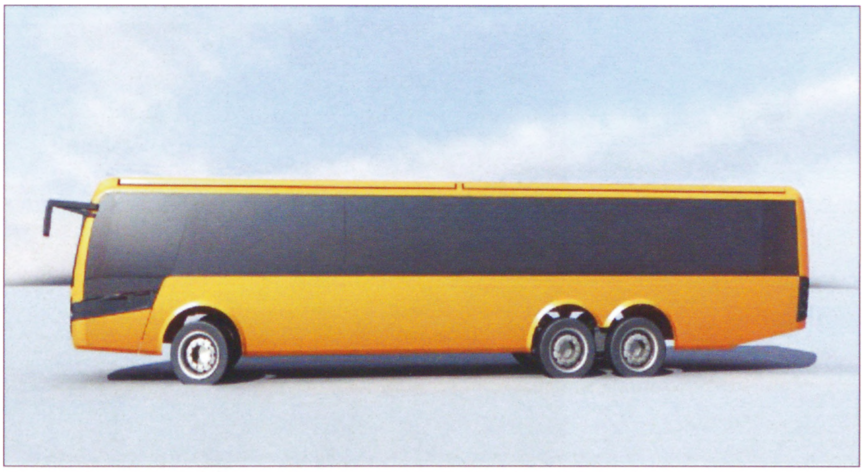


Figure 160: Side view of Ehsan's concept.

Ehsan's design started inspired by a caterpillar, and evolved into a consideration of a chameleon. The detail of the semi-circular bubbles incorporated all over the side plastic protection along the vehicle is similar to the chameleon's skin (see Figure 161). The front end was emphasised volumetrically in order to be associated with the head of the animal, while the sequential vertical columns of the glazed area of the vehicle are not only reminiscent of the sections of the caterpillar's body (see Figure 162), but also of sticks of cut sugar canes, as we can see in Figure 163. As we can see in Figures 164, 165, 166, and also in Appendix 6, in his concept, Ehsan emphasised the front end of the vehicle to communicate power and robustness, which, combined with the featured strongly side protection bumper, also communicates the ability to deal and interact with different harsh environments.

Figure 161: Chameleon.
Figure 162: Caterpillar.

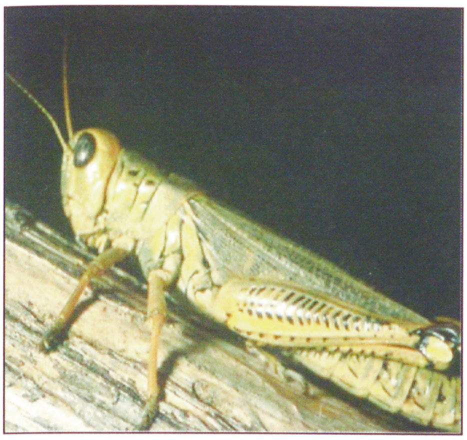
Figure 163: Sugar cane.

Figure 164: Front perspective of Ehsan's concept.

Figure 165: Back perspective of Ehsan's concept.

Figure 166: Side view of Ehsan's concept.

For his part, Do decided to adopt the attributes of the grasshopper (see Figures 167 and 168) as a source of inspiration for his design, using the front of the insect to transmit a more aggressive and robust, but not intimidating image for the vehicle (see in Figures 169, 170, 171 and 172).



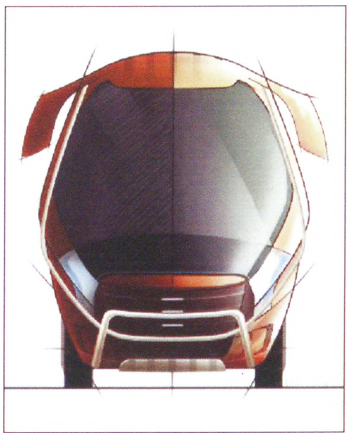


Figure 167: Grasshopper'skin.
Figure 168: Grasshopper's face.
Figure 169: Front view of Do's concept

Figure 170: Front perspective of Do's concept.

Figure 171: Side view of Do's concept.

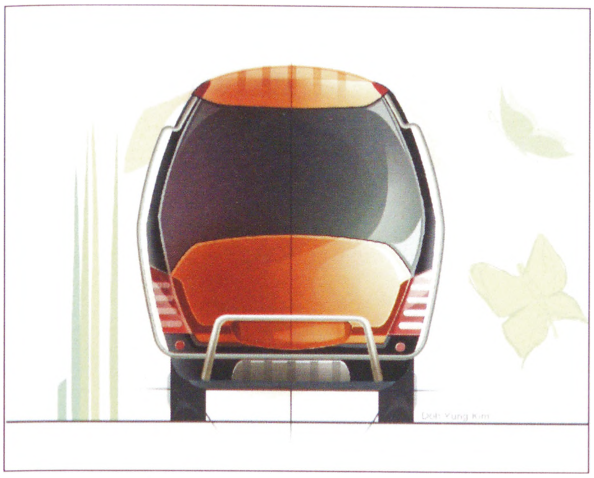


Figure 172: Rear view of Do's concept.

As this research found, the external corners of the vehicle are its most vulnerable parts, being exposed to all kinds of potential damage. The design solution in this case is to cover these elements with independent parts, as we can see in Hélio's concept (see Figure 173). Similar elements are already used in a number of commercial vans, which keep the integrity of the surrounding parts of the vehicle body and are easy to replace when damaged. They could be produced in plastic which is more resistant to bumps and impacts, such as PP reinforced with calcium carbonate, the same combination currently used for car bumpers. However, tubular structures may be attached to the front and to the rear of the vehicle as an effective protection against serious bumps, as we can see in Ehsan's and Do's concepts (see Figure 174 and 175). In addition, other elements of the vehicle which also work as a kind of shield, such as the parts positioned directly above the windscreen and the back window (see Figures 176 and 177), could be produced in the same plastic.

Figure 173: Plastic protection corners in Hélio's concept.
Figure 174: Tubular protection corners in Ehsan's concept.
Figure 175: Tubular protection corners in Do's concept.

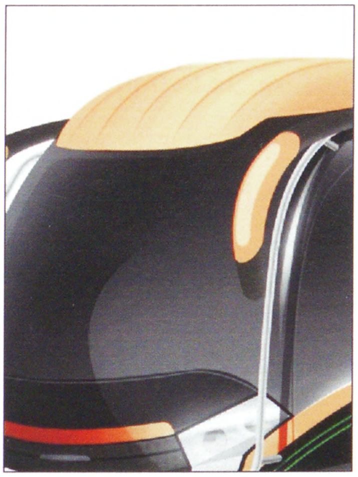


Figure 176: Front shield in Ehsan's concept.
Figure 177: Front shield in Do's concept.

The front and rear ends of the vehicle in Hélio's concept is divided into separate plastic modules, also making their replacement easy and cheap when necessary, as we can see in Figure 178. In their turn, Ehsan's and do's concepts are including metal skids that work as protection against bumps underneath the vehicle and as a bumper at the same time, as we can see in Figures 179 and 180. This part could be easily made in pressed stainless steel: however, due to the high cost of tooling, the solution could be also produce it in fibreglass, combined with a core structure of steel.

Figure 178: Front end of the vehicle in Hélio's concept.
Figure 179: Front end of the vehicle in Ehsan's concept.
Figure 180: Front end of the vehicle in Do's concept.

The choice of the headlights and tail-lights for the vehicle must combine practicality and economy. In Hélio's concept, cheap off-the-shelf, round lights are proposed (see Figure 181). As the lenses of both headlights and tail-lights are a frequently and easily damaged by sugar cane plants, in Ehsan's concept hidden head and tail-lights are proposed, as we can in Figure 182. There would be a compartment with doors for both lights that would be opened automatically when the lights are switched on. Do's concept (see Figure 183) proposes the adoption of existing components already used by other vehicles. However, regardless of the concepts, the design solution for the tail-lights should be based on LED light technology. The light provided by these is virtually instantaneous, resulting in a short reaction time, which is crucial in automotive lighting systems, particularly brake light systems.



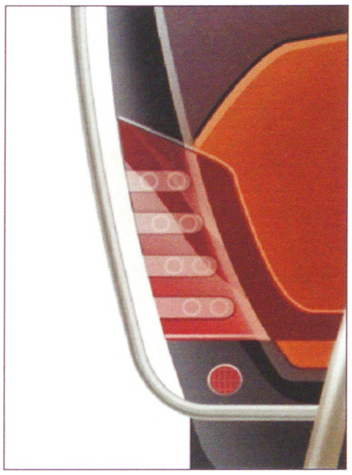


Figure 181: Tail-lights in Hélio's concept.
Figure 182: Tail-lights in Ehsan's concept.
Figure 183: Tail-lights in Do's concept.

Another important aspect regarding the design of the exterior is the fact that the lower parts of its side walls have to deal with tree stumps, rocks and ditches. To cope with this, the design solution is a side protection bumper, produced in reinforced PP and attached to the lower part of the side walls of the vehicle, as we can see in Figure 184 and 185.

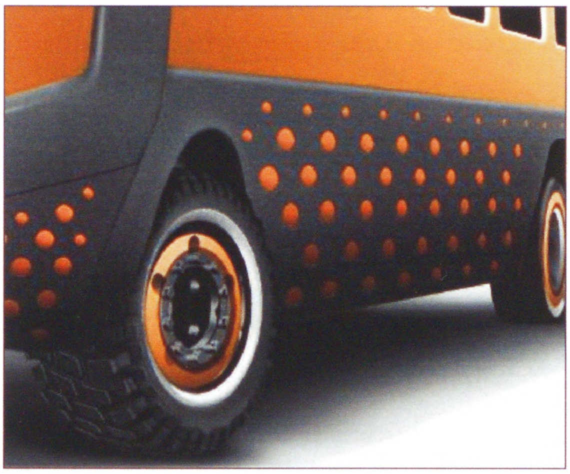
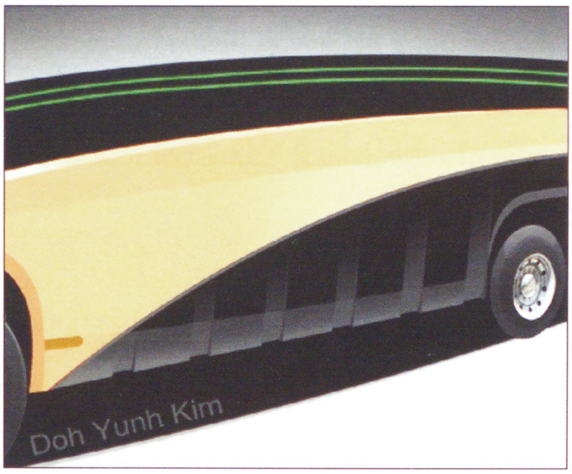




Figure 184: Plastic side protection bumper in Ehsan's concept.
Figure 185: Plastic side protection bumper in Do's concept.

More images of the design solutions for the exterior design of the vehicle, can be seen in Appendices 6.2, 6.3 and 6.4.

As we can see in Appendix 7, the table comparing the cost and weight of the previous and the proposed vehicle shows that it was possible to reduce the weight of the vehicle by about 20%, whereas the cost increased by 40%, which is much higher than was previously expected. However, it is important to state that the costs of each solution were based on retail prices rather than bulk rates. This means that the final manufacturer price, taking into account the cost reduction because of purchase of parts and components in bulk, will be 15% more expensive than the initial target instead of 40%. Nevertheless, taking into account the importance of truly appropriate vehicle for this transportation context, associated with the benefits which would be offered to the cutters because of the design solutions, this vehicle will definitely have a multiply beneficial cost-benefit for the sugar cane companies.

Finally, as the design of the vehicle has been computer modelled, tri-dimensional images and drawings are available and can be requested anytime according to different needs and purposes.

## 7.7 Conclusions

This analysis shows that the proposed design model should be oriented by integrated systems instead of being oriented by product development practices only. This is for two reasons: first, an interface must be established between users and buyers, in a situation in which the buyer is not the user. Second, a closer interaction between the legislation and industry must be created in order to improve the level of legislators' knowledge of manufacturing issues, and vice-versa.

In viewing the specific characteristics of the transportation of sugar cane cutters, instead of a normative model, based solely on deterministic data, the ergonomic descriptive model is more suitable. As the behaviour of the sugar cane cutters is not linearly predictable, the adoption of a normative model would be a mistake in this case.

The analysis of the history of the vehicles used for the transportation of cutters, detailed in Chapter 4, indicates that, contrary to what has been seen in the car industry, there is no developed design language for these vehicles, or indeed for agricultural vehicles in general. The design briefing presented in this chapter shows that a significant part of it relates to the legal, technical and economic aspects of the project. However, as the identification of the key design elements contributing to the establishment of a design language (noted earlier) is the responsibility of the designer, if he/she just refers to the design briefing only, he/she will be able to produce a **design**, but not a **design language** for the product. Therefore, for the establishment of a design language, these key design elements are crucial to inform and guide the designer in the right direction. On account of this, I also question Sullivan's 'Form follows function' principle, proposed in the 1930s, because if it were applied here, it would be likely to guide the designer in a different direction, again relating to the briefing only.

Moreover, reinforcing this scenario, for this type of vehicle values like branding and user perception have traditionally been more related to reliability and performance than usability and human-machine interaction. This means that, naturally, design and product development in this sector still focus more on the vehicle as a product or machine than as an integrated system. Hypotheses 6 and 7 can therefore be seen to be supported.

In the next chapter I present the final conclusions and recommendations of this research.

# CHAPTER 8 - CONCLUSIONS

The present study challenges a range of issues related to the transportation of sugar cane cutters. The whole process was based on the Research Interactive Analysis (RIA) model. The analysis consisted of three sessions of investigation involving different groups of users, vehicle and terrain in Brazil. Through this analysis, it was possible to combine the users' (sugar cane cutters') needs, the transportation trends for this agricultural sector and the sugar cane companies' expectations. The result offers vehicle design solutions and specifications capable of providing mutually beneficial situation for the cutters, as well as the sugar cane companies, manufacturers and legislators. In addition, this research confirmed that knowledge is not something rigid and unchangeable constituted by a progressive accumulation of data, but subject to a flexible, continuous and adaptable process of change, generating a living and independent system, quite different from a simple database.

In comparison with more traditional fields of knowledge and study, design, and vehicle design in particular, is a relatively new area for research. Nonetheless, the purpose of this research is not only to generate knowledge, but most importantly to create new opportunities and possibilities for converting and improving an existing product (in this case a vehicle) and context, meaning that rather than just studying the transportation of people over rough terrain, this research, above all, is about improving the sugar cane cutters' everyday life. Besides, this research has been an opportunity to focus on a defined area of study, and also to investigate new ideas about extending the language of mobility through new approaches, trends and technologies. This means that although both the design solutions and the specifications were established for the purpose of transporting sugar cane cutters, they could be applied equally to other services related to the transportation of people in off-road conditions.

By looking at the situation for both the workers and the bus drivers, it can be concluded that the current vehicles which transport sugar cane cutters are inappropriate for the purpose. It is necessary to note three points in relation to this: firstly, the bulk of the fieldwork took place in sugar cane plantations in the interior of Sao Paulo State in Brazil, so the transportation of rural workers was studied essentially from a Brazilian perspective. Secondly, for a number of operational and economic reasons, the Brazilian authorities are not sufficiently equipped to inspect this type of transportation, as it operates mostly in the countryside. Thirdly, a study of the body of the vehicle only would be insufficient to fulfil the objectives, test the hypotheses and answer the research question. Therefore, this research reveals that in most of cases legislators have a major influence in bringing about improvements to the transportation of people to and from the plantations. However, there still is a significant difference between the legislation produced by and the real needs of the cutters, which means there are gaps which need to be filled.

This study proves that through the establishment of design solutions and innovation, based on interdisciplinary analysis, it is possible to combine cultural and technological knowledge to create products truly capable of improving the workers' everyday life. Without an in-depth study of the technical aspects of the vehicle and the terrain, it would not be possible to achieve a high level of interpretation of user-experience data from the sugar cane cutters. Furthermore, the depth of understanding about user-experience evident in this research would not be effective if the technical support were not central. As a consequence, the technical approach of this research was the most challenging, because it involved different, specialised fields of knowledge beyond my own expertise. However, the results turned out to be highly rewarding.

From its early stages, this investigation explores the possibilities of transporting people from one place to another safely, quickly, comfortably and for an acceptable cost. It is certainly possible. It was confirmed by the results of the ethnographic and user-experience studies, in association with the involvement of all stakeholders. A good solution is possible as long as the vehicle designed for this purpose fulfils a series of recommendations combining the users' needs and the way they interact with the vehicles with a better understanding about the business context, vehicle manufacture and current legislation. From a wider perspective, this approach can also be viewed at a micro level (the research problem), and at the same time at a macro level (the research context). I firmly believe therefore, that through interdisciplinary and broader research, it is possible to offer people not only what they 'want', but also what they really 'need'.

In this chapter, the tested hypotheses are answered in the light of the objectives of this research.

Hypothesis 1: 'It is believed that the inadequacy of the vehicles to this task represents an imminent risk to the rural workers, a challenge to the agricultural companies and a social problem for the country.'

Based on an analysis of the mechanical parts of the vehicle, it is clear that the combination of some of its systems associated with its size and weight seriously compromise the vehicle's dynamics, which, in turn, combined with the conditions of the terrain, increases exponentially the possibility of accidents. Therefore, the urban bus currently in use, put into service straight from the manufacturer, is not capable of fulfilling the requirements of the transportation of sugar cane cutters. This is supported by Regulation NR-31 and also by the fact that the bus was initially designed to serve another, quite different, transportation purpose. This is also supported by references such as Costa Neto (2006), Maclaurin (2006 and 2007), Perseguim (2005) and Rodrigues (1993).

Could the adapted and modified bus, meeting Regulation NR-31, comply with these transportation requirements? The answer to this is also no. The field research shows clearly the problems and limitations regarding such adaptations. In addition, the core of the problem with the adapted vehicle is its overall concept, and the current range of adaptations cannot by itself change the concept of the vehicle. This is supported by references such as Damada (2007) and Antunes Jr. (2007). These constitute some of the reasons why the bus manufacturers are not carrying out any formal research on improving this transportation towards achieving a better product as a result. This will happen only when the approach moves from mere adaptations to a new and specific concept for the vehicle.

Take, for example, an accident with 30 fatalities, based on field research information, the number of people affected becomes more like at least 105 (30 cutters directly, and 75 relatives indirectly), the real number to be taken into consideration in terms of damages. This constitutes not only an enormous social problem for the families of the victims, compensation claims and legal work for the companies, and an impact on national social security payment, but most importantly, damage to society as a whole. This hypothesis can thus be confirmed.

Hypothesis 2: 'It is suggested that the current vehicles do not meet the specifications that both workers and sugar cane companies need.'

One of most important findings of the research is that rather being just a vehicle, the urban buses are currently recognised by the cutters as a mobile facility centre. The vehicle's status as a shelter, shed and workshop on the plantation is thus confirmed. Apart from the inadequacy of many of the current adaptations in the vehicle as part of these facilities, both the field research sessions and the analysis of shock, vibration and movement, confirmed that the inappropriateness of the vehicle for off-road use, combined with the conditions of the terrain, compromises the cutters' health, comfort and welfare in this transportation context. Despite the evidences from the field research, this is also supported by references such as Griffin (1996 and 1998), Machado et al. (1997), Pastore et al. (1986), Tensche, K. et al. (1999) and Zamberlan et al. (1988).

Furthermore, it was found that the sugar cane companies themselves are not satisfied with their investment in vehicle adaptations, and are more interested in acquiring more appropriate vehicles for the transportation of their workers. This, then, constitutes a clear signal that the industry has already begun to understand the importance and benefits of improvements in this transportation, for both the cutters and the company. The proof of this is the fact that in 2007 a group of six sugar cane companies from Sao Paulo State in Brazil decided to move further than their involvement with the field research in this study, and formalize their financial support for the production of the prototype of the vehicle proposed in this research. This is also supported by references such as Beleboni (2006), Damada (2007), Ribeiro (2006) and Sacomani (2007). This hypothesis therefore, is largely supported, and Objective 3 is fulfilled, confirming that it is definitely possible to offer the cutters a better transport experience.

Hypothesis 3: 'It is suggested that the truck-based platform is inadequate to this transportation, and that as well the current combination of a platform and a body produced by different manufacturers for different purposes is even more inadequate.'

Putting aside the unquestionable importance of the body of vehicle as the cell for accommodating users, this research confirms the significant influence of the platform of the vehicle in the transportation process, in particular in off-road conditions. This observation led the research to conclude that even a supposedly high quality platform can be harmful and compromising to workers' health, comfort and welfare if the right combination of elements in real transportation needs were missed or neglected. This is supported by references such as Costa Neto (2006), Maclaurin (2006 and 2007) and Perseguim (2005).

