Improving carpool flexibility without compromising trust or guaranteed rides

Fernando Lobo Pimentel [1*]

[1] *Bank of Portugal*

The analyses, opinions and findings of this paper represent the views of the author; they are not necessarily those of the Banco de Portugal or the Eurosystem.

Abstract

Aiming at the same transport with less car usage, carpool systems are a more economical and ecological way to travel when compared to drive-alone behaviour. However, carpooling is difficult to promote. People do not carpool for schedule flexibility and trust concerns, and when addressing the first issue by bringing more people to the carpools to increase schedule options, one loses on the trust side because prior acquaintance is no longer guaranteed, or one looses a guaranteed ride. We tried to address this problem.

We used operations research (OR) methodology to formulate the problem, then we relaxed a carpool system's restriction: the schedule coincidence requirement. This allowed the design of a several departure time carpool. Next we optimized the system using LP (linear programming) for a sub problem. Finally two preliminary surveys were conducted. The first in Oeiras municipality (Portugal), to test potential carpoolers adherence to the model, and the second through an email chain, to anticipate effective enrolment in a carpool with a specific several departure time schedule.

We found that a small group of people with different but compatible schedules, and who meet each other previously, can join the same carpool and benefit from it, provided that the system operates under the optimised configurations presented, so that the increase in the number of departure times available does not decrease vehicle occupancy rates more than necessary. Surveys revealed the likely readiness and schedule compatibility of about 10% of car commuters to enrol in such system.

By designing the carpool system around the idea of several guaranteed departures available, groups can be smaller and steadier because they self-contain wider schedule options. Scale increases are no longer mandatory and riding with strangers or unpredictable ride availability can be prevented. Therefore our model is a contribution to improve carpool flexibility without compromising trust concerns or guaranteed rides.

Keywords: Carpooling, Carpool flexibility, Operations Research, Optimization

[*] Corresponding author: Fernando Lobo Pimentel (fpimentel@bportugal.pt; margarida.fernando@gmail.com)

1. Introduction

The traditional environmental strategy focused on controlling industry emissions through legislation while modern environmental strategies focus on an extended concern over all the product’s life cycle phases. Optimising a products life cycle is therefore to optimise, as a priority, the product life cycle phases responsible for the major environmental impacts (Ferrão, 1998).

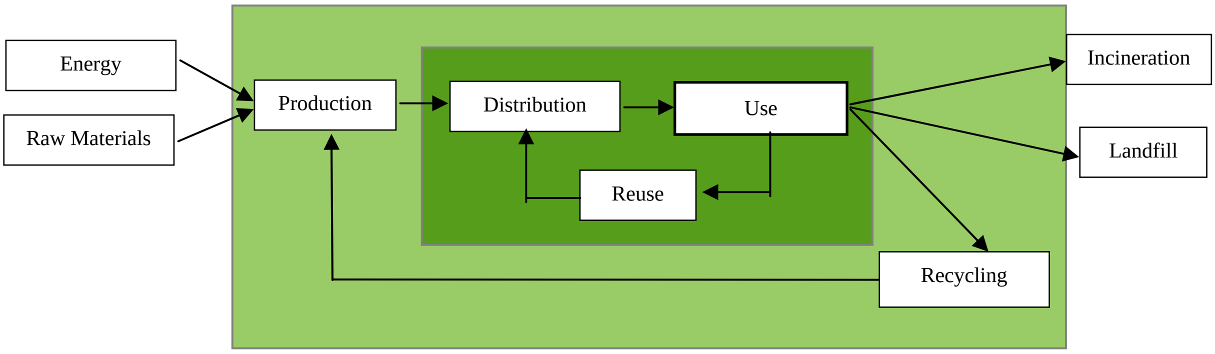

Figure 1: Life cycle of economic goods illustrated.
Source: Adapted from (Ferrão, 1998).

Considering the car industry case under analysis, it is in fact during the usage phase of their life cycle (in bold in Figure1) that most of cars environmental impact is produced. In fact, for conventional internal combustion engine vehicles, the use phase accounts for the majority of global warming potential (GWP) impact (Hawkins, 2013).

While car production industries have significantly modernized and become more eco-efficient, it is widely recognized that, from an environmental point of view, traffic is a major problem for big cities. Besides the traffic congestion negative impact on the quality of life of local citizens, driving affects a host of ecological systems ranging from global climate to local air quality. Road transport contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2), and cars are responsible for around 12% of total EU emissions of carbon dioxide (CO_2), the main greenhouse gas. (European Commission, 2014).

There are two ways to reduce environmental impacts during the usage phase of cars: one is to produce cars that pollute less, for example through the use of better combustion technologies; another one is to promote a more rational use of cars, which is the focus of our paper. One can’t compare the environmental impact of two cars if one of them transports three persons in average and the other one just carries the driver. Taking into account the “function” of these two cars, and assuming their fuel consumption is the same, the relative impact assessment (in terms of emissions) per functional unit can be quantified: The car in drive-alone mode pollutes three times more. In fact, this is the way pollution costs are usually computed: on a pollution cost per passenger basis (Hawkins, 2013).

To gather in the same cars people that usually travel the same way (alone) would therefore be a straightforward way to optimise the car life cycle environmental impact. This type of arrangements already exists under the name of carpooling. By carpooling we mean an arrangement where two or more people share the use and cost of privately owned automobiles in travelling to and from pre-arranged destinations together.