The literature review confirmed that the range of frequency (from 5 to 25Hz) within which a diesel engine operates, in conjunction with the flexibility of the truck ladder chassis, can be very harmful indeed to the cutters. Also, the truck multi-leaf spring suspension type of the platform, combined with the physical characteristics of the body of the bus, can be very risky in off-road conditions. This is supported by references such as Griffin (1996 and 1998), Stayner (2001) and Zamberlan (1988). This hypothesis is thus also upheld, and Objective 2 is fulfilled, confirming that it is possible to improve the cutters' health, safety, welfare and consequently their everyday life.

**Hypothesis 4: 'It is suggested that a better-performing vehicle in off-road conditions increases mobility, ensuring at the same time a better ride, a reduction in travel times and most importantly a reduction in the number of accidents.'**

By studying off-road transportation and conducting an analysis of terrain, it becomes clear that the level of motion resistance exerted on a vehicle operating in off-road conditions is much higher than the level experienced by vehicles on paved roads, and most importantly, different designs would be necessary to deal with different types of soil, in order to maximize the vehicle's performance. As these conditions are directly connected with the vibration absorption capacity and the dynamics of the vehicle, this ends up seriously compromising safety. Thus, as 50% of the cutters' transportation takes place in off-road conditions, this constitutes an important issue to be tackled in terms of accidents involving this type of vehicle and transportation. This is supported by references such as Maclaurin (2007 and 2008), Popov et al. (2003) and Viviani (1998).

A better-performing vehicle would be able to reduce the number of times in which the vehicle is immobilised in mud following the frequent rainfalls. It would consequently reduce journey interruptions, not only allowing the cutters to arrive at their destination on time, but also reducing their travelling time. In addition, it would save the companies money, by helping to minimize the effect of rainy days on harvest and production levels. This is supported by references such as Antunes Jr. (2007), Damada (2007), Maclaurin (2006 and 2007) and Ribeiro (2006). This hypothesis is therefore confirmed, as well as fulfilling Objective 4, showing that it is possible to reduce transportation costs.

If we consider that the current conditions of the transportation of sugar cane cutters in Brazil are directly associated with the success of the country's agribusiness, in particular the sugar cane sector, both the sugar cane companies and the government must embrace this transportation issue by adopting improvements and solutions. If the current vehicle does not perform well for this task, again the fault is not with the manufacturers or the legislation but due to the lack of a research approach capable of offering a more substantial informational background, and consequently proposing the right design specifications and solutions for a more appropriate vehicle. As this research shows, neither current manufacturing methods nor legislation have led to a desirable solution. Therefore, despite the fact that the current adapted urban bus used for the transportation of cutters undoubtedly represents a huge advance in this area compared with the previous means of transportation, it is still not an appropriate vehicle for the task required of it.

Hypothesis 5: **'It is suggested that land transportation, using a bus-type vehicle, remain the only viable option that should be explored for this transportation.'**

By analysing different alternatives of transportation, it is clear that the natural solution would be paving unpaved roads. However, the comparative cost analysis revealed that although building a proper paved road, or even a railway system, are options, they are not economically or technically viable solutions. This can be supported by references such as Beenhakker (1993), Barbieri (2006), James & Ruhle (2006), Kawamoto (1993), Macedo (2006), Queiroz (2006), Salgado (2006) and World Bank (1981). In addition, the use of an aircraft (helicopter) was also considered, as this would seem to solve the problem effectively, but the cost is also prohibitive, putting this solution out of question. This is supported by references such as Boeing (2006), British Army (2006) and US Army (2006). Therefore, the present research confirms the development of a more appropriate and specifically designed vehicle for the transportation of sugar cane workers as the most suitable solution for the task.

Hypothesis 6: 'It is believed that a holistic analysis is needed involving all stakeholders but with focus on the users' needs.'

A review of off-road vehicles currently available on the market, an analysis of the prevailing terrain types and a study of the effects of the journeys on the users have expanded this research. This research confirmed that the involvement of specific knowledge from different fields, such as soil mechanics and vibration, was crucial for the design solutions. This multidisciplinary nature of this work has been emphasised by the approach adopted, which analyses the problem in its legal, social, technical, economic and environmental aspects.

The research approach which was confirmed as appropriate and relevant to the conceptualisation of this particular problem focused on observation, compilation and intervention. The basic idea was to establish a strong connection with the users' context, to be able not only to identify and discuss the problems, but most importantly, to present design solutions which could be implemented. The films of the cutters, made during the ethnographic sessions of the field research, proved to be a good way of establishing such a connection with the transportation situation question, contributing considerably to this investigation, particularly during the open conversations. The three-part structure of this research – the user, the vehicle and the terrain – proved to be fruitful, establishing a triangular communication between the three, allowing the investigation to see, understand and present the problem in a different way, fusing design and research in one single piece of work.

Generating more appropriate vehicle design solutions and specifications, rather than improving the vehicle as just a means of locomotion, would improve the vehicle's usefulness as a mobile facility centre for the cutters. Among other things, a more dynamically balanced vehicle would provide more stability and controllability, which means better safety. A vehicle capable of dealing with rough terrain or mud more effectively would reduce travel times, which means time saved. A vehicle with an appropriate interior layout and ambience would provide a homely atmosphere for the cutters, leading to a more comfortable experience. This hypothesis is therefore supported.

Hypothesis 7: 'It is believed that a more appropriate vehicle designed for this purpose will improve not only the workers' everyday life, but also the sugar cane industry as well.'

The documentation and analysis of a range of different aspects allowed me to argue that a new vehicle type is required for this kind of transportation. Among other things, it was possible to confirm not only that the consideration of the platform of this vehicle can make a difference in terms of locomotion, but also that it is a determining factor in the success of the industry as well.

Being unable to fulfil all the expectations imposed upon the current urban buses in comparison with the trucks they replace, on one hand they have slightly frustrated the objectives of the government, failing to ensure safer and healthier transportation for rural workers. On the other hand, they have frustrated the expectations of the agricultural companies regarding a good cost-benefit relationship to the financial investment. According to the agricultural companies, the adaptations and modifications necessary for the vehicles in order to comply with the NR-31 make the cost-benefit even worse. This is because at the end of the day the vehicle still remains a simple adapted vehicle, costing 20% more, and because a vehicle designed specifically for this purpose does not exist. Although the move to transport sugar cane workers in buses, rather than adapted trucks, was forced by the challenge of complying with the NR-31, the field research demonstrated that the replacement of the trucks with urban buses clearly presented additional benefits to the sugar cane industry through an improvement in the cutters' production levels over the last 15 years.

It was observed that a single message was coming from all stakeholders: for this kind of transportation the vehicle must be designed as an integrated product. Thus it has to bring together the right dynamic and shock absorption capabilities for the chassis and the right human-interface concept for the body, combining design and engineering. Throughout this thesis I have investigated the integration of the areas above towards better design solutions. How is it possible to achieve this combination of cultural and technological knowledge in order to improve everyday life through design innovation? Part of the answer is because there is a wide gap between the 'expectation' of the buyers (the sugar cane companies), who barely understand the needs of the users and the 'needs' of the users (the rural workers) who rely on the vehicle as a means of transportation as well as a source of support on the plantations. For this reason, in order to fulfil the objectives, support the hypotheses and answer the research question, the present thesis proposes not just a list of recommendations, but also a range of solutions.

Hypotheses 6 and 7 can be seen to be supported by Hypotheses 1 to 5, and Objectives 1 and 5 are fulfilled, thus confirming that it is possible to improve the transportation of people in off-road conditions by way of appropriate vehicle design solutions, increasing agricultural production at the same time. However, it is important to state that if the best way to test and prove these hypotheses is through a prototype, which is outside the scope of this research, both hypotheses 6 and 7 might be considered as a provisional.

Finally, the undertaking of this research offered me opportunity to present own interpretation of the problem that has been investigated. During the development of the studies, it was possible to present my work on many different occasions, ranging from tutorials to presentations at conferences, lectures and exams. This of course has made the research stronger. However, as with any research, this project will lead not only to a continuation, but most importantly it will thereby move the investigated problem steps ahead. Therefore, I sincerely hope that this investigation is a possible answer to the issue discussed, as it will improve considerably the workers' conditions. It may well be a useful reference, not only for the establishment of new technical specifications and company policy, but also as a basis for new regulations, not only in Brazil, but worldwide.

## 8.1 Recommendations

Based on the results of this research, with the intention of improving of rural workers' transportation, all the stakeholders should consider my recommendations, as follows:

### 8.1.1 The Automotive Industry

- **Designing and developing the vehicle:** although the bus industry is far more flexible in terms of product development compared to the car industry, paradoxically it is not paying as much attention to new opportunities and the creation of market niches as it should be. Thus I recommend that this industry combines the current IPPD (the Integrated Product Process Development model) with the BLUM (the Buyer, Legislator, User and Manufacturer model) in order to establish a real man-machine system design.

- **Defining a design language:** the design solutions presented in this study should be considered as a starting point for a new design language, not only for the vehicle for the transportation of sugar cane cutters, but also for agricultural vehicles generally.

- **Developing a more holistic view:** as the meaning of the vehicle transporting cutters is quite different in each of the contexts involved in this study, the bus industry must not only understand this concept, but also be able to reconcile these meanings, positioning the vehicle beyond a mere means of transportation.

- **Using ergonomic principles:** as a bus-type vehicle is basically designed and manufactured to serve people, the bus industry must review its ergonomic / anthropometric approach, incorporating principles of usability in the design solutions of their products. This can be achieved by combining the methods of investigation used in this research, based on ethnographic and user-experience studies, and design based on an inside-out approach. Therefore, as the behaviour of vehicle users, sugar cane cutters in particular, is not linear and predictable, I recommend that the bus industry adopts a descriptive ergonomic model, instead of a normative one.

- **Manufacturing the vehicle:** as the development of the vehicle which is the subject of this research not only focuses on an improvement in quality, but is also based on new attributes improving a conventional product, the bus industry should base its manufacturing strategy on two different principles: 'Sustainable Innovation' and 'Disruptive Technology'.

- **Defining a mechanical concept:** the chassis and the body of the bus are usually considered as independent and separate systems, but I strongly recommend that the bus industry rethink this approach, whether or not the vehicle is equipped with a chassis supplied by a manufacturer from another industry. Otherwise, this would present an insurmountable obstacle to considering, designing and manufacturing the vehicle as an integral product.

- **Using production resources:** because the bus industry adopts a less progressive strategy than the car industry in relation to material and process exploration, it ends up by not exploring the full possibilities of this field. Therefore, due to the necessary level of flexibility in product development and production, the bus industry should invest more extensively in resources for the exploration of existing materials and processes for its needs.

- **Researching vehicle design:** research in vehicle design is still at an early stage of development, and consequently the automotive industry has little experience of design research. As the previous experiences of some manufacturers as far as adaptations are concerned have not been based on research, the bus industry as well as the automotive industry, as a whole, should be supported by research such as this project.

- **Improving the business model:** lastly, instead of merging or acquiring a competitor as a solution to sharing components, parts and technology, the automotive industry should open up new avenues in starting to fully explore the use of off-the-shelf components and parts produced by other types of industry. A similar approach has already been successfully taken in other industries: for example, Apple Computer Inc., and its 'design chain' model, but not by the automotive industry. This model would ensure a massive reduction in investment in this industry and consequently the opportunity to serve market niches as yet unexplored, due to both high costs and lack of flexibility in terms of product development and production.

### 8.1.2 The Sugar Cane Industry

- **Showing an example:** the sugar cane industry in Brazil is the best in the world in terms of production and technology, acting as a reference point for the other producing countries. This means that this sector must also being seen as a reference in terms of environmental, social and, most importantly, labour practices. With this international profile, any level of improvement inevitably ends up being viewed and considered by others. For this reason, as a leading player in the agricultural arena, particularly in the context of sugar cane production, the Brazilian industry must show an example, and take responsibility for promoting the importance of the transportation of workers to a level more compatible with its high level of production and technology.

- **Combining improvements and benefits:** the sugar industry should adopt the recommendations of this research, for several reasons: reduction of fuel consumption through more efficient travel and less immobilization of the vehicle, even on rainy days; reduction of cutters' fatigue during transportation, increasing production as a result; reduction in the number of accidents and consequently the amount of compensation and social damage.

- **Pushing technological boundaries:** lastly, the sugar cane industry in Brazil should lead and support the progress of development of a hybrid electric / ethanol engine, as it did in the late 1970s and early 1980s with diesel engines running on ethanol. An electric / ethanol engine would utilise well two abundant resources of energy associated with this industry.

### 8.1.3 The Government

- **Leading policy in sugar cane practices:** as there is a discrepancy between the technology and production and labour practices regarding the bio-fuel programme in Brazil, the government policy for the sector should include practices more compatible with the country's leading position in agribusiness.

- **Matching practices nationally:** the government should take on board many of the better practices and experiences in the sugar cane industry in Sao Paulo State, thus creating a national institutional mechanism to require that the same conditions apply in other States.

- **Investing in design research:** the government must continue to invest in studies like this in order to create a local research resource based on technical and scientific studies capable of improving the working conditions in the country's agribusiness, as well as starting to create a proper literature in this field, also provide a global research basis.

- **Improving legislation though design research:** despite the fact that legislative power could rapidly change the context of this transportation, the lack of research and technical work in this field have compromised the legislators' work when they have tried to update or create new regulations. On account of this, Regulation NR-31 was not based on any previous research. Therefore the government, through its Labour Ministry and general attorneys, should aim to update and create new, more specific, regulations, based on design solutions and technical specifications proposed by research such as this one.

- **Thinking outside the box:** Lastly, instead of only investing in new paved roads in agricultural areas, the government should allocate funding for roads into incentives and support for the development of more appropriate vehicles capable to operate successfully in off-road conditions and specifically designed for the transportation of rural populations.

## 8.2 Suggestions for Further Research

Taking into account the fact that the construction of a prototype will be the next step, after the conclusion of this research, the first stage would naturally be to carry out research for testing, proving or disproving the hypothesis regarding the design solutions presented in this study. This might be achieved by a continued collaboration between design and engineering. An experimental user-experience approach to vehicle design might help to resolve some of the problematic subtleties of performance and design.

This study has raised interesting questions about the ways in which a specific transportation activity as part of a non-European work activity context might use a vehicle to commute to and from sugar cane fields. The fact that the person who buys the product is not the same person who uses the vehicle resulted in the need for a new method and approach. In this sense, there is much to be gained from observing, documenting and even participating in its development. Thus I suggest that new studies in this direction might be useful for the automotive industry as a whole.

There is also scope to develop new projects which are designed to explore specific aspects of ergonomics that combine technical and social issues. However, it would be advisable to try to make projects as small and self-contained as possible, as they inevitably end up dealing with large amounts of data in order to establish and communicate ideas and arguments.

Finally, I would like to finish this study by raising one more question: What is design? As a multidisciplinary creative activity, it could be answered in different ways, as many authors have already done. However, in looking for the best definition that truly reflects what has been proposed and defended in this research, I suggest that design is the search for ways to achieve the best solutions for a group of real-life needs in the light of a given set of circumstances.

## REFERENCES


Afelor, R.M. & McNeil, S. (1989) 'Method for Determining Optimal Blading Frequency of Unpaved Roads', *in: Transportation Research Record*, Washington DC.

Antunes Jr., N. (2007) *Interview about the Transportation of Rural Workers*, Lencóis Paulista: GVAgro.

Barbieri, A.C. (2006) *Interview about trains and railways project*, Bauru: UNESP – Sao Paulo State University, 14, 21 and 31 Aug 2006.

Barduco, R. (2006) *Interview about urban buses*, Botucatu: Induscar-Caio, 31 Oct and 18 Dec 2006.

Barrios, J.M. (2005) *New Concept for a Three-point Seat Belt and Child Restraint system for Buses* [online], available from:
http://www.testing-expo.com/europe/05txeu_conf/pres/crash/barrios.pdf
[Accessed 15 Oct 2007]

Beenhakker, H.L. (1983) *Economic Appraisal of Rural Roads: Simplified Operational Procedures for Screening and Appraisal*, Washington D.C.: The World Bank.

Bekker, M.G. (1960) *Off-the-Road Locomotion*, [s.l.]: University of Michigan.

Beleboni, J. (2006) *Interview about agricultural transportation and mechanisation*, Bauru: interviewee's home, 16 Jul 2006.

Bertelsen, W. (1986) *Progress Report on Bertelsen Research and Development of an Air Cushion Crawler All-Terrain Vehicle* in: Canadian International Conference on Air Cushion Technology, Toronto: Canadian Aeronautics and Space Journal.

Boeing, (2006) *CH-47 Chinook Helicopter* [online], Seatle: available from:
http://www.boeing.com/rotorcraft/military/ch47d/
[Accessed 21 September 2006]

British Army, (2006) *CH-47 Chinook Helicopter* [online], London: available from:
http://www.army-technology.com/projects/chinook/
[Accessed 21 September 2006]

Bunsha, D. (2002) Machines that Mow Down Migrants: The Arrival of Imported Cane-harvesting Machines in sugarcane Fields may Push Migrant Cane Cutters Deeper Bondage, [online], available from:
http://www.asiana-press-agency.com/articles/2002-bunsha-0215.html
[Accessed 9 March 2008]

Bürdek, B.E. (1994) *Diseño. Historia, Teoría y Práctica del Diseño Industrial*, Barcelona: Gustavo Gilli.

Camara, J.J.D. et al. (2001) 'Ergonomia no Design Automotivo: A Seleção de Materiais como Paradigma na Segurança Automotiva', *in: Abergo 2001*, Gramado RS Brazil.

Castendijk, W. (Wcastendijk@cs.com), (08 April 2005) RE: Hovercraft, E-mail to O.V. Rodrigues (osmar.rodrigues@rca.ac.uk).

Chetthamroungchai, P. et al. (2001) 'Assessing the Transportation Problems of the Sugar Cane Industry in Thailand', in: *Communications Bulletin for Asia and the Pacific.*

Costa Neto, A. (2006) *Interview about vehicle dynamics*, Sao Carlos: USP – Sao Paulo University, 16 Aug 2006.

Crossley, C.P. (1987) 'The Application of a Computer Program to the Analysis of Sugar Cane Transport – a Case Study', in: *Journal of Agricultural Engineering Research* , 36, 17-30.

Damada, C.A. (2007) *Interview about the Transportation of Rural Workers*, Sao Manuel: Sao Manoel mill.

De Old A.R. et al. (1986) *Transportation: The Technology of Moving People and Products*, Worchester MA: Davis Publications.

Dreyfuss, H. (1955) *Designing for People*, New York: Simon and Schuster.

English, A. (2005) Can Your X5 Do This?, *Telegraph Motoring*, 5 March, 1

Evans, D. & Grubba, P. (2007) *How to Write a Better Thesis*, Melbourne: Melbourne University Press.

FAO (2003) *Fertilizer by Crop in Brazil* [online], available from:
http://www.fao.org/docrep/007/y5376e/y5376e06.htm
[Accessed 15 May 2008]

FAO (2007) *Agricultural area / population [online], forestry Compendium Statistics* – Volume 1, available from:
http://www.fao.org/DOCREP/X2613E/x2613e0i.htm#TopOfPage
[Accessed 21 March 2007]

Fenton, J. (1999) *Advances in Vehicle Design*, London: Professional Engineering Publishing.

Ferreira, A.A. (1992) *Interview about the Transportation of Rural Workers*, Sertaozinho: Interviewee's home.

French, T. (1989) *Tyre Technology*, Bristol: Adam Hilger.

Fundacentro [s.d.] *Seguranca e Saúde em Transporte de Trabalhadores Rurais*, [s.l.]: Fundacentro, available from:
http://www.fundacentro.gov.br/CTN/p2s5.PDF
[Accessed 10 Aug 2007]

Fundacentro (2005) *Encontro dos Trabalhadores Canavieiros da Regiao Nordeste – Organizacao do Trabalho e Controle da Producao, Acidentes e Doencas, Migração e Transporte, Terra e Moradia*, Igarassu: Fundacentro, available from: http://www.fundacentro.gov.br/CTN/teses_pdf/NORDESTE%20_%20FINAL.pdf [Accessed 10 Aug 2007]

Garcia, R.W. (2006) *A Falta de Fiscalização, a Falta de Seguranca e a Ocorrência de Graves Acidentes com Trabalhadores Rurais no Interior de São Paulo é Alvo de Investigação e Atuação do Ministério Público do Trabalho (MPT)*, [online], available from:
http://www.sucre-ethique.org/MPT-exige-melhorias-nas-condicoes
[Accessed 18 April 2008]

Gencat (2007) *Accidents* [online], [s.l.]: available from:
http:www.gencat.net/mediamb/eng/EA/mobilitat/modelpocsostenible/accidentalitat.htm
[Accessed 12 August 2007]

Goedert, J. (2007) (jean_goedert@busscar.com.br), (19 Dec 2007) RE: Ar Condicionado, E-mail to O. Rodrigues (osmar.rodrigues@rca.ac.uk).

Griffin, M. J. (1996) *Handbook of Human Vibration*, Academic Press, U.S., 988 p.

Griffin, M. J. (1998) 'A Comparison of Standardized Methods for Predicting the Hazard of Whole-Body Vibration and Repeated Shocks', in: *Journal of Sound and Vibration*, 215(4), 883-914.

Happian-Smith, J. (2002) *An Introduction to Modern Vehicle Design*, Oxford: Butterworth-Heinemann.

Hayes, M.H.B. (2007) No Need for Gloom if We Pick the Right Biofuel Crops, *The Independent*, Letters to the Editor, 6 March, 1.

Hodkinson, R. & Fenton, J. (2001) *Lightweight Electric/hybrid Vehicle Design*, Oxford: Butterworth-Heinemann.

Hunnicut, R.P. (2002) *Armoured Car: History of American Wheeled Combat Vehicles*, Novato CA: Presidio. 340 p.

Idea News (2004) O Novo Eldorado Canavieiro, n° 5 (Feb.) p.5

ISO Standard 2631 (1997) *Mechanical Vibration and Shock – Evaluation of Human Exposure to Whole Body Vibration*, Geneva: ISO.

Jacobs, W. (hoverhire@supalife.com), (21 April 2005) RE: Hovercraft Questions!, E-mail to O.V. Rodrigues (osmar.rodrigues@rca.ac.uk).

James, R. & Ruhle, D. (2006) *The Development of Resilient Fastening for the Plantation Railways of the Australian Sugar Industry* [online], available from:
http://www.pandrol.com/estudies/c34_bdy.htm
[Accessed 06 December 2006]

Kawamoto, E. (1993) *Análise de Sistemas de Transporte*, Escola de Engenharia de São Carlos da Universidade de São Paulo.

Queiroz, R. (2006) *Interview about trains and railways project*, Bauru: UNESP - Sao Paulo State University, 14, 21 and 31 Aug 2006.

Kunur. M. & Gheerawo, (2007) *Connections: Mobility, Ageing and Independent Living*, London: Royal College of Art.

Larica, N. J. (2003) *Design de Transportes: Arte em Função da Mobilidade*, Rio de Janeiro: 2AB and PUC-Rio.

Lebo, J. & Schelling, D. (2001) 'Design of Rural Transport Infrasctruture', in: *Rural Travel and Transport Program 2001*, 2001 Washington: World Bank. 13 p.
Macedo, S. (2006) *Interview about paved roads project*, Bauru: Interviewee's home, 07 and 15 Aug 2006.

Macedo, S. (2006) *Interview about paved roads project*, Bauru: Interviewee's home, 07 and 15 Aug 2006.

Machado et al. (1997) 'Rodovias Municipais Não Pavimentadas - Rodovias Vicinais: Metodologia para Priorização de Investimentos em Melhoramentos', in: *Simpósio Internacional de Pavimentação de Rodovias de Baixo Volume de Trafego*, Rio de Janeiro.

Maclaurin, B. (2008) *Tutorial about weight distribution*, London: Royal College of Art, 20 Oct 2008.

Maclaurin, B. (2008) *Tutorial about gar turbine engines*, London: Royal College of Art, 07 Jul 2008.

Maclaurin, B. (2008) *Tutorial about CTI and Tyre Deflection*, London: Royal College of Art, 06 Feb 2008.

Maclaurin, B. (2007) *Tutorial about suspension and dynamics*, London: Royal College of Art, 09 May 2007.

Maclaurin, B. (2006) *Tutorial about suspension and dynamics*, London: Royal College of Art, 13 Dec 2006.

Maclaurin, B. (2006) *Tutorial about suspension and dynamics*, London: Royal College of Art, 02 Jun 2006.

Maturana, J.F.R. (2007) *Interview about the legislation behind the rural worker transportation*, Bauru: Procuradoria Regional do Trabalho, 13 Mar 2007.

Mazza, J.A. (2004) *Atributos dos Solos Relacionados ao seu Potencial Produtivo*, Piracicaba: Escola Superior de Agricultura da Universidade de São Paulo.

Ministerio dos Transportes (2000) *Anuário Estatístico 2000* [online], Brasília: Brazilian Government , available from:
http://www.transportes.gov.uk
[Accessed 3 May 2005]

National Farmers' Federation (2008) *Farm facts: Australian Farmers – Punching above their Weight...* [online], Barton Act: NFF, available from:
http://www.nff.org.au/farm-facts.html?hilite sugar+cane+workers
[Accessed 5 March 2008]

Oxford Dictionary (2008) *AskOxford* [online], Oxford: Oxford University Press, available from:
http://www.askoxford.com/?view uk
[Accessed 7 May 2008]

Pastore, E.L. et al. (1986) 'Contribution to the Studies of Surfacing Earth Roads in São Paulo State, Brazil', in: *International IAEG Congress*, Buenos Aires.

Pastore, E.F. (1997) 'Estudos para o Planejamento da Conservação de Estradas de Terra do Município e de Usinas de Açúcar e Álcool de São Joaquim da Barra, Estado de São Paulo', *in: Simpósio Internacional de Pavimentação de Rodovias de Baixo Volume de Trafego,* Rio de janeiro.

Peacock, B. & Karwowski, W. (1993) *Automotive Ergonomics*, London: Taylor & Francis.

Perseguim, O.T. (2005) *Dinamica Veicular Relativa ao "Ride" de Veículos e Métricas para sua Avaliação*, Thesis (PhD), Escola de Engenharia de São Carlos da Universidade de São Paulo. 220 p.

Phillips, E.M. (2005) *How to Get a PhD*, Berkshire UK: McGraw Hill.

Popov, A.A. et al. (2003) Laboratory Measurement of Rolling Resistance in Truck Tyres under Dynamic Vertical Load, in: *Journal of Automotive Engineering*, 217(12), 1071-1079.

Queiroz, R. (2006) *Interview about trains and railways project*, Bauru: UNESP – Sao Paulo State University, 14, 21 and 31 Aug 2006.

Raijmakers, S.W.JJ (2007) *Design Documentaries: Using Documentary Film to Inspire Design*, London: RCA

Ribeiro, L.D. (2006) *Interview about the Transportation of Rural Workers*, Olímpia: Guarani mill.

Rios, M. (2007) Transporte de Pessoal Moderniza-se, *Jornal da Cana*, August, 5-8.

Ripoli, T.C.C. (2008) (ccripoli@esalq.usp.br), (18 Mar 2008) RE: Transporte de Trabalhadores Rurais, E-mail to O. Rodrigues (osmar.rodrigues@rca.ac.uk)

Rodrigues, O.V. (1992) *Anthropometric Analysis of Rural Workers in Sao Paulo State*, Bauru: Unesp.

Rodrigues, O.V. (1993) *O Problema do Transporte de Trabalhadores Rurais: Análise e Proposta de Solução*, Florianópolis: UFSC.

Rodrigues, V.L.G.S. (1985) *Acidentes de Trabalho e Modernização da Agricultura Brasileira*, Campinas: Unicamp.

Rumsay, J. & Wheatley, J. (2008) *Práticas Ambientais e Trabalhalistas Condenáveis Maculam a Indústria do Etanol no Brasil* [online], available from: http://noticias.uol.com.br/midiaglobal/fintimes/2008/05/21/ult579u2465.jhtm [Accessed 21 May 2008]

Sacomani A.C.R. (2007) *Interview about bus manufacturing for rural workers transportation*, Botucatu: Induscar, 05 Feb. 2007.

Salgado, H.M. (2006) *Interview about investment amortising costs*, Bauru: UNESP – Sao Paulo State University, 07 Aug 2006.

Samanez, C.P. (2001) Matemática Financeira – Aplicações a Análise de Investimentos, São Paulo: Prentice Hall.

Santos, A.P. (2004) *Ergonomia dos Onibus Urbanos – Estudo de Caso da Cidade de Santos SP*, Dissertation, Centro de Ciências Exatas e de Tecnologia da Universidade Federal de Sao Carlos

Stamford, F. (frank.stamford@bigpond.com), (9 March 2008) RE: Rural Workers Transportation, E-mail to O.V. Rodrigues (ovrodrigues@hotmail.com)

Stayner, R. M. (2001) *Whole-body Vibration and Shock: A Literature Review*; Research Report 333, Ludlow UK: RMS Vibration Test Laboratory

Simon, H. (1969) *The Sciences of the Artificial*, Cambridge MA: MIT Press.

Tenschke, K. *et al.* (1999) *Whole Body Vibration and back Disorders Among Motor Vehicle Drivers and Heavy Equipment Operators*, Report to Workers' Compensation Board of British Columbia, Vancouver: Department of Health Care and Epidemiology and Occupational Hygiene Program of University of British Columbia.

The British Royal Air Force, (2006) *CH-47 Chinook Helicopter* [online], London: available from:
http://www.army-technology.com/projects/chinook/
[Accessed 21 September 2006]

The Economist (2007) Fuel for Friendship, *The Economist*, 3 March, 3.

The Economist (2007) Dreaming of Glory: A Special Report on Brazil, *The Economist*, 14 April, 16.

US Army, (2006) *CH-47 Chinook Helicopter* [online], Company H, 4th Battalion, 7th Aviation Regiment: available from:
www.chinook-helicopter.com
[Accessed 20 September 2006]

Viviani, E. (1998) *A Utilização de um Sistema de Informação Geográfica como Auxílio a Gerencia de Manutencao de Estradas Rurais Não-pavimentadas*, Thesis (PhD), Escola de Engenharia de São Carlos da Universidade de São Paulo.

Westwood, R. (roddz@iprimus.com.au), (07 April 2005) RE: Hovercraft, E-mail to O.V. Rodrigues (osmar.rodrigues@rca.ac.uk).

World Bank (1981) *The Road Maintenance Problem and International Assistance*, [s.l.]: World Bank.

Zamberlan, M.C.P.I. et al. (1988) *Avaliação ergonômica de tratores agrícolas.* Rio de Janeiro: INT.

# Agrivehicle: Design for the Vehicle Transporting Sugar Cane Cutters

Osmar V. Rodrigues

## Appendices

September 2008

Royal College of Art
Postgraduate Art & Design

Sponsored by CNPq
Conselho Nacional de Desenvolvimento
Científico e Tecnológico

# CONTENTS

# 1 – SUGAR CANE COMPANIES INVOLVED

2005

Company: Quata

Tel: 00 55 18 33661221

Venue: Quata SP

Contact: Osvaldo Resende

Date of research: 25/08/2005

2006

Company: Tecnocana

Tel: 00 55 14 32681533

Venue: Borebi SP and Macatuba SP, respectively

Contact: Fabio Alves / Dito Camilo

Date of research: 17/08/2006 – 03/09/2006

Company: Guarani

Tel: 00 55 17 32801000

Venue: Olimpia SP

Contact: Jose Donizete Ribeiro / Ademar

Date of research: 30/08/2006

2007

Company: Agricana

Tel: 00 55 14 32681927

Venue: Agudos SP and Macatuba SP

Contact: Erica Martins / Alessandro

Number of buses: 5

Number of rural cutters: 250

Date of research: 16/01/2007 and 16/02/2007

Company: Centro Empresarial Agricola

Tel: 00 55 14 32691600

Venue: Lencois Paulista SP

Contact: Nelson Antunes

Number of buses: 14

Number of rural cutters: 600

Date of research: 17/01/2007

Company: Tecnocana

Tel: 00 55 14 32681533

Venue: Borebi SP

Contact: Fabio Alves / Dito Camilo

Number of buses: 11

Number of rural cutters: 450

Date of research: 23/01/2007

## 2 - INTERVIEWS

2005

Jualino Beleboni – Usina Santa Cândida – Bocaina – SP (agriculture)

Warwick Jacobs – (Hovercraft Museum) – Gosport – UK

Wouter Castendijk – (Hoverholic) – The Netherlands and

Rodd Westwood – (Victorian Hovercraft Club) – Torquay Victoria – Australia

Allan Jonas – Vehicle Safety Standards (ATRS) – Camberra – Australia

William Handke – Corporate Governance (DAFF) – Barton – Australia

Christopher Baker – Australian Greenhouse Office (DEH) – Adelaide – Australia

2006

Dr. Peter Crossley – Cranfield University – Silsoe, Bedfordshire – UK (soil)

Dr. Dick Godwin – Cranfield University – Silsoe, Bedfordshire – UK (soil)

Dr. Rubismar Stolf – Universidade de Sao Carlos – Sao Carlos – SP (soil)

Osvaldo Resende – Companhia Agricola Quata – Quata – SP (cutters)

Leandro Sanches Ferreira – UDOP – Aracatuba – SP (sugar cane company)

2007

Marcelo Castilho – Busscar

Roberto Barduco – Induscar (recorded)

Antonio Sacomani – Induscar (recorded)

Abimael Parejo - Irizar

Dr. Rudney Queiroz – Unesp (railways)

Dra. Eliane Viviani – Unesp (unpaved roads)

Professor Antonio Carlos Barbieri – Unesp (railways)

Professor Sergio Macedo – Unesp (paved roads)

Dr. Henrique Salgado – Unesp (statistics)

Dr. Álvaro Costa Neto – USP (vehicle dynamics) (recorded)

Juliano Beleboni – Usina Santa Cândida – Bocaina SP (recorded)

Sergio Artioli – Tecnocana – Macatuba SP

Cláudio Sentinari – Agricana – Macatuba SP

Mario Nunes – Centro Empresarial Agrícola – Lençóis Paulista SP

Nelson Antunes – Centro Empresarial Agrícola

Lairton Brigido – Centro Empresarial Agrícola

Marcos Geraldi – Centro Empresarial Agrícola

Luis Capelari – Centro Empresarial Agrícola

Carlos Damada – Usina São Manoel – São Manuel SP (recorded)

Luiz Ribeiro – Usina Guarani – Olímpia SP

Valeria Sestini – Departamento de Estradas de Rodagem – DER – R. Preto SP

Heloisa Gomes - Departamento de Estradas de Rodagem – DER – R. Preto SP

Dr. Fernando Maturana – Procuradoria Regional do Trabalho – MPT – Bauru SP (recorded)

Bráz Albertini – Federação dos Trabalhadores da Agricultura do Estado de São Paulo – FETAESP – São Paulo SP (recorded)

# 3 - QUESTIONNAIRES

## 3.1 - Sugar Cane Cutters' Questionnaire

Royal College of Art

**PROJETO DE PESQUISA**
**"O TRANSPORTE DE PESSOAS EM TERRENOS IRREGULARES"**

(QUESTIONÁRIO DOS RURÍCOLAS)

**1-** Antes dos ônibus, o **transporte** dos trabalhadores era feito em **caminhões**. Você teve oportunidade de viajar neles?

(X) SIM ( ) NÃO

**2-** Quais os principais **problemas** dos **caminhões** que faziam esse transporte?

Faz tanto tempo, não lembro

**3-** Existe alguma coisa naqueles **caminhões** que você acha que era **melhor** do que nos ônibus de hoje?

Não

**4-** Quais as principais **vantagens** que você vê no **ônibus** para o transporte de trabalhadores?

Confortável

**5-** Você acha que existe alguma coisa no **ônibus** que poderia ser **melhorada** para o transporte de trabalhadores?

Não está mais confortável agora.

**6-** O que normalmente você mais **faz** durante a **viagem** da cidade até a lavoura?

(X) CONVERSA COM COLEGAS ( ) OLHA A PAISAGEM

(X) DORME ( ) JOGA

( ) LÊ ( ) OUTRO:

**7-** Qual a capacidade do **galão** de água que você **carrega**?

( ) 3 LITROS (X) 5 LITROS

**8-** Essa **quantidade** de **água** é suficiente para o dia todo?

(X) SIM ( ) NÃO. Regarrega ( ) UMA VEZ
( ) DUAS VEZES
( ) TRÊS VEZES

9- Onde você **recarrega** o **galão** quando precisa?

( ) NO ÔNIBUS ( ) OUTRO:

10- Você costuma **viajar** no ônibus com a própria **roupa** de trabalho?

(X) SIM ( ) NÃO

11- O que você normalmente **carrega** de casa para a **lavoura** com você?

(X) COMIDA ( ) ROUPAS

(X) GALÃO COM ÁGUA (X) EPIs

( ) LIMA ( ) OUTRO:

12- De todos esses, quais você costuma **carregar** em sua **mochila**?

(X) COMIDA ( ) ROUPAS

( ) GALÃO COM ÁGUA (X) EPIs

( ) LIMA ( ) OUTRO:

13- Você costuma **carregar** tudo isso com você pelo **canavial** ou deixa alguma coisa no ônibus?

( ) CARREGA TUDO (X) DEIXA NO ÔNIBUS menos Água

14- Você acha que **ter** a barraca sanitária como **banheiro** na lavoura é importante?

(X) SIM ( ) NÃO. POR QUE:

15- Quando você pára para **descansar**, você normalmente **senta-se** aonde?

(X) GALÃO COM ÁGUA (X) CHÃO As Vezes

16- Você prefere **descansar** por **tempos** menores parando mais vezes ou prefere parar menos e descansar por um tempo maior?

(X) PARAR MAIS VEZES ( ) PARAR MENOS VEZES

17- Você **gosta** da **viagem** até a lavoura por alguma razão ou é apenas uma necessidade para você?

(X) NÃO GOSTA necessidade ( ) GOSTA. POR QUE:

**18-** Você gostaria de ter menos **tempo** de viagem e poder **trabalhar** mais?

( ) SIM (X) NÃO

**Nome do trabalhador:** Marilizia

**Empresa:** Tecnocana

**Nome do entrevistador:** Marta Leite

**Local e data:** 23/01/07 - Agudo

3.2 - Drivers' Questionnaire

PROJETO DE PESQUISA
"O TRANSPORTE DE PESSOAS EM TERRENOS IRREGULARES"

(QUESTIONÁRIO DOS MOTORISTAS)

**1-** Antes dos ônibus, o **transporte** dos trabalhadores era feito em **caminhões**. Você teve oportunidade de dirigi-los?

(X) SIM ( ) NÃO

**2-** Quais os principais **problemas** que você via ao dirigir aqueles **caminhões**?

NUNCA TEVE PROBLEMA

8 anos c/ caminhão

**3-** Existe alguma **vantagem** em se dirigir aqueles **caminhões,** se comparado aos ônibus de hoje?

( ) SIM (X) NÃO
QUAL?

**4-** Quais as principais **vantagens** que você vê nos **ônibus** de hoje, para o transporte de trabalhadores?

MAIS CONFORTO

**5-** Você acha que existe alguma coisa no **ônibus** que poderia ser **melhorado** para esse tipo de transporte?

(X) SIM ( ) NÃO
QUAL?
BANHEIRO

**6-** Quais as **dificuldades** que você enfrenta com o ônibus em períodos de **chuva**?

( ) ELE ATOLA ( ) ELE PATINA

( ) ELE ENCALHA ( ) ELE PRECISA SER REBOCADO

(X) OUTROS: PARA NO CAMINHÃO PARA NÃO TER PROBLEMA

**7-** Quais as **dificuldades** que você enfrenta para entrar e sair das **lavouras**?

NÃO TEM

**8-** Quais as **dificuldades** que você enfrenta viajando pelos **carreadores** no meio das lavouras?

NÃO TEM DIFICULDADE PARA MONOBRAIL

**9-** Qual o tipo de **terreno** mais **difícil** para o ônibus, nas lavouras?

TERRA VERMELHA

**10-** Você acha que a **potência** do motor do ônibus é **adequada** para esse tipo de transporte?

(X) SIM ( ) NÃO. Deveria ser: ( ) MAIOR
( ) MENOR
POR QUE?

**11-** Você acha que o **torque** do motor do ônibus é **adequado** para esse tipo de transporte?

(X) SIM ( ) NÃO. Deveria ser: ( ) MAIOR
( ) MENOR
POR QUE?

**12-** Você acha que o **peso** do ônibus é **adequado** para esse tipo de transporte?

(X) SIM ( ) NÃO. Deveria ser: ( ) MAIOR
( ) MENOR
POR QUE?

**13-** O que você normalmente **carrega** de casa para a **lavoura** com você?

(X) COMIDA ( ) ROUPAS

(X) GALÃO COM ÁGUA ( ) EPIs

( ) LIMA (X) OUTRO: (CAFÉ)

**14-** De todos esses, quais você costuma **carregar** em sua **mochila**?

( ) COMIDA ( ) ROUPAS

( ) GALÃO COM ÁGUA ( ) EPIs

( ) LIMA ( ) OUTRO:

**15**- Você costuma **carregar** tudo isso com você pelo **canavial** ou deixa alguma coisa no ônibus?

( ) CARREGA TUDO (X) DEIXA NO ÔNIBUS

**16**- Você acha que **ter** a barraca sanitária como **banheiro** na lavoura é importante?

(X) SIM ( ) NÃO. POR QUE?

**17**- Com a nova exigência do uso dos **banheiros**, você acha que seria melhor se o ônibus pudesse já estar **equipado** com um?

(X) SIM ( ) NÃO. POR QUE?

**18**- A **turma** que viaja em seu **ônibus** é sempre a mesma?

(X) SIM ( ) NÃO. POR QUE?

**19**- Quando alguém se machuca, o **atendimento de emergência** na lavoura é prestado normalmente por que tipo de veículo?

( ) PRÓPRIO ÔNIBUS ( ) PICK UP

(X) CARRO ( ) OUTRO. QUAL:

**20**- Você acha que o ônibus funcionaria melhor se o **número de pessoas** transportadas fosse diferente?

( ) SIM (X) NÃO. Deveria ser: ( ) MAIOR
( ) MENOR
POR QUE?

É QUASE IGUAL, NÃO INFLUI

**21**- Se você pudesse mudar ou **melhorar** alguma coisa no **ônibus**, o que você mudaria ou melhoraria?

JÁ É O IDEAL

**Nome do motorista:** JOSÉ PEDRO DA SILVA

**Empresa:** Agricana

**Nome do entrevistador:** João Marcelo

**Local e data:** Macatuba - 16/01/2007

## 3.3 - Sugar Cane Companies' Questionnaire

Royal College of Art

PROJETO DE PESQUISA
"O TRANSPORTE DE PESSOAS EM TERRENOS IRREGULARES"

(QUESTIONÁRIO DAS EMPRESAS)

**01**- Qual o tamanho em hectares da **área cultivada** em sua empresa?
25.000 ha  2  2,3  2,7 MILHÕES TON.

**02**- A sua empresa produz e comercializa **energia elétrica**? 100% CONSUMO PRÓPRIO

( ) SIM  (X) NÃO

**03**- Qual o número de **rurícolas** em sua empresa?
1.660

**04**- Qual o número de **operadores** de máquinas, motoristas e tratoristas em sua empresa? 350

**05**- Qual o número de **ônibus** destinados ao transporte de todos os trabalhadores rurais em sua empresa? 8 ÔNIBUS 45 P.
22 CAMINHÕES 60 P. (TERCEIRIZADOS)

**06**- Em sua empresa é utilizado algum **outro tipo de veículo** (micro ônibus, por exemplo) para o transporte dos operadores de máquinas, tratoristas e motoristas?

(X) SIM  ( ) NÃO

**07**- Em caso positivo, qual o número de **micro ônibus** em sua empresa?
4 MICRO ÔNIBUS 20 P.  6 ÔNIBUS
19 KOMBIS 10 P.  3

**08**- Em sua empresa, a **equipe de rurícolas** mantém-se basicamente a mesma para cada ônibus?

(X) SIM  ( ) NÃO

**09**- Percentualmente falando, qual e o **tipo de terreno** por onde trafega o ônibus transportando os trabalhadores em sua empresa:

(20)% EM ESTRADAS PAVIMENTADAS  (70)% EM ESTRADAS DE TERRA

(10)% NOS CARREADORES  ( )% NAS PLANTAÇÕES

**10**- De acordo com a política da empresa, qual o **tempo de uso** dos ônibus na atividade até que sejam substituídos?
ÔNIBUS 10 ANOS
KOMBIS 5 ANOS

**11**- Em sua empresa, qual a menor e a maior **distância percorrida** pelos ônibus transportando trabalhadores do embarque até a lavoura?

MENOR DISTÂNCIA: 10Km MAIOR DISTÂNCIA: 35 Km

**12**- Em sua empresa, qual o menor e o maior **tempo de viagem** praticado pelos ônibus do embarque até a lavoura?

MENOR TEMPO: 45 min. MAIOR TEMPO: 190 min

**13**- Em sua empresa, no **atendimento de emergência** aos rurícolas na lavoura é prestado normalmente por que tipo de veiculo?:

( ) PRÓPRIO ONIBÜS (X) PICK UP

(X) CARRO ( ) OUTRO. QUAL: AMBULÂNCIA CASOS MAIORES

**14**- Em sua empresa, qual o percentual dos atendimentos no campo que exigem a **remoção do paciente** ao posto médico mais próximo?

25 P/ DIA SIO 13.400 PAROTI 19.900 GOL 45.000 SAN/SET/2000

**15**- Qual o **número de atendimentos** médicos no campo por mês em sua empresa?

( ) SEM REMOÇÃO DO PACIENTE 10 ( ) COM REMOÇÃO 25

**16**- Você considera o **peso do ônibus** demasiado (super dimensionado) para o transporte de rurícolas?

( ) SIM (X) NÃO PODERIA SER + ROBUSTO

**17**- Você considera o **tamanho do ônibus** adequado para a realidade de sua empresa?

( ) SIM (X) NÃO. Deveria ser: (X) MAIOR
( ) MENOR

**18**- Você considera o número de **pessoas transportadas** pelo ônibus adequado para a sua empresa?

( ) SIM (X) NÃO. Deveria ser: (X) MAIOR
( ) MENOR

**19**- Sua empresa observou alguma mudança significativa nos **hábitos dos trabalhadores** ao passarem a ser transportados pelos ônibus?

(X) SIM ( ) NÃO! ~~Tel. celular~~

**20**- Em caso positivo, você poderia citar alguma(s)?

USO DE CELULAR
HOMOSSEXUALISMO + VISÍVEL

**21**- Com a adoção dos ônibus para o transporte de ruricolas, qual o percentual de **redução de acidentes** envolvendo esse tipo de transporte, registrado por sua empresa?

**22**- Sua empresa já pensou em algum **uso alternativo** para o ônibus quando este não estivesse transportando os trabalhadores?

( ) SIM (X) NÃO

**23**- Em caso positivo, você poderia citar algum(s)?

**24**- Com a nova exigência referente ao uso de **banheiros**, você acredita que seria muito mais conveniente se o ônibus pudesse já estar equipado com um?

(X) SIM ( ) NÃO POR QUE?

NECESSITARIAM + DE 200 l DE RESERVATÓRIO
+ QUÍMICO + RESERVATÓRIOS = HIGIENIZAÇÃO

**25**- Qual é o **custo de manutenção** por quilômetro das estradas de terra e carreadores em sua empresa?

**26**- Seria mais conveniente para a sua empresa adquirir um **ônibus já equipado** com todos os acessórios exigidos pela legislação, tais como: toldo, barraca, compartimentos especiais etc?

(X) SIM ( ) NÃO

**27**- Em relação ao preço do veiculo, qual o percentual gasto por sua empresa com os **acessórios e adaptações** necessárias ao cumprimento das normas?

R$ 10.000

**28**- Qual o valor do **investimento em máquinas** e equipamentos para a construção e manutenção das estradas utilizadas pela empresa? 1 MOTONIVELADORA
1 TANQUE 2 ROLOS-COMPACTADORES

**29**- Qual o **custo mensal** (operacional e manutenção) dessa maquinaria destinada à construção e manutenção das estradas em sua empresa?

**30**- Sem considerar as normas e os muitos esforços empreendidos até o momento na melhoria no transporte dos trabalhadores rurais e, levando em consideração a realidade de sua empresa, você diria que o ônibus e mesmo o **veiculo mais adequado** para tal atividade?

( ) SIM ( ) NÃO POR QUE?

31- Em sua opinião, qual o **principal aspecto** nas normas que regulamentam o transporte de trabalhadores rurais que merece ser revisto ou melhor estudado?

ADOÇÃO DOS CORRIMÃOS

32- Você gostaria de receber uma cópia com os **resultados finais** desse estudo, quando concluído?

( ) SIM ( ) NÃO

Na certeza de que a sua colaboração será essencial não só para a consolidação dos dados da pesquisa, mas principalmente por propiciar uma proposta de projeto e especificações o mais próximo possível da realidade e da necessidade desse tipo particular de transporte, em nome do CNPq, do RCA e em meu próprio, o nosso muito obrigado.

**Nome da empresa:** USINA SÃO MANUEL

**Endereço:** FAZ. BOA VISTA C.P. 123 18650-000 S.MANUEL

**Nome do responsável pelas informações:** CARLOS ALBERTO DAMADA

**e-mail para contato:** cadamada@saomanuel.com.br

**Local e data:** SÃO MANUEL, 12/02/07

- MECANIZAÇÃO Ñ + DO QUE 40% EM FUNÇÃO DOS TERRENOS
- KOMBIS E VANS FRÁGEIS P/ A FUNÇÃO. MICROS SÃO OS MELHORES
- 2: USO DO VEÍCULO P/ COMPROMETER O USO NO TRANSPORTE DOS RURÍCOLAS
- BARRACA SANITÁRIA - AS MULHERES NÃO EM DUPLA ⇒ UTILIZAM + AS BARRACAS DO QUE OS HOMENS

## 3.4 - Bus Manufacturers' Questionnaire

Royal College of Art

PROJETO DE PESQUISA
"O TRANSPORTE DE PESSOAS EM TERRENOS IRREGULARES"

(QUESTIONÁRIO DOS FABRICANTES)

**01**- Qual o pedido que mais lhe chamou a **atenção** ate hoje?
GELADEIRA ELÉTRICA

**02**- Qual a **preocupação mais comum** dos clientes (usinas) ao fazer o pedido de um ônibus? CUSTO

**03**- Qual o **tamanho de ônibus** solicitado para o transporte de ruricolas nas usinas?
60 PESSOAS

**04**- Quais são as **exigências das usinas** na compra dos ônibus destinados ao transporte dos ruricolas? CAIXA P/ GALÕES, MESINHA NO BANCO P/
MACA, REFESCÃO (LEGISLAÇÃO)
KIT PRIMEIROS SOCORROS, ESPAÇO DA LIMA NO BANC

**05**- Qual o **tamanho de ônibus** solicitado para o transporte de operadores de maquinas tratoristas e motoristas?
20 PESSOAS

**06**- Quais são as **exigências das usinas** na compra dos ônibus destinados ao transporte dos operadores de maquinas, tratoristas e motoristas?

**07**- Com que freqüência os ônibus para essa atividade são **substituidos nas frotas** das usinas? 10 ANOS

**08**- Qual a **percentagem de aquisição** de veiculos novos e usados para essa atividade?

(10)% NOVOS (90)% USADOS

**09**- As **solicitações das usinas** estão mais ligadas ao cumprimento da legislação ou existe uma preocupação por parte delas em melhorar esse transporte para alem das normas?

**10**- Qual o **tamanho do mercado** de veículos para o transporte de trabalhadores rurais no Brasil?

**11**- Qual o numero de veiculos para essa finalidade, **produzido por essa empresa**?

( ) POR MÊS (50) POR ANO

**12**- Qual o **custo médio extra** das modificações solicitadas pelas usinas, em relação aos modelos de serie? 20%

**13**- Dentre as solicitações das usinas, essa empresa já recebeu alguma ligada ao **atendimento de emergência** aos ruricolas na lavoura em caso de acidente de trabalho?

MALA

**14**- Pela politica dessa empresa, considerando o mercado atual e o crescente numero de modificações necessárias, existe alguma perspectiva por parte da empresa em relação ao **desenvolvimento de um modelo** especial para essa atividade, já contemplando todos os itens exigidos pela legislação?

**15**- Você considera o **peso do ônibus** demasiado (super dimensionado) para o transporte de ruricolas?

( ) SIM ( ) NÃO

**16**- Os clientes (usinas) têm comentado alguma mudança nos **hábitos dos trabalhadores** desde que passaram a ser transportados por ônibus?

(X) SIM ( ) NÃO!

**17**- Em caso positivo, você poderia citar alguma(s)?

GINÁSTICA, SOM, MICROFONE, VISIBILIDADE

**18**- Com a adoção dos ônibus para o transporte de ruricolas, qual o percentual de **redução de acidentes** envolvendo esse tipo de transporte?

**20**- Qual tem sido o pensamento dos clientes (usinas) referente ao uso de **banheiro nos veículos**, em cumprimento a legislação?

**21**- E como fica essa **questão do banheiro** do ponto de vista técnico para a empresa, como fabricante?

( ) SIM ( ) NÃO

**22**- Em sua opinião, qual o **principal aspecto** nas normas que regulamentam o transporte de trabalhadores rurais que merece ser revisto ou melhor estudado?

**23**- Sem considerar as normas e os muitos esforços empreendidos até o momento na melhoria no transporte dos trabalhadores rurais e, levando em consideração a realidade de sua empresa, você diria que o ônibus e mesmo o **veículo mais adequado** para tal atividade?

( ) SIM ( ) NÃO POR QUE?

Na certeza de que a sua colaboração será essencial não só para a consolidação dos dados da pesquisa, mas principalmente por propiciar uma proposta de projeto e especificações o mais próximo possível da realidade e da necessidade desse tipo particular de transporte, em nome do CNPq, do RCA e em meu próprio, o nosso muito obrigado.

**Nome da empresa:** INDUSCAR / CAIO BOTUCATU

**Endereço:** ROD. MAL. RONDON km 252,2 DIST. IND

**Nome do responsável pelas informações:** SACOMANI / BARDUCO

**e-mail para contato:** sacomani@caio.com.br

**Local e data:** 5/03/07

3.5 - Bus Designers' Questionnaire

Royal College of Art
Postgraduate Art & Design

PROJETO DE PESQUISA
"O TRANSPORTE DE PESSOAS EM TERRENOS IRREGULARES"

(QUESTIONÁRIO DOS DESIGNERS)

01- Qual a **preocupação mais comum** no desenvolvimento de um ônibus?
O conforto e segurança dos passageiros e facilitar a manutenção da carroceria pelos frotistas.

02- Qual e a sua **visão pessoal** sobre o ônibus? O que ele significa?
Vejo um ônibus como um produto 100% função. Tem pouca ou nenhuma emoção em seu conceito.

03- Em sua opinião, qual o requisito mais **importante para o cliente** (frotista)?
A facilidade e o custo da manutenção.

04- Em sua opinião, qual o requisito mais **importante para o fabricante** (encarrocador)?
Facilidade e custo da produção.

05- O que mais lhe **incomoda no projeto** de um ônibus?
O uso de vários modelos de chassis para um mesmo modelo de carroceria, o que exige grande número de adaptações.

06- O que mais lhe **agrada no projeto** de um ônibus?
A possibilidade de trabalhar com diversidade de materiais num único produto.

07- Existe alguma coisa nas normas que, do ponto de vista do design, **não agregam valor** ou não cumprem o propósito original?
Não

08- Qual(is) a(s) exigência(s) mais comuns dos **motoristas**, atualmente?
Cockpit amplo, melhor ventilação da cabine e nível de ruído mais baixo.

09- Qual(is) a(s) exigência(s) mais comuns dos **passageiros**, atualmente?

Poltronas maiores e macias.

10- As fabricas normalmente costumam permitir que se avance alem do cumprimento das normas, no **processo de desenvolvimento** de um ônibus?

Em alguns aspectos.

11- Qual o componente, sistema ou parte com maior impacto para o **peso** da carroçaria de um ônibus?

As poltronas, a quantidade e o material do qual são compostas são determinantes no peso total da carroceria.

12- Qual o componente, sistema ou parte com maior impacto para o **custo** da carroçaria de um ônibus?

Os revestimentos da carroceria, que é determinado pela qualidade dos revestimentos aplicados no interior do salão e pelo corte das chapas que revestem a parte externa.

13- A empresa e aberta ao atendimento de **pedidos especiais**, com modificações nos veículos de serie?

Sim, o produto é focado na necessidade específica do cliente.

14- Qual a maior **limitação** que você, como designer, enfrenta no desenvolvimento de um ônibus?

A qualidade do acabamento e aplicação de novos materiais. A demanda do produto ônibus, se comparada a de outros produtos, é relativamente baixa, o que inviabiliza o investimento em técnicas de produção e acabamentos que exijam alta tecnologia. Além disso, o produto ônibus é focado na necessidade específica de cada cliente,que é um fator que dificulta a padronização do produto, reduzindo ainda mais a possibilidade de investimento em tecnologia de produção e materiais.

15 - Em sua opinião, Qual a principal evolução ocorrida nos ônibus nos últimos 10 anos?

O surgimento de chassis que permitem a construção de carrocerias com piso baixo, o que proporcionou melhor acessibilidade e conforto aos passageiros. Com relação a estética permite o uso de janelas panorâmicas, que além de permitir um desenho externo mais limpo e reduz a sensação de confinamento nos passageiros.

Na certeza de que a sua colaboração será essencial não só para a consolidação dos dados da pesquisa, mas principalmente por propiciar uma proposta de projeto e especificações o mais próximo possível da realidade e da necessidade desse tipo particular de transporte, em nome do CNPq, do RCA e em meu próprio, o nosso muito obrigado.

**Nome da empresa:**

Induscar-CAIO

**Endereço:**

Rodovia Marechal Rondon Km 253

Botucatu - SP

Brasil

**Nome do responsável pelas informações:**

Victor Samuel de Souza Pinheiro Chagas

**e-mail para contato:**

victorsamuel@caio.com.br

**Local e data:**

Botucatu 23/03/2007

# 4 - SURVEY RESULTS

## 4.1 - Sugar Cane Cutters' Survey Results

| THE TRANSPORTATION OF SUGAR CANE CUTTERS: ANALYSIS AND RECOMMENDATIONS | | | | | |
|---|---|---|---|---|---|
| RURAL CUTTERS' SURVEY | AGRICANA | | CEN. EMP. AGRICOLA | TECNOCANA | TOTAL |
| Location | MACATUBA | AGUDOS | LENCOIS PAULISTA | AGUDOS | |
| Date | 16/01/2007 | 16/02/2007 | 17/01/2007 | 23/01/2007 | 143 |
| Men | 13 | 22 | 37 | 24 | 96 |
| Women | 21 | 14 | 2 | 10 | 47 |
| | | | | | % |
| 1) Before the buses, the cutters' transportation was done by trucks. Did you have opportunity to travel on them? | | | | | |
| Yes | 18 | 26 | 32 | 24 | 70 |
| No | 16 | 10 | 7 | 10 | 30 |
| | | | | | |
| 2) What were the major problems of those trucks used for this transportation? | | | | | |
| Less comfort | 1 | 7 | 7 | 1 | 12 |
| Hard seats / much vibration | 3 | 12 | 17 | 9 | 29 |
| broke down | | | 1 | 3 | 3 |
| Entirely different | | | 1 | 4 | 3 |
| All bad | | 2 | 3 | | 3 |
| very noisy | 1 | | 4 | | 3 |
| Access much more difficult | 1 | | 1 | | 1 |
| Dust / rain / cold / wind | 4 | 6 | 3 | 3 | 11 |
| Difficult to cope with | | | 1 | | 1 |
| Lack of external vision | | 3 | | | 2 |
| Very hot | 1 | 3 | | | 3 |
| standing up due to discomfort | 1 | | | | 1 |
| No problem | 7 | 3 | 1 | 2 | 9 |
| Many problems | | | | 2 | 1 |
| Tools in the vehicle | | | | 2 | 1 |
| Lack of safety | | 2 | | 2 | 3 |
| Do not remember | | 2 | | 2 | 3 |
| The water tank was in steel | | | | 1 | 1 |
| Not practical | | 1 | | | 1 |
| Unpleasant feeling | | 1 | | | 1 |
| Lack of space / packed | | 2 | | | 1 |
| Without toilet | | 1 | | | 1 |
| | | | | | |
| 3) Is there anything in those trucks that you think that is better than in the buses nowadays? | | | | | |
| No / nothing | 19 | 23 | 26 | 24 | 64 |
| The bus is better | 1 | 1 | 6 | | 6 |
| Bigger | 1 | | | | 1 |
| Everything | 2 | 1 | | | 2 |
| Seats and external vision | 2 | | | | 1 |
| Safety | 3 | | | | 2 |
| Comfort | 9 | 3 | | | 8 |

| | | | | | |
|---|---|---|---|---|---|
| Tranquil / awning | 1 | | | | 1 |
| Without wind | 1 | 1 | | | 1 |
| Do not know | | 1 | | | 1 |
| Not for this transportation | 1 | | | | 1 |
| | | | | | |
| 4) What are the major advantages that you can see in the buses used for cutters' transportation? | | | | | |
| More comfortable | 10 | 22 | 34 | 23 | 62 |
| Better seats | 1 | 1 | 3 | 9 | 10 |
| Better environment | | 2 | 1 | | 2 |
| Faster | 1 | | 1 | | 1 |
| More safety | 3 | 1 | 2 | 4 | 7 |
| Do not know | 3 | 3 | | | 4 |
| Better for resting | 1 | | | | 1 |
| Spacious | 1 | 1 | | 1 | 2 |
| Normal | 1 | 1 | | | 1 |
| No rain / no wind | 2 | | | 1 | 2 |
| Toilets | | 4 | | 1 | 3 |
| Awnings | | 3 | | | 2 |
| Softer / Less vibration | | 4 | | | 3 |
| External vision / ventilation | | 3 | | | 2 |
| | | | | | |
| 5) Is there anything in the buses that could be improved for the cutters' transportation? | | | | | |
| Do not know | 11 | 5 | 27 | 10 | 36 |
| That is good | 10 | 13 | 6 | 13 | 29 |
| Bigger awnings | | | 1 | | 1 |
| Cold water | 1 | 1 | 1 | | 2 |
| Seat belts | | 1 | 1 | | 1 |
| Curtains on the windows | 2 | 1 | | 2 | 3 |
| Adjustable foam seats | 1 | 16 | | 6 | 16 |
| Put wings | 1 | | | | 1 |
| Loo in the vehicle | 2 | | | 1 | 2 |
| More comfort | 1 | | | | 1 |
| Food on plantations | 2 | | | | 1 |
| Not break down | 1 | 1 | | | 1 |
| Music | | | | 2 | 1 |
| Air conditioning | | | 3 | | 2 |
| | | | | | |
| 6) What do you normally do during the trip from the town to the plantation? | | | | | |
| Talk to colleagues | 19 | 11 | 18 | 17 | 45 |
| Sleep | 16 | 23 | 19 | 17 | 52 |
| Read | | | | | 0 |
| See the landscape | 5 | 4 | 8 | 3 | 14 |
| Play | | | | | 0 |
| Music / crochet / doing nothing | 1 | 4 | 1 | 2 | 6 |
| | | | | | |
| 7) What is the capacity of the drinking water container that you take with you? | | | | | |
| 3 litres | 6 | 3 | 3 | 5 | 12 |
| 5 litres | 28 | 33 | 35 | 30 | 88 |
| | | | | | |
| 8) Is this amount of drinking water enough for all day long? | | | | | |
| Yes | 26 | 29 | 18 | 25 | 69 |
| No | 7 | 7 | 20 | 9 | 30 |
| No / refill it once | 6 | 7 | 11 | 8 | 74 |
| No / refill it twice | 1 | | 9 | 1 | 26 |

| | | | | | |
|---|---|---|---|---|---|
| No / refill it three times | | | | | |
| | | | | | |
| 9) Where do you refill the drinking water container when necessary? | | | | | |
| Bus | 34 | 36 | 39 | 34 | 100 |
| | | | | | |
| 10) Do you usually travel with the proper work clothes? | | | | | |
| Yes | 29 | 28 | 27 | 25 | 76 |
| No | 5 | 8 | 12 | 9 | 24 |
| | | | | | |
| 11) What do you normally take from home to the plantations with you? | | | | | |
| Main meal | 34 | 36 | 39 | 34 | 100 |
| Drinking water container | 34 | 36 | 38 | 34 | 99 |
| File | 33 | 36 | 36 | 30 | 94 |
| Clothes | 30 | 35 | 30 | 25 | 84 |
| Personal safety equipment | 27 | 35 | 36 | 33 | 92 |
| Coffee / biscuit / bread / juice / MP3 | 7 | 10 | 4 | 11 | 22 |
| | | | | | |
| 12) From all of these things, which ones do you usually take in your backpack? | | | | | |
| Main meal | 34 | 36 | 39 | 34 | 100 |
| Drinking water container | | | | | |
| File | 33 | 21 | 37 | 23 | 80 |
| Clothes | 30 | 18 | 30 | 28 | 74 |
| Personal safety equipment | 27 | 15 | 36 | 25 | 72 |
| Coffee / biscuit / bread / juice / MP3 | 6 | 10 | 4 | 11 | 22 |
| | | | | | |
| 13) Do you take everything with you through the plantation or leave something in the bus? | | | | | |
| Take everything | 22 | 19 | 29 | 9 | 55 |
| Leave on the bus | 11 | 17 | 11 | 25 | 45 |
| | | | | | |
| 14) Do you think that having the improvised toilet on plantation is important? | | | | | |
| Yes | 29 | 36 | 38 | 32 | 94 |
| No | 2 | | 1 | 1 | 3 |
| | | | | | |
| 15) When stopping to take a rest, where do you usually sit? | | | | | |
| Water container | 30 | 31 | 39 | 30 | 91 |
| Ground | | 5 | 2 | 2 | 6 |
| foldable chair / bus | | | 2 | 2 | 3 |
| | | | | | |
| 16) Do you prefer take a rest for short periods, stopping more times or prefer to stop less resting for a longer period? | | | | | |
| Stop more times | 10 | 7 | 9 | 11 | 25 |
| Stop less times | 23 | 28 | 29 | 23 | 72 |
| Depends | | 1 | | | 1 |
| | | | | | |
| 17) Do you enjoy the trip from home to plantations or for you it is just a necessity? | | | | | |
| Do not like | 18 | 21 | 20 | 17 | 53 |
| Like | 16 | 15 | 19 | 17 | 47 |
| | | | | | |
| 18) Would you like to spend less travel time being able to work more? | | | | | |
| Yes | 19 | 27 | 8 | 8 | 43 |
| No | 13 | 6 | 31 | 26 | 53 |
| Does not matter | | 3 | 1 | | 3 |

## 4.2 - Drivers' Survey Results

| THE TRANSPORTATION OF SUGAR CANE CUTTERS: ANALYSIS AND RECOMMENDATIONS | | | | | |
|---|---|---|---|---|---|
| BUS DRIVER'S SURVEY | AGRICANA | | CEN. EMP. AGRICOLA | TECNOCANA | TOTAL |
| Location | MACATUBA | AGUDOS | LENCOIS PAULISTA | AGUDOS | |
| Date | 16/01/2007 | 16/02/2007 | 17/01/2007 | 23/01/2007 | 8 |
| Men | 2 | 1 | 4 | 1 | 8 |
| Women | | | | | 0 |
| | | | | | % |
| 1) Before the buses, the cutters' transportation was done by trucks. Did you have opportunity to drive them? | | | | | |
| Yes | 1 | 1 | 3 | 1 | 75 |
| No | 1 | | 1 | | 25 |
| | | | | | |
| 2) Which were the major problems that you noticed when driving those trucks? | | | | | |
| very noisy | | 1 | 1 | 1 | 38 |
| Cutters did not like them | | | 1 | | 13 |
| Discomfort | | | 2 | | 25 |
| No problem | 1 | | 1 | | 25 |
| | | | | | |
| 3) Is there any advantage in driving those trucks if compared to the current buses? | | | | | |
| No / nothing | 1 | 1 | 1 | 1 | 50 |
| Yes / isolated from cutters' noise | | | 1 | | 13 |
| Less stuck | | | 1 | | 13 |
| Do not know | 1 | | 1 | | 25 |
| | | | | | |
| 4) Which are the major advantages that you can see in the buses used for cutters' transportation? | | | | | |
| More comfortable | 1 | | 3 | 1 | 63 |
| Better seats | | 1 | | | 13 |
| Better environment | | 1 | | | 13 |
| Socialisation | | | 1 | | 13 |
| Do not know | 1 | | | | 13 |
| | | | | | |
| 5) Is there anything in the buses that could be improved for the cutters' transportation? | | | | | |
| Yes / Toilet | 1 | | | | 13 |
| No | 1 | | 2 | 1 | 50 |
| Yes / curtain for the windows | | 1 | | | 13 |
| Yes / bigger awnings | | | 1 | | 13 |
| Yes / awning easier to assembly | | | 1 | | 13 |
| | | | | | |
| 6) Which are the difficulties that you have encountered with the bus on rainy days? | | | | | |
| No problem | 1 | | | | 13 |
| Run aground / stuck | | 1 | 3 | | 50 |
| Be towed | | | 2 | | 25 |
| More risks | | | | 1 | 13 |
| Slippage | | 1 | 2 | | 38 |
| Interruption of the journey | 1 | | | | 13 |
| More attention | | | 1 | | 13 |

| | | | | | |
|---|---|---|---|---|---|
| 7) Which are the difficulties that you have encountered when getting in and getting out of the plantations? | | | | | |
| Sugar canes invading the corridors | | | 1 | | 13 |
| No problem | 2 | | 1 | | 50 |
| Corridors / manoeuvrability | | | 1 | | 13 |
| Unknown path | | | | 1 | 13 |
| Soil | | | 1 | | 13 |
| New path | | 1 | | | 13 |
| | | | | | |
| 8) Which are the difficulties that you have encountered when travelling by corridors through plantations? | | | | | |
| Sugar canes invading the corridors | | | 1 | | 13 |
| Less space | | 1 | | 1 | 25 |
| Surface in bad condition | | | 1 | | 13 |
| No problem | 1 | | 1 | | 25 |
| Manoeuvrability | 1 | | | | 13 |
| Much narrow | | | 1 | | 13 |
| | | | | | |
| 9) What is the most difficult kind of terrain for the bus deal with on plantations? | | | | | |
| Red soil / dry or wet | 1 | 1 | 3 | 1 | 75 |
| Sand soil | | | 1 | | 13 |
| Sloping | 1 | | | | 13 |
| | | | | | |
| 10) Do you think that the power of the bus is adequate for this kind of transportation? | | | | | |
| Yes | 2 | 1 | 4 | 1 | 100 |
| No | | | | | |
| | | | | | |
| 11) Do you think that the torque of the bus' engine is adequate for this kind of transportation? | | | | | |
| Yes | 2 | 1 | 4 | 1 | 100 |
| No | | | | | |
| | | | | | |
| 12) Do you think that the weight of the bus' engine is adequate for this kind of transportation? | | | | | |
| Yes | 2 | 1 | 2 | 1 | 75 |
| Yes / only for sandy soil | | | 1 | | 13 |
| No / less / better manoeuvrability | | | 1 | | 13 |
| | | | | | |
| 13) What do you normally take with you from home to plantations? | | | | | |
| Main meal | 2 | 1 | 4 | 1 | 100 |
| Drinking water container | 2 | 1 | 3 | 1 | 88 |
| Coffee | 1 | | | | 13 |
| File | | | 1 | | 13 |
| Personal Safety Equipment | | | 2 | | 25 |
| | | | | | |
| 14) From all of these, which of them do you normally take in your backpack? | | | | | |
| Main meal | 1 | | 3 | 1 | 63 |
| Drinking water container | 1 | | 1 | | 25 |
| Coffee | | 1 | | 1 | 25 |
| Personal Safety Equipment | | | 1 | | 13 |
| | | | | | |
| 15) Do you usually take everything with through plantation or leave part of them in the bus? | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Take everything | | | | | |
| Leave part of them in the bus | 2 | 1 | 4 | 1 | 100 |
| | | | | | |
| 16) Do you think that having the sanitary canvas as a toilet on plantation, is important? | | | | | |
| Yes | 2 | 1 | 4 | 1 | 100 |
| No | | | | | |
| | | | | | |
| 17) Do you think that it would be better a bus that could be bought equipped with toilet, instead of having to adapt one? | | | | | |
| Yes | 2 | 1 | 4 | 1 | 100 |
| No | | | | | |
| | | | | | |
| 18) Is the group of cutters that travel in your bus always the same? | | | | | |
| Yes | 2 | 1 | 4 | 1 | 100 |
| No | | | | | |
| Does not matter | | | | | |
| | | | | | |
| 19) In case of accidents involving the cutters, what kind of vehicle is normally used for emergency assistance? | | | | | |
| Car | 2 | 2 | 1 | 1 | 75 |
| Bus | | | 4 | 1 | 63 |
| Pick up | | 1 | | | |
| | | | | | |
| 20) Do you think that the bus's performance would be better if the number of cutters transported were different? | | | | | |
| Yes | | | 1 | | 13 |
| No | 2 | 1 | 3 | 1 | 75 |
| Does not matter | | | | | |
| | | | | | |
| 21) If you could change or improve anything in the bus, what would you change or improve? | | | | | |
| Nothing | 2 | 1 | 1 | | 50 |
| Thermal drinking water tank | | | 1 | | 13 |
| Radio | | | | 1 | 13 |
| Floor and seats / cleaning | | | 1 | | 13 |
| Awnings | | | 1 | | 13 |

## 4.3 - Sugar Cane Companies' Survey Results

| THE TRANSPORTATION OF SUGAR CANE CUTTERS: ANALYSIS AND RECOMMENDATIONS | | | |
|---|---|---|---|
| SUGAR CANE COMPANY SURVEY | | | |
| AGRICANA | SAO MANOEL | CEN. EMP. AGRICOLA | TECNOCANA |
| 1) What is the dimension of the plantation area of the company? | | | |
| 4,379ha | 25,000ha | 16,000ha | 1,793ha |
| 2) Does the company produce and sell electric energy? | | | |
| No | Yes | No | No |
| 3) What is the number of sugar cane workers of the company? | | | |
| 200 | 1,660 | 1,000 | 450 |
| 4) What is the number of agricultural machinery and truck drivers of the company? | | | |
| 50 | 350 | 500 | 176 |
| 5) What is the number of buses used for the transportation of rural workers in the company? | | | |
| 4 | 30 | 20 | 10 |
| 6) Does the company use any other type of the vehicle for the transportation of machinery operators and drives? | | | |
| Yes | Yes | Yes | Yes |
| 7) If the answer to the previous question is yes, what is the number of vehicles used for this transportation? | | | |
| 2 | 23 | 7 | 1 |
| 8) Does the group of sugar cane cutters in each bus remain basically the same? | | | |
| Yes | Yes | Yes | Yes |
| 9) What is the proportion of each type of terrain over which the bus transporting sugar cane cutters travel? | | | |
| | 20% paved roads<br>70% unpaved roads<br>10% corridors | 70% paved roads<br>20% unpaved roads<br>10% corridors | |
| 10) What is planed time of use for the bus in the company? | | | |
| | 10 years | 7 years | 3 years |
| 11) What is the shortest and the longest travel distance travel by the bus in the company? | | | |
| 2km and 80km | 10km and 35km | 8km and 15km | 5km and 60km |
| 12) What is the shortest and the longest travel time take by the bus in the company? | | | |
| 5min. And 2h | 45min. and 90min. | 15min. and 45 min. | |
| 13) What kind of vehicle normally transports the cutters in case of emergency on plantations? | | | |
| Car<br>Pick up truck | Car<br>Pick up truck<br>Ambulance | Bus<br>Car<br>Vehicle with nurse | Car<br>Pick up truck |

| | | | |
|---|---|---|---|
| 14) What is the proportion of emergencies which requires the removal of the patient to the hospital? | | | |
| 5% | 2.5 cases/day | | |
| 15) What is the number of medical assistances on plantations per month in the company? | | | |
| | 10 | | |
| 16) Is the weight of the current bus above the necessity for the transportation of sugar cane cutters? | | | |
| | No | Yes | |
| 17) Is the size of the current bus adequate for the company's need? | | | |
| Yes | No | | |
| 18) Is the number of cutters transported by the bus adequate to the company? | | | |
| Yes | No | Yes | |
| 19) Any significant change in the habits of the cutters was observed with the replacement of the trucks for the buses? | | | |
| Yes | | Yes | |
| 20) If the answer to the previous question is yes, could you please cite some the changes? | | | |
| Mobile phone | | Higher level of satisfaction | |
| 21) With the adoption of the bus, what was the reduction in accidents involving the cutters' transportation? | | | |
| | | | |
| 22) Does the company already consider any alternative use for the bus when not transporting cutters? | | | |
| No | No | No | No |
| 23) If the answer the previous question is yes, Could you please indicate some alternative? | | | |
| | | | |
| 24) Would be more convenient if the bus could be acquired already equipped with the toilet? | | | |
| Yes | Yes | Yes | |
| 25) What is the cost for unpaved roads maintenance in the company? | | | |
| | | £4,5/ton of sugar cane | |
| 26) Would be more convenient if the bus could be acquired already equipped with all the accessories required? | | | |
| Yes | Yes | Yes | Yes |
| 27) Compared to the price of the bus, what is proportion spent in adaptations complying with the legislation? | | | |
| 20% | £4,000 | £6,000 | 30% |
| 28) What is the investment of the company in terms of machinery used for unpaved road construction and maintenance? | | | |
| £35,000 | | £400,000 | £150,000 |
| 29) What is monthly cost of the company to operate and maintain such machinery? | | | |
| £2,000 | | | |

| | | | |
|---|---|---|---|
| | | | |
| 30) Taking into account the company's reality, does the bus the most adequate vehicle for this kind of transportation? | | | |
| | | | |
| | | | |
| 31) What is the most important aspect in the regulation which should be revised or better studied? | | | |
| | Handrail | | |
| | | | |
| 32) Would the company like to have a copy of this investigation when concluded? | | | |
| Yes | Yes | Yes | |

# 5 - ANTHROPOMETRIC STUDY OF THE RURAL WORKERS IN SAO PAULO STATE

## 5.1 - Example of one of the anthropometric variables

VARIÁVEL A2 - SACRO-POPLITEAL - (GERAL)

| | | | |
|---|---|---|---|
| Nº DE PESSOAS : | 234 | COEF. VARIAÇÃO : | 5.49 % |
| MÉDIA : | 47.04 cm | VALOR MÍNIMO : | 37.50 cm |
| VARIÂNCIA : | 6.67 cm | VALOR MÁXIMO : | 56.00 cm |
| DESVIO-PADRÃO : | 2.58 cm | INTERVALO : | 18.50 cm |

PERCENTÍS

1.00 = 39.00
2.50 = 42.00
5.00 = 43.00
25.00 = 45.50
50.00 = 47.00
75.00 = 49.00
95.00 = 51.00
97.50 = 51.50
99.00 = 52.50

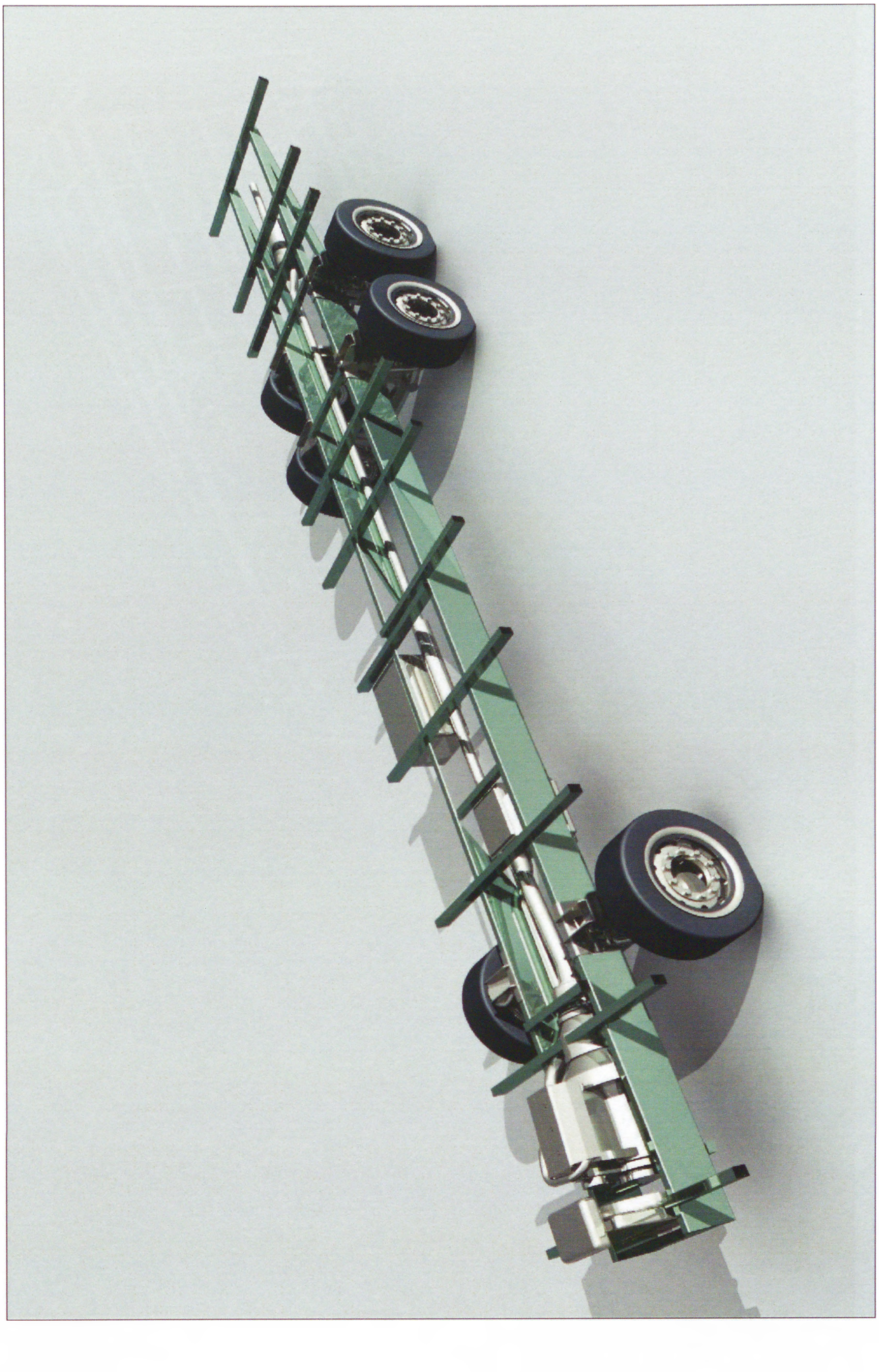
| GRUPOS DE IDADE - | de 18 | 18-24 | 25-34 | 35-44 | 45-54 | 55 e + |
|---|---|---|---|---|---|---|
| Nº DE PESSOAS : | 12 | 69 | 71 | 49 | 26 | 6 |
| MÉDIA cm : | 46.58 | 47.51 | 46.99 | 46.85 | 46.77 | 46.00 |
| DESVIO-PADRÃO cm : | 3.20 | 2.47 | 2.63 | 2.24 | 2.87 | 2.45 |
| COEF. VARIAÇÃO % : | 6.87% | 5.20% | 5.59% | 4.78% | 6.14% | 5.32% |

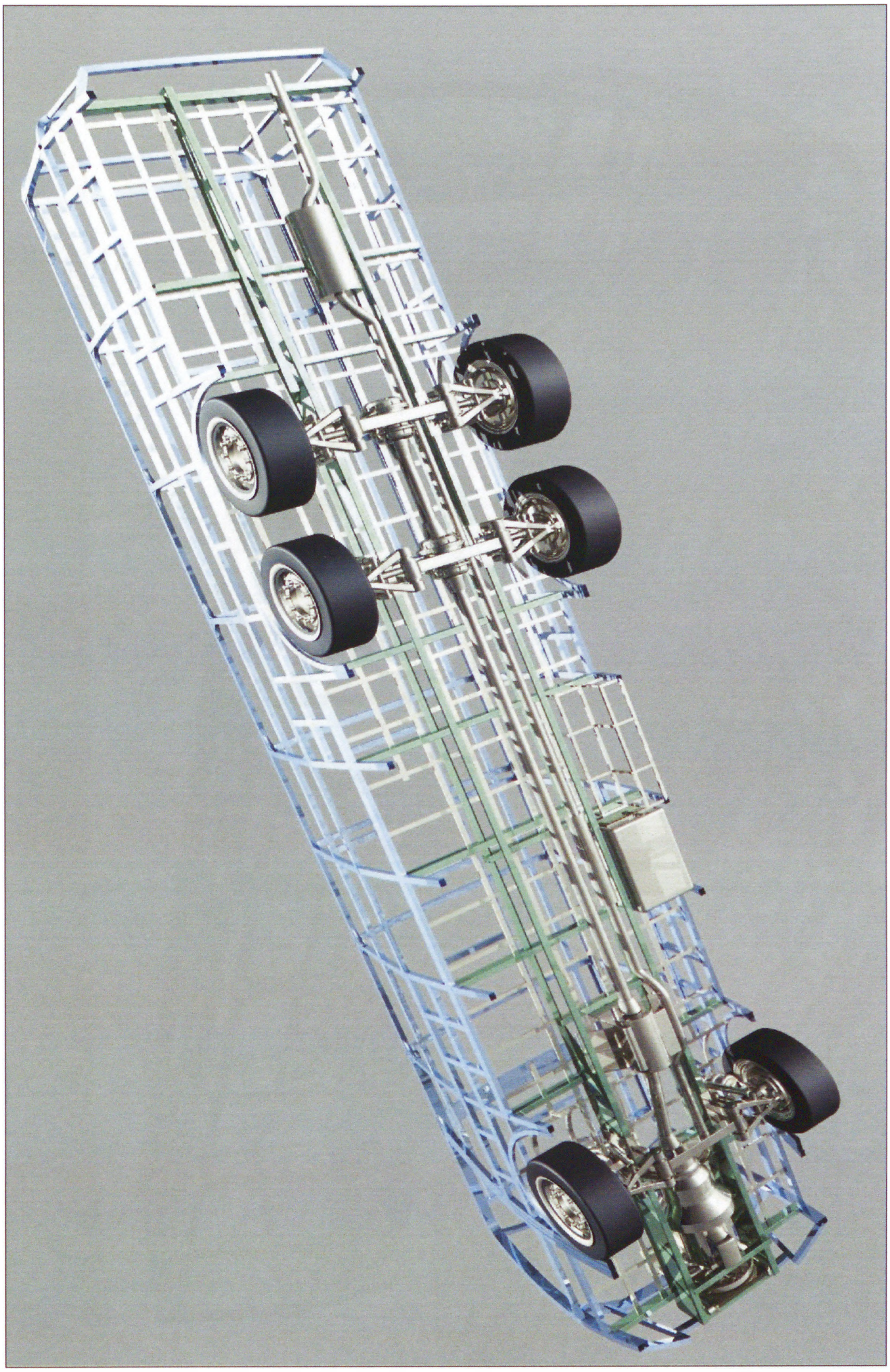
| NATURALIDADE | REG 2 | REG 3 | REG 4 | REG 5 | REG 7 |
|---|---|---|---|---|---|
| Nº DE PESSOAS : | 39 | 12 | 138 | 44 | 1 |
| MÉDIA cm : | 47.26 | 46.25 | 47.18 | 46.63 | 46.00 |
| DESVIO-PADRÃO cm : | 2.08 | 2.38 | 2.59 | 2.94 | 0.00 |
| COEF. VARIAÇÃO % : | 4.41% | 5.14% | 5.48% | 6.31% | 0.00% |

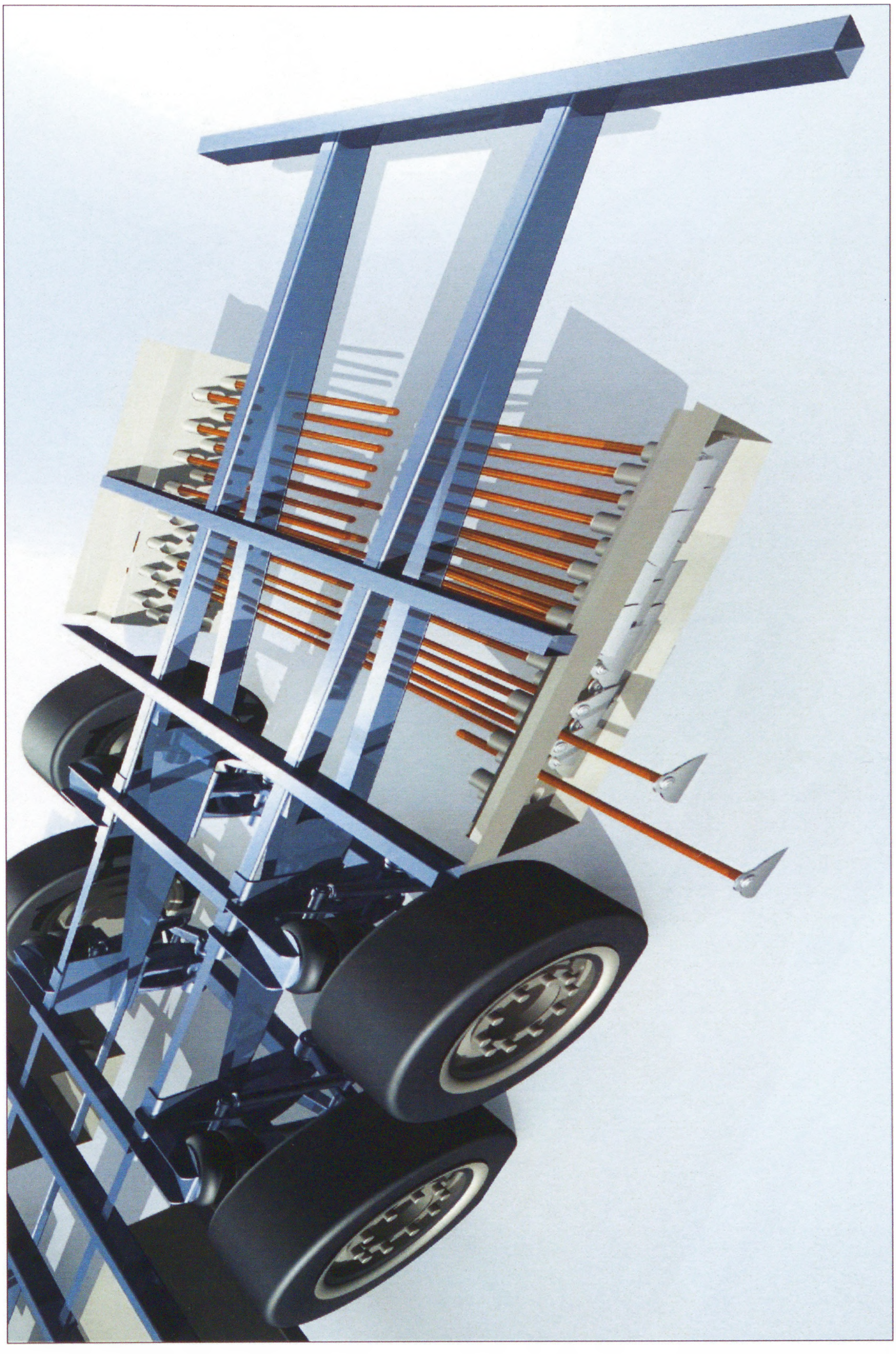
| PROCEDÊNCIA | REG 2 | REG 3 | REG 4 | REG 5 | REG 7 |
|---|---|---|---|---|---|
| Nº DE PESSOAS : | 37 | 13 | 140 | 41 | 2 |
| MÉDIA cm : | 47.07 | 46.92 | 47.15 | 46.71 | 46.75 |
| DESVIO-PADRÃO cm : | 1.84 | 2.83 | 2.59 | 3.05 | 0.75 |
| COEF. VARIAÇÃO % : | 3.91% | 6.04% | 5.50% | 6.53% | 1.60% |

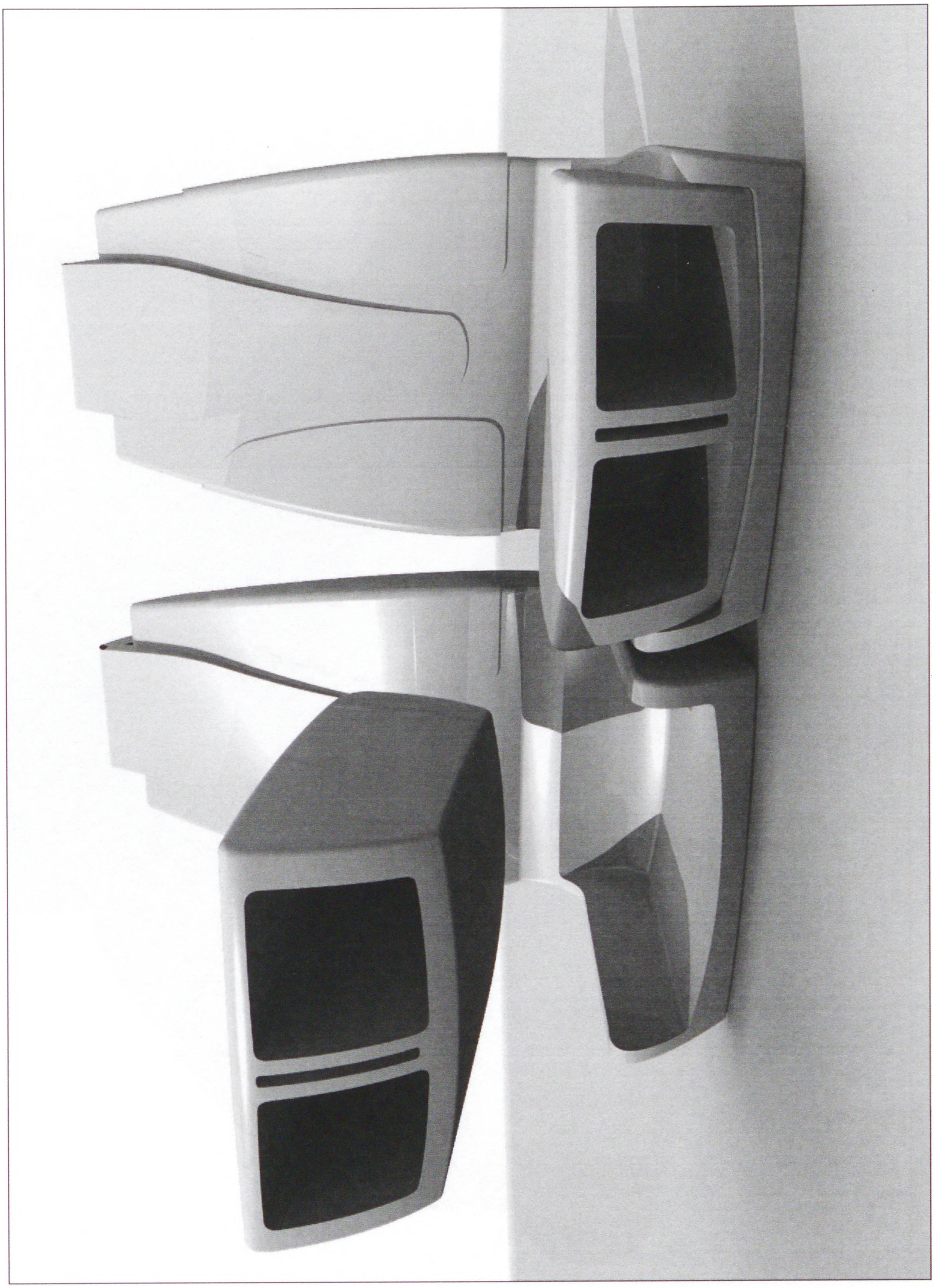
# 6 – VEHICLE'S EXTERIOR CONCEPTS

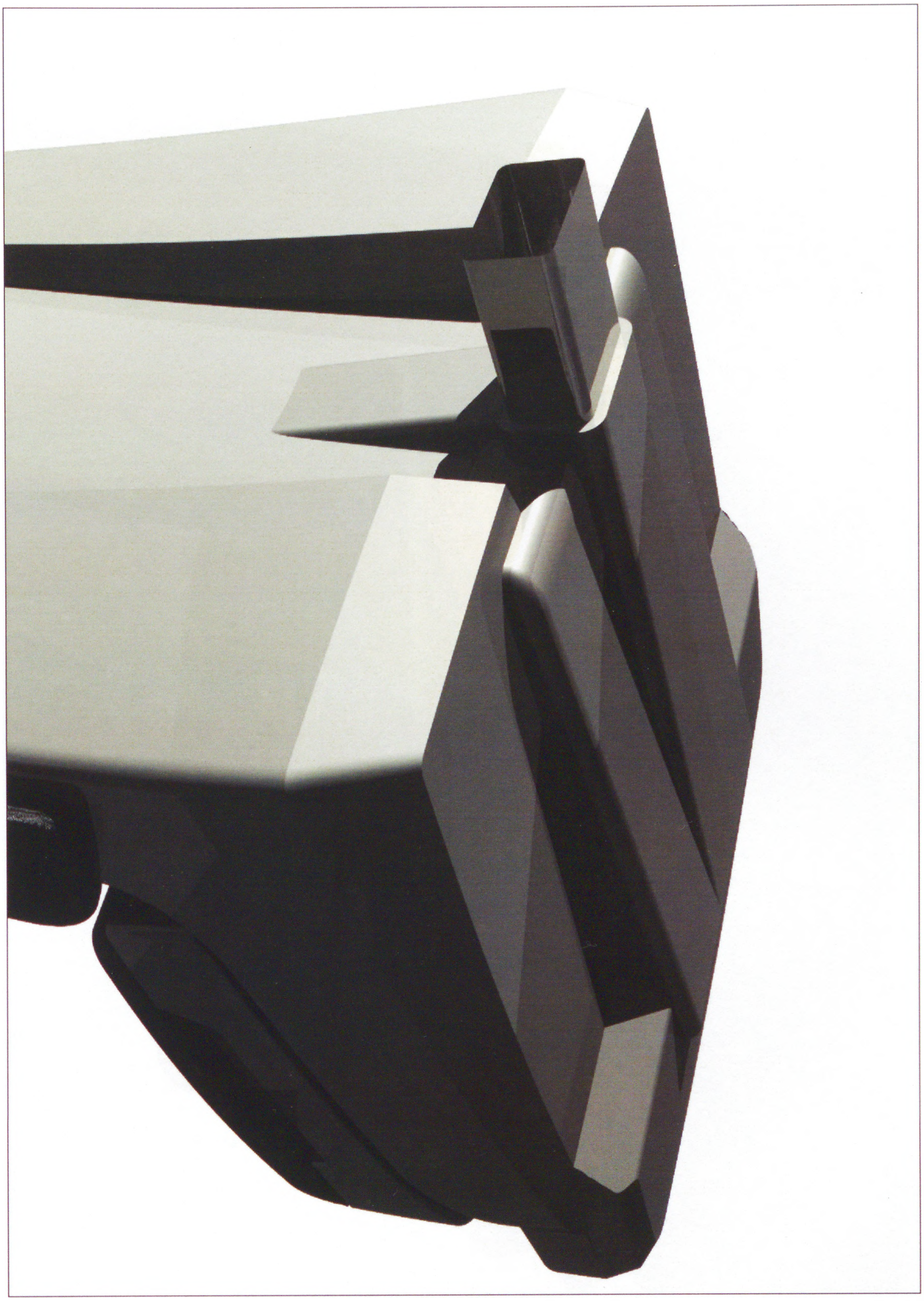
## 6.1 – Design Solutions

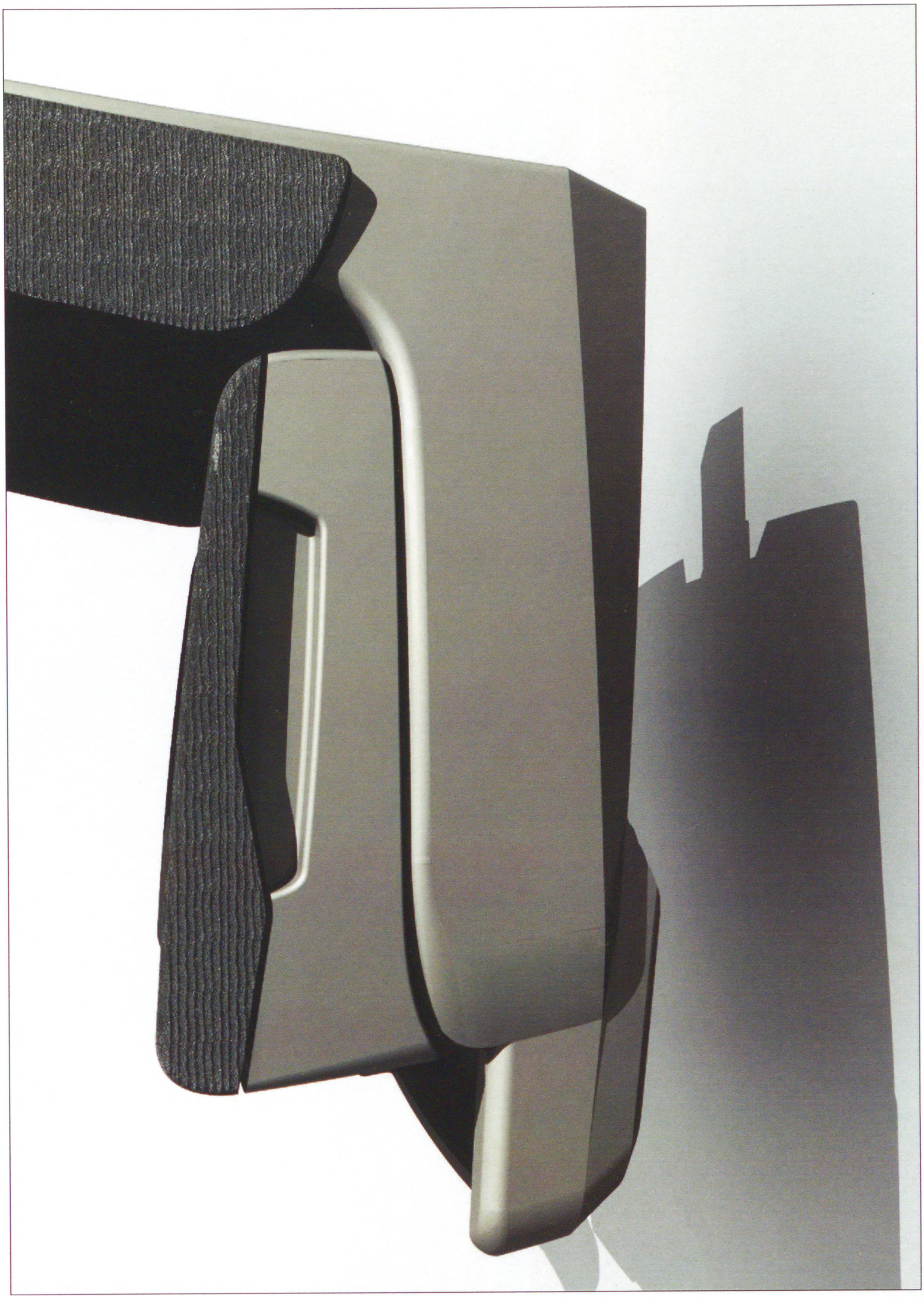


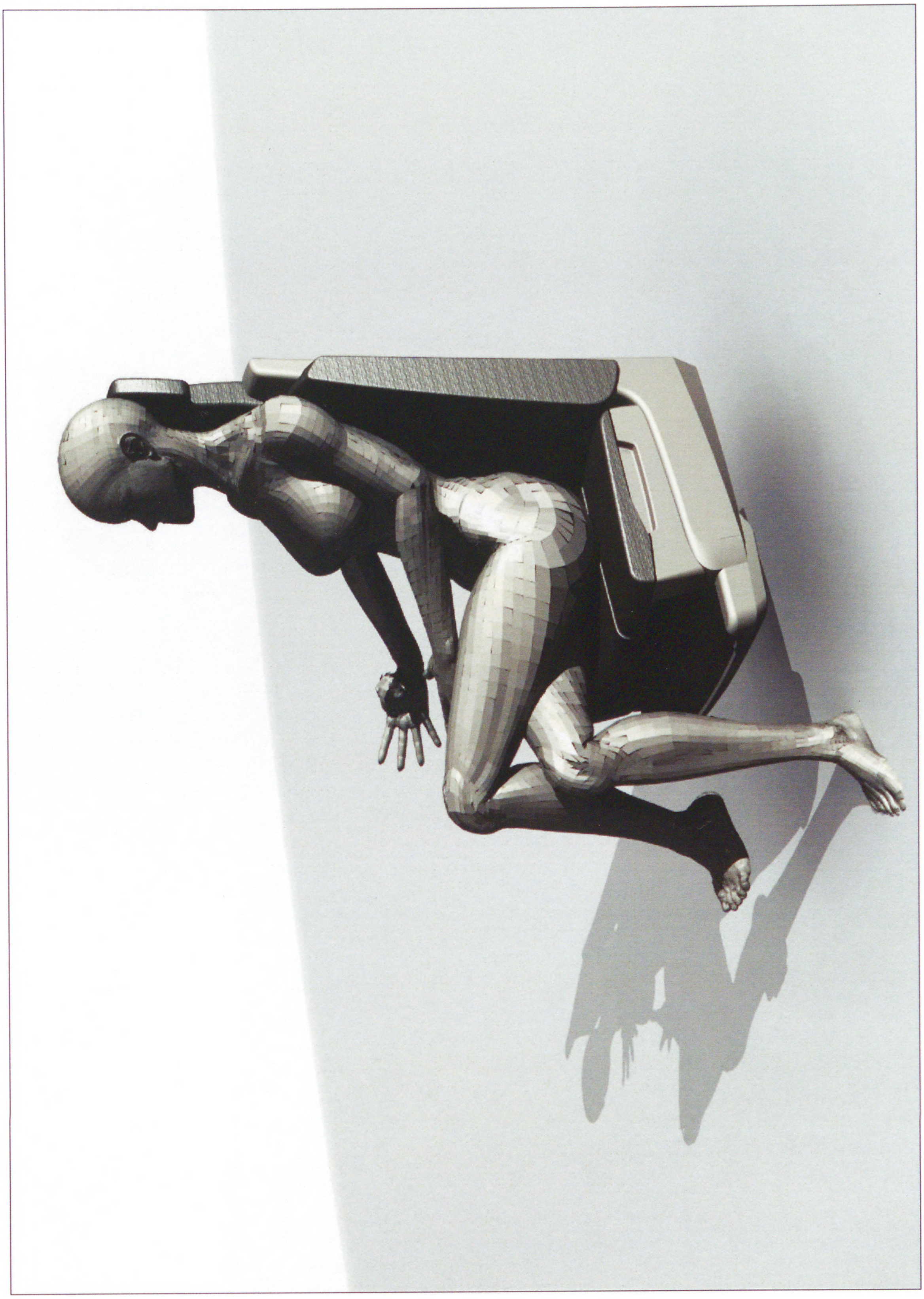


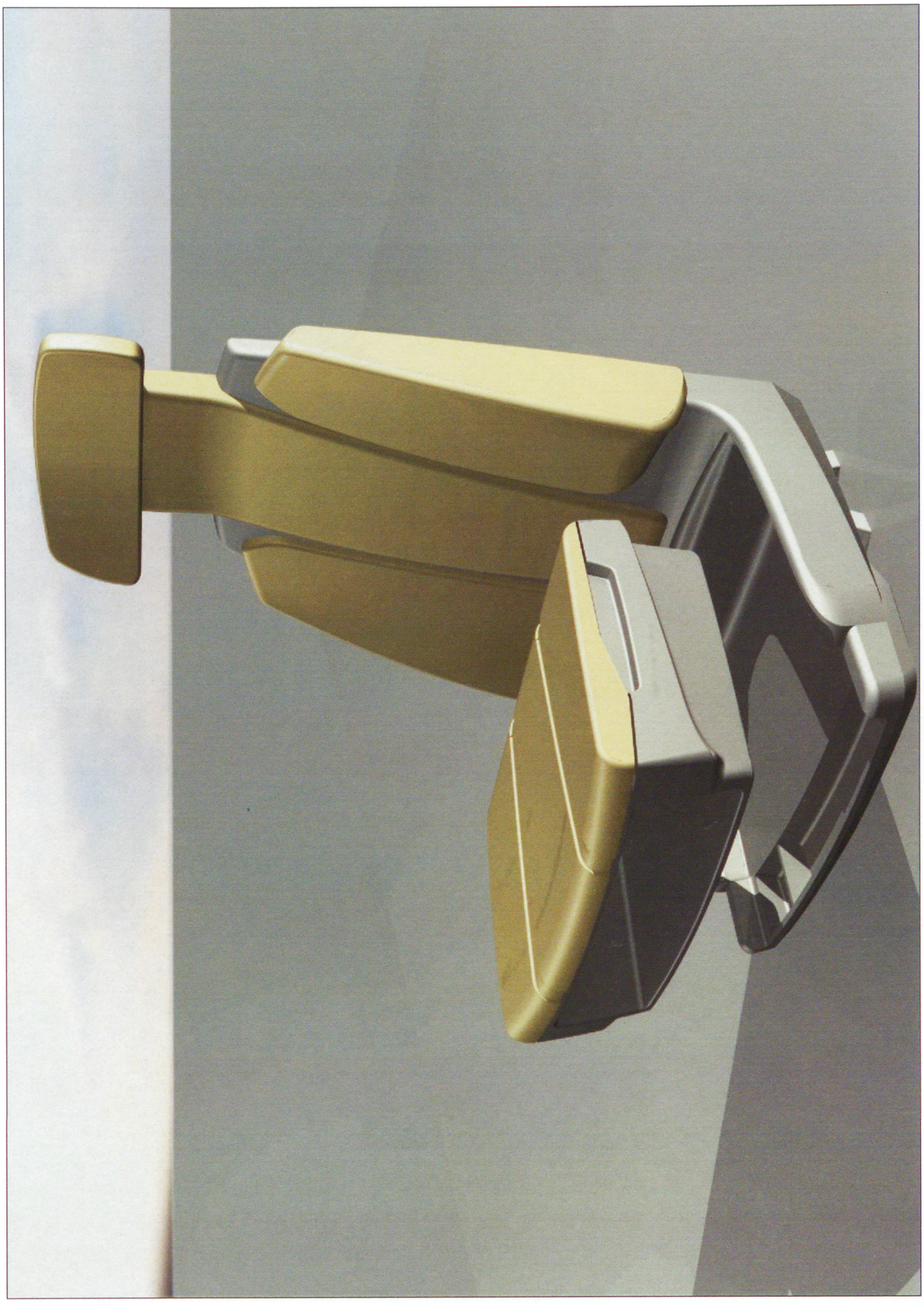


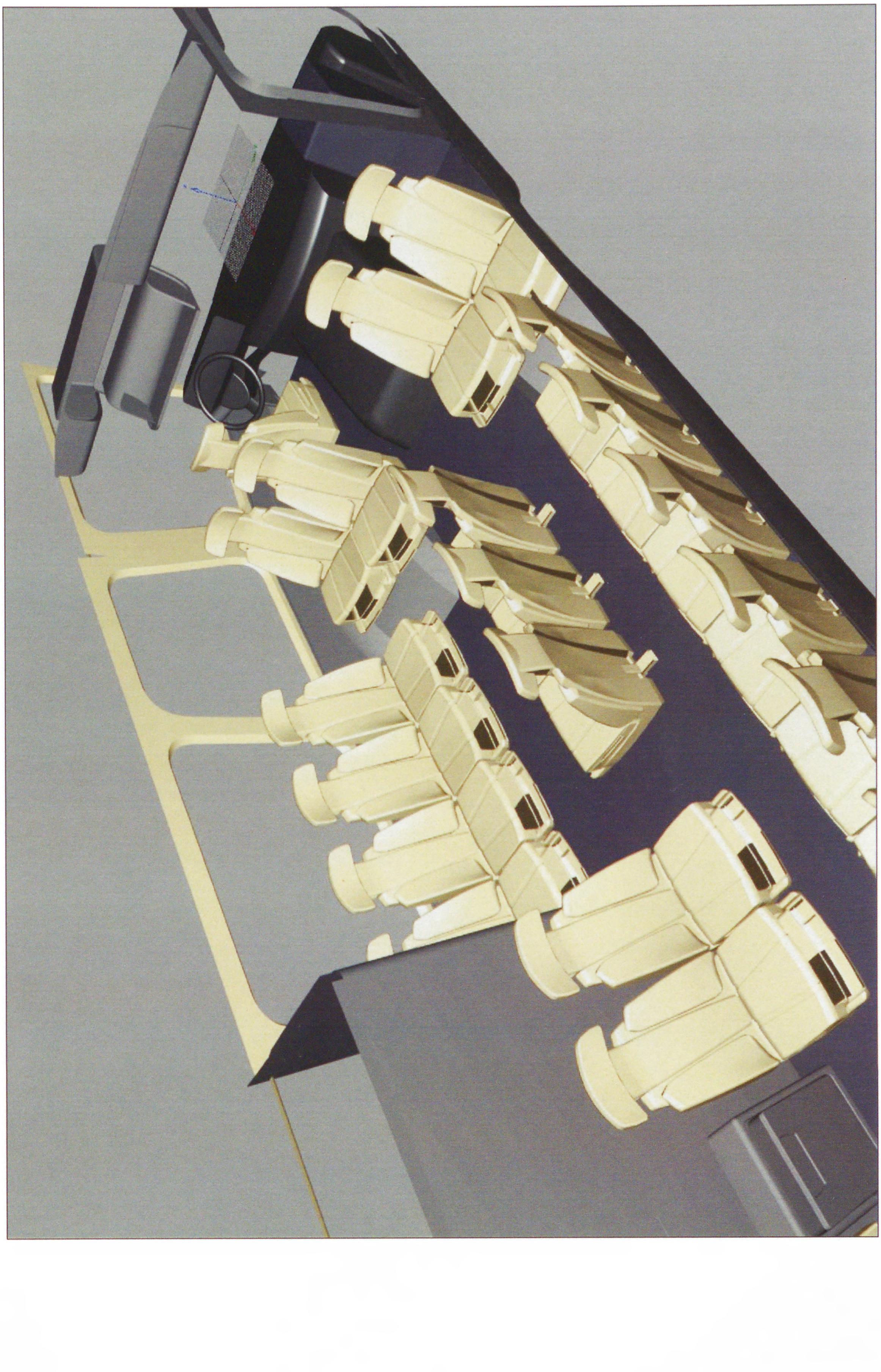


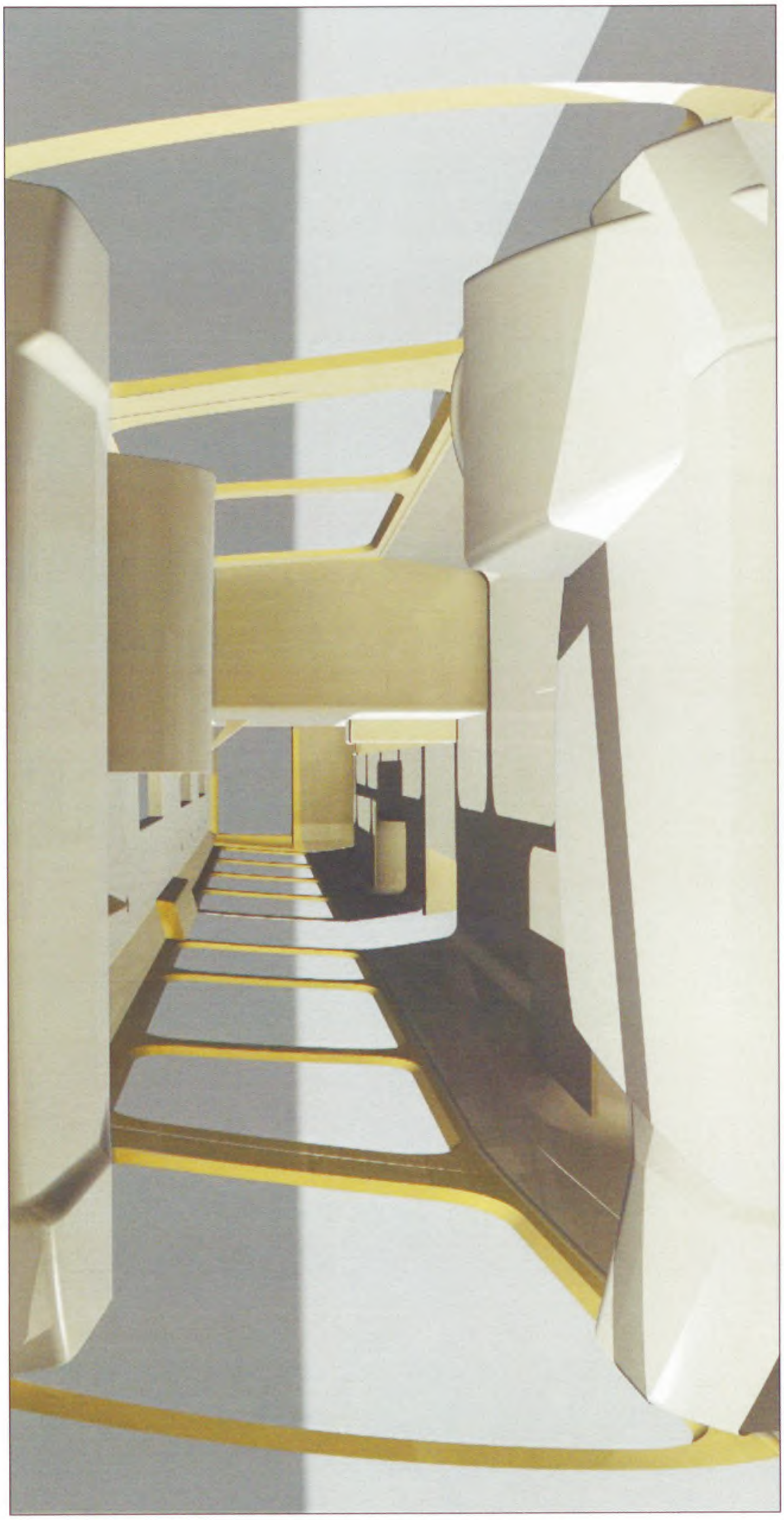


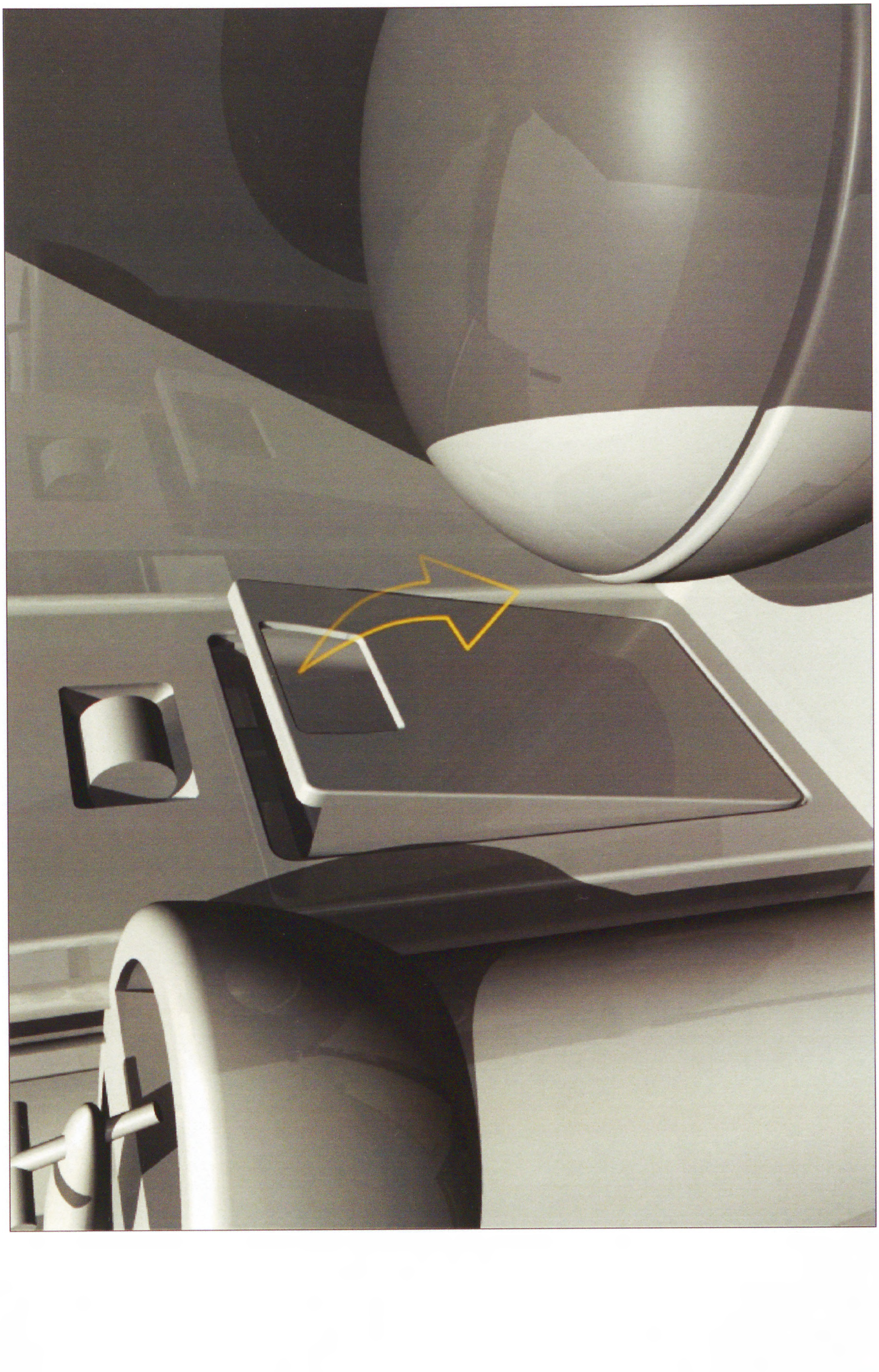






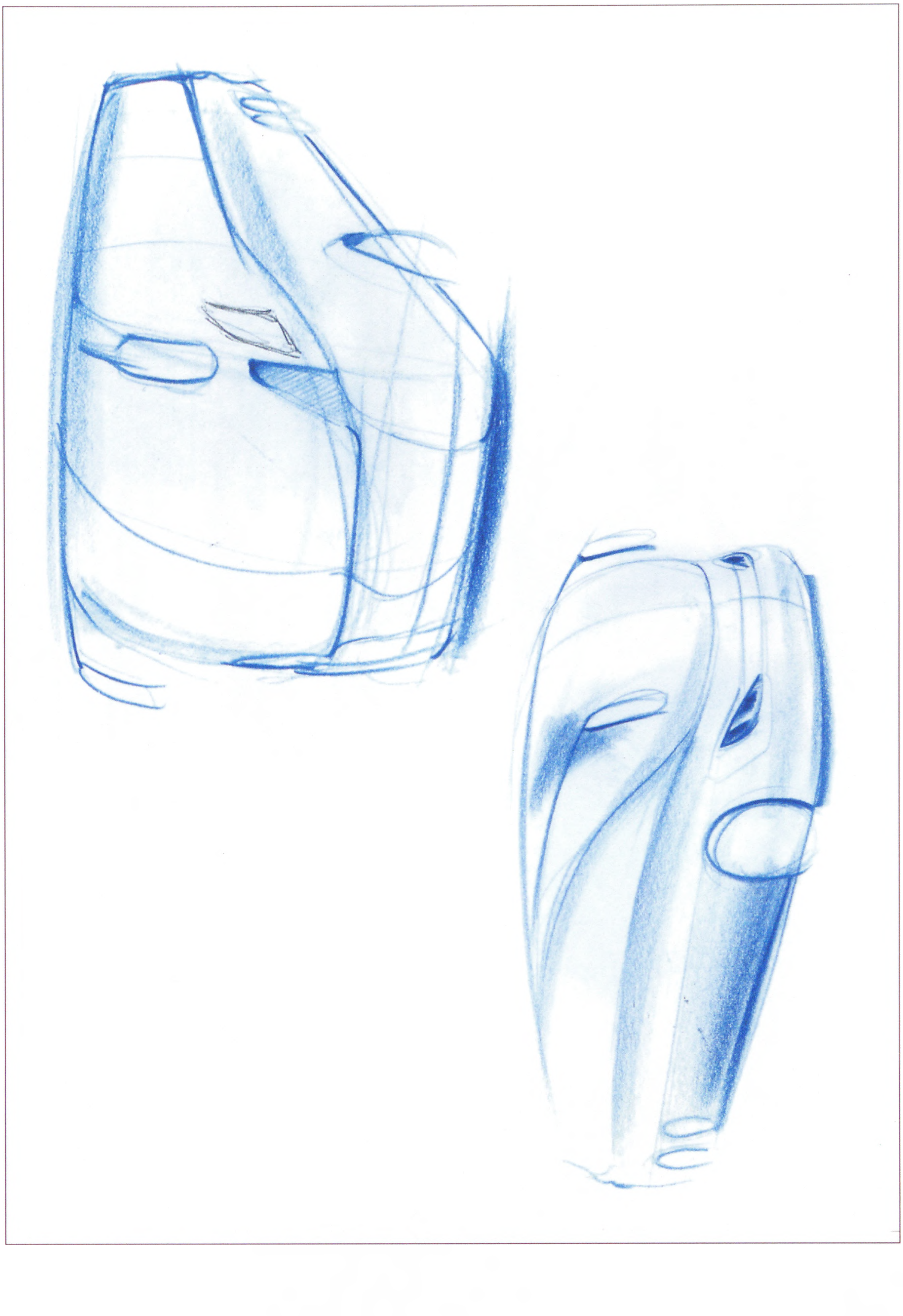


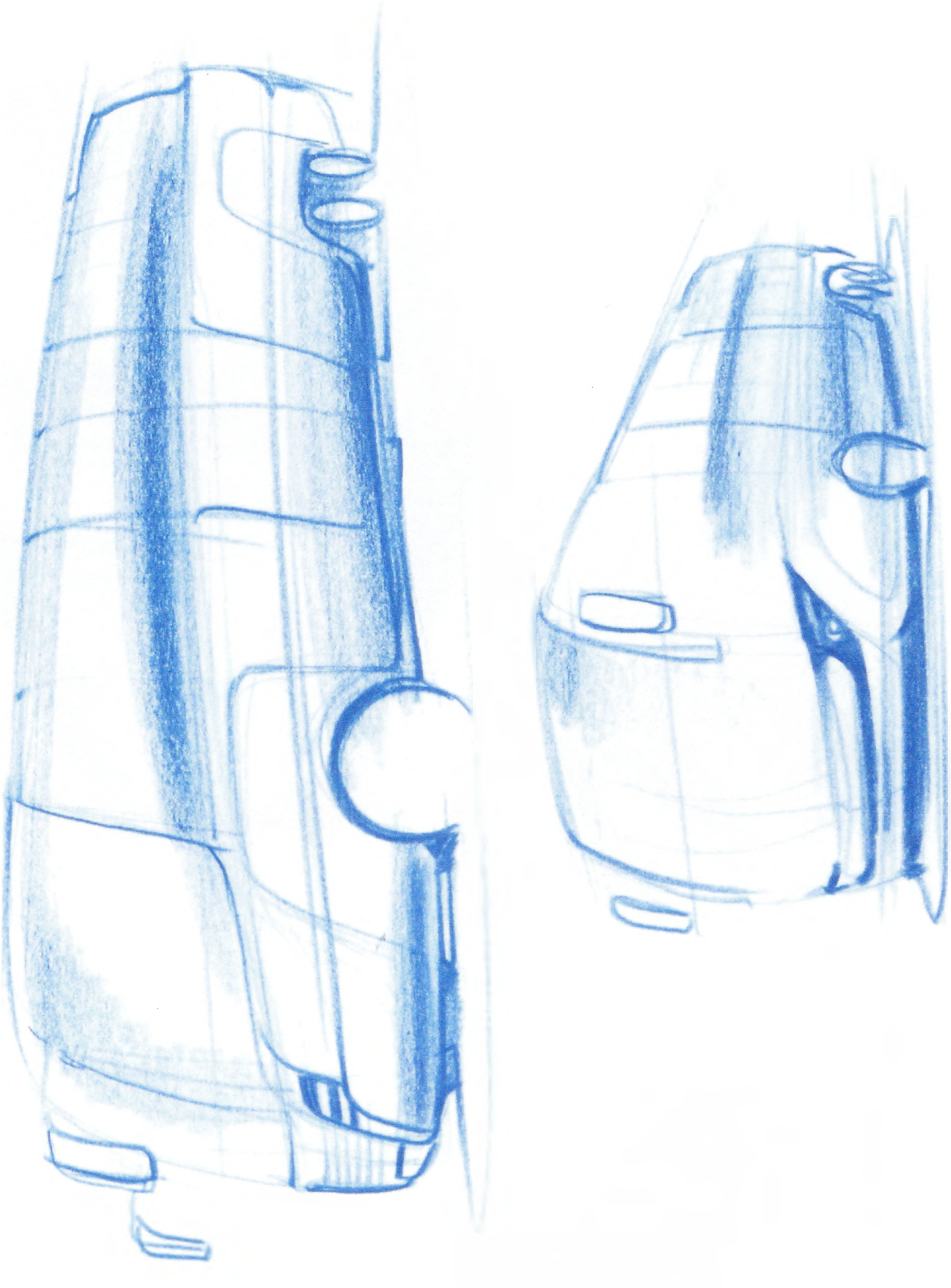


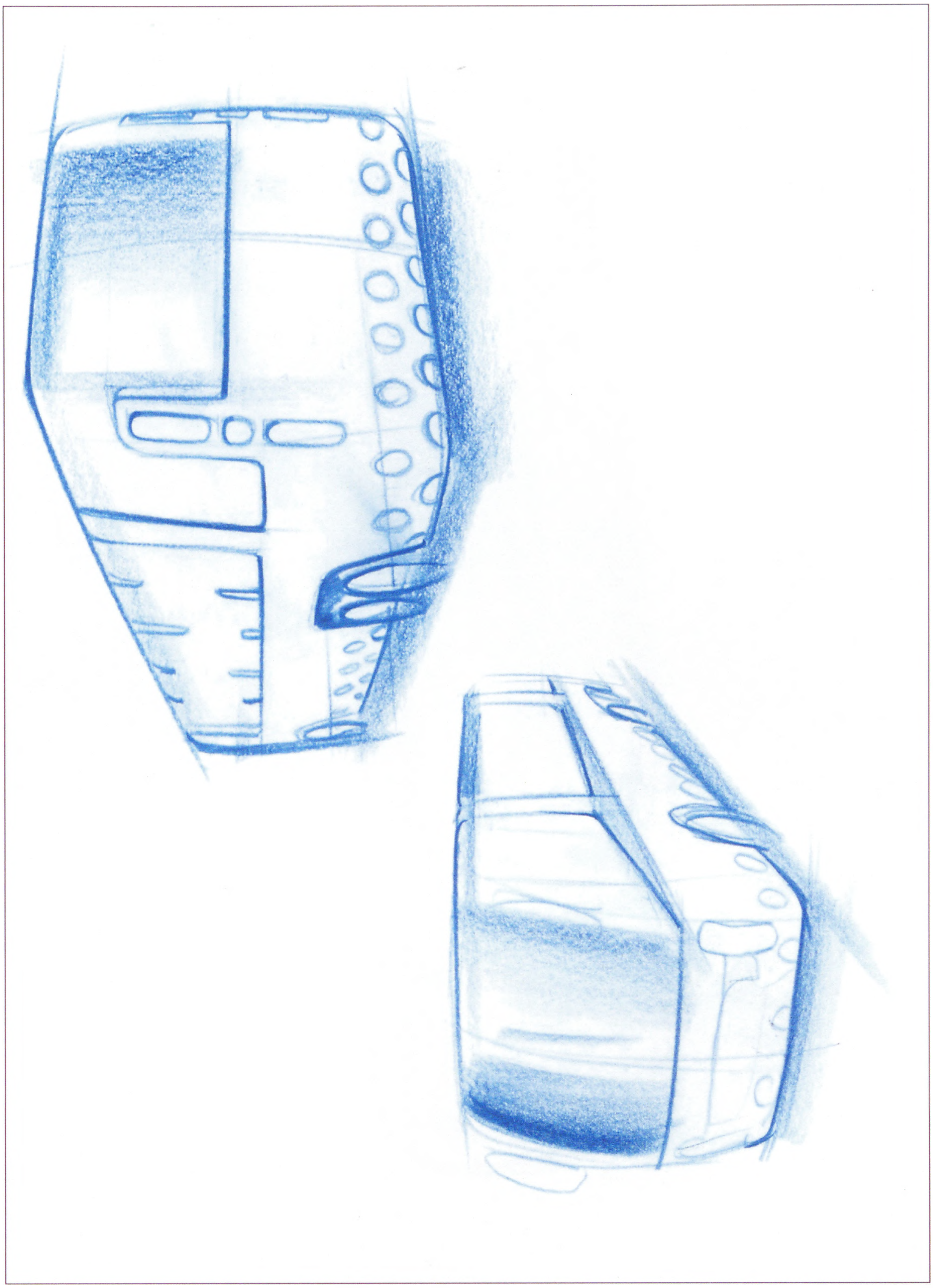


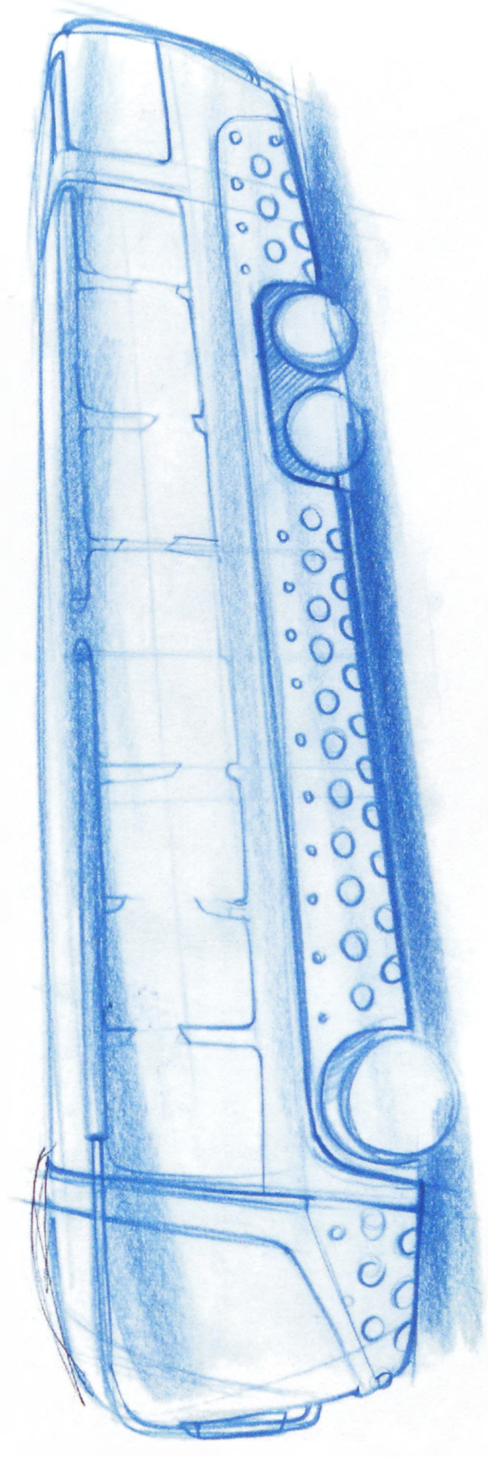
6.2 – Hélio's Concept

6.3 - Ehsan's Concept

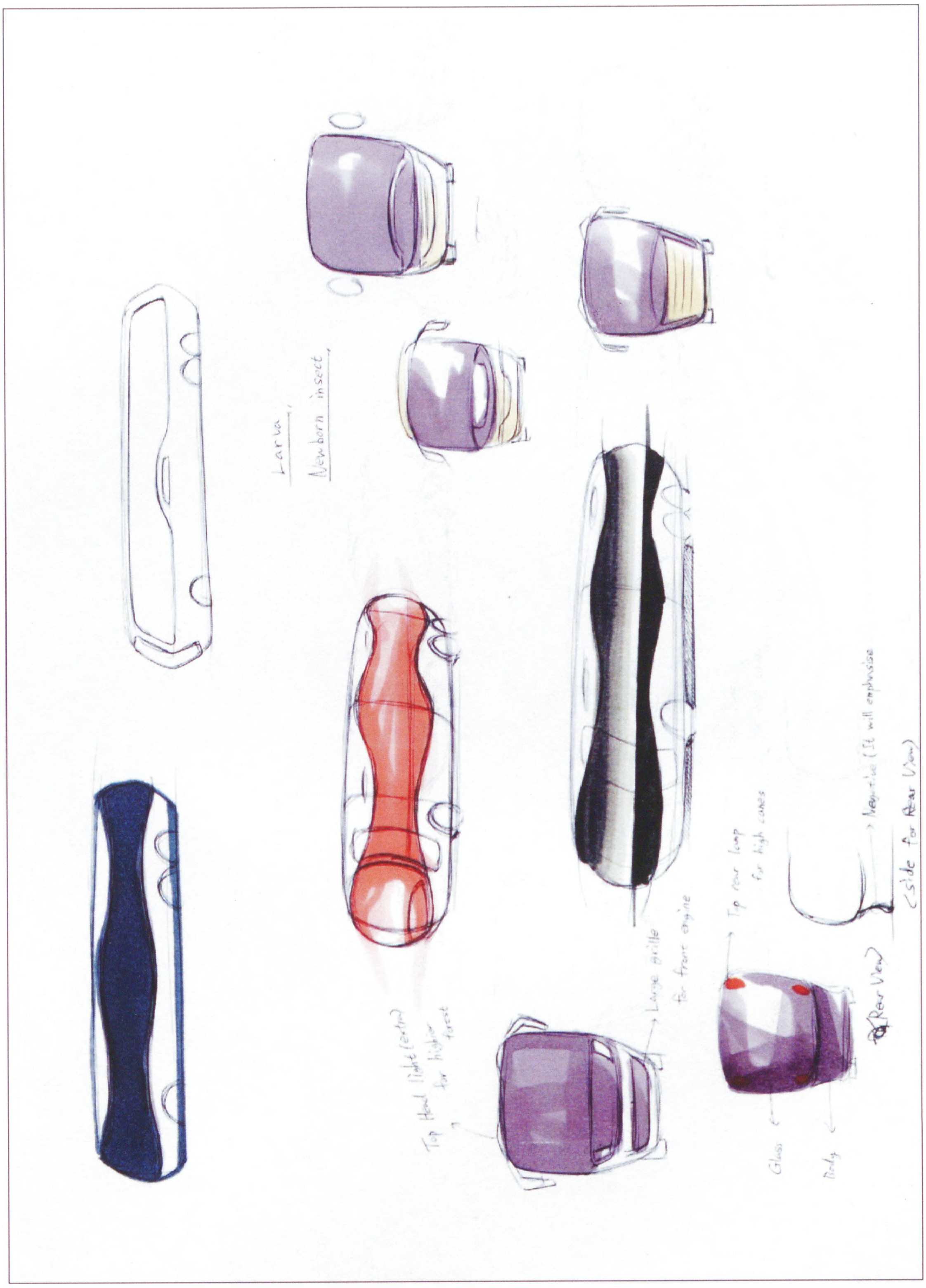




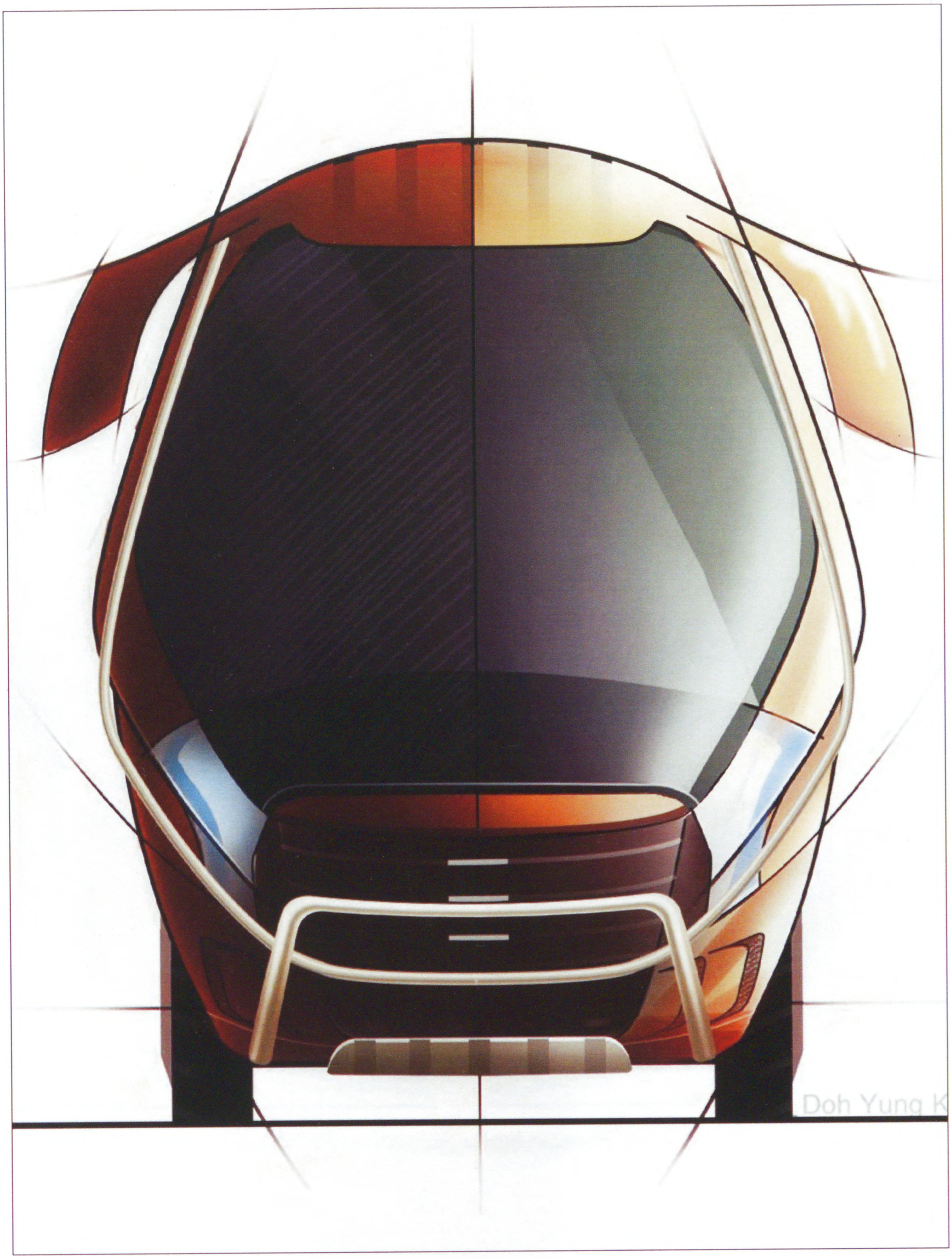




## 6.4 - Do's Concept




DOh


Doh Yung K


Doh yung Kim

# 7 - COST AND WEIGHT OF DESIGN SOLUTIONS

| TRANSPORTATION OF RURAL WORKERS | | | | |
|---|---|---|---|---|
| | COST ( £ ) | | WEIGHT ( kg ) | |
| RECOMMENDATIONS | Current | Proposed | Current | Proposed |
| Improving off-road drive layout | No | £2,100 | No | 200kg |
| Improving turning capacity | No | £400 | No | 50kg |
| Improving the chassis + suspension | £25,000 | £30,000 | 4,800kg | 3,000kg |
| Improving the body structure | £1,700 | £1,500 | 4,700kg | 5,100kg |
| Replacing tyres | £2,700 | £3,600 | 180kg | 200kg |
| Adopting a Central Tyre Inflation | No | £175 | No | 30kg |
| Improving protection against sun | £760 | £1,400 | 110kg | 400kg |
| Replacing tables and chairs on plantation | £430 | £460 | 244kg | 150kg |
| Adopting flooring underneath the awning | No | £690 | No | 30kg |
| Improving the seats | £750 | £2,320 | 1,080kg | 870kg |
| Improving thermal conditions onboard | No | £3,200 | No | 90kg |
| Adopting a door for the driver | No | £70 | No | 40kg |
| Enlarging the glazing area | £700 | £1,700 | 410kg | 134kg |
| Improving workers accessibility | £375 | £125 | 210kg | 70kg |
| Improving the toilets onboard | £1,500 | £1,300 | 300kg | 300kg |
| Optimising drinking water storage | £150 | £300 | 200kg | 220kg |
| Keeping the water tank disinfected | No | £200 | No | |
| Providing workers washing up conditions | £120 | £90 | 200kg | 100kg |
| Replacing flooring on the vehicle | £810 | £195 | 218kg | 69kg |
| Accommodating driver belongings | No | £30 | No | 8kg |
| Improving lighting onboard | £168 | £60 | 39kg | 9kg |
| Moving and assisting injured workers | £30 | £40 | 15kg | 7kg |
| TOTAL | £35,193 plus 20% | £50,955 | 12,306kg | 10,777kg |