The focus of this work was put on the research and enhancement of the carpool concept through the application of operations research views and methods to the optimisation of carpool organization.

2. Problem statement

Addressing the product Life Cycle Assessment methodology as a way to build a view on our system's environmental behaviour, the product in mind is the car and the life cycle phase is the usage phase (Ferrão, 1998). The focus is put on how the product is being used and on the resulting impacts on the environment. Considering the two major distinctive components of the environment: physical and social/economical (Ferrão, 1998), from a multi-criteria perspective it is reasonable to take the following Fundamental Points of View - FPV's (Bana e Costa, 1992) - as the ones that represent major environmental concerns: Economic, Safety, Social and Ecological (Halcrow Fox, 2002).

Table 1 shows the criteria[1] used to evaluate the major direct environmental impacts of the alternative car usage policies according to the previously defined FPV's. Analysing them, criteria weighting proves unnecessary to conclude that a switch from a drive-alone behaviour to carpooling would lead to a significant improvement in the car transport system environmental performance. The carpooling alternative clearly dominates drive-alone behaviour across every criteria.

Table 1: Multi-criteria comparison of drive-alone behaviour environmental impact on society versus carpooling behaviour environmental impact on society ('+' means good impact and '-' bad impact).

	FPV's	*Criteria*	*Drive-alone behaviour impact*	*Carpooling impact*
Social and Economical Environment	*Economic*	*Traffic congestion (time savings)*	-	+
		Fuel savings	-	+
		Parking savings	-	+
	Social	*Social Capital*[2]	-	+
Physical Environment	*Ecological*	*Local air quality*	-	+
		Global emissions	-	+
		Noise	-	+

[1]Obeying restrictions of completeness, operationality, decomposability, redundancy absence and parsimony [5]
[2] Measure of the degree to which a community cooperates

Therefore, the car environmental performance problem can be reformulated in more detail, considering the system to be a carpool based transport system, and the aim to make the carpool system deliver the best environmental performance (at the lowest cost).

For some people (at least in Portugal), public transport is not a competitive option, whether due to autonomy or travel duration reasons (surveys conducted during this work revealed that these are important advantages of commuting by car), or simply because the public transport offer is not enough. These are our potential carpool users. Target carpoolers are current drivers, not public transport users: this is a pre-condition for adherence to the system proposed, and the model assumes everyone will have to be a driver, to avoid promoting car usage, for environmental reasons. Also, the carpool flexibility proposed in this paper is probably not enough to attract public transport users who currently have almost continuous departure times available. For anybody who can rely on public transportation, this will always remain better. In section 4. we refine our analysis of the interplay between carpooling and public transport, considering the possibility of carpooling freeing up space in roads and lead to user changes from public transport to single user car use.

To show that potential carpoolers exist for whom public transport is not an option, we present in table 2 numbers on commuting trips in Lisbon suburbs area that connect relatively distant points for which there is no direct and easy public transportation available, and for which the indirect connections would very likely impose long waiting times, given the peripherical nature of the places and the distances between them. For these commuters car usage is almost mandatory and carpool savings on fuel become very attractive. Though these are a small percentage of potential carpoolers, they are the ones who might benefit more from our system.

Therefore, from an Operations Research point of view one can take a look at the car environmental performance problem with a systemic approach and formulate it, first in qualitative terms, as an optimisation problem:

- A system - a carpool based transport system
- An aim - to make the system deliver the best environmental performance (at the lowest cost)
- Restrictions - satisfying car users’ needs, such as journey schedules and trust concerns

The problem is now reduced to a carpool definition optimisation problem. Following an environmental impact analysis methodology, once identified the major consequences and criteria for the evaluation of car usage impact on the environment, the next step would be to minimize some of these consequences, through an optimisation of the technique and of the management methods (Ferrão, 1998). Excluding the car design technique improvement, not under consideration in this study, as well as the car usage technique improvement, which is a problem for the driving schools and government authorities to worry about, the focus here will be put on the “management methods”.

Taking the carpool policy, improving the car-usage “management methods” means working towards increasing car occupancy, i.e., to gather the highest possible number of individual drivers in groups sharing common routes. However, this search should be constrained by the problem restrictions.

Table 2: Long car commuting trips (only those more than 100) in Lisbon area (more than 40 minutes), Metropolitan Area of Lisbon, 2001.

	DESTINATION																
ORIGIN	*Almada*	*Amadora*	*Azambuja*	*Barreiro*	*Cascais*	*Loures*	*Mafra*	*Moita*	*Montijo*	*Odiv.*	*Oeiras*	*Palmela*	*Seixal*	*Sesimb*	*Setúb.*	*Sintra*	*VFXira*
Almada		*378*			*177*	*353*			*111*		*786*			*140*	*525*	*400*	
Amadora																	*206*
Barreiro	*328*																
Cascais	*353*	*701*				*390*											
Lisboa			*122*	*168*			*202*		*117*			*180*			*441*		
Loures	*367*				*338*											*960*	
Moita	*281*																
Odivelas	*227*				*280*												
Oeiras													*124*				*246*
Seixal		*253*			*159*	*276*			*144*		*653*				*717*	*336*	
Sesimbra	*441*																
Setúbal	*469*																
Sintra	*538*	*4143*				*1709*					*5911*		*105*		*215*		*416*
V. F. Xira		*333*									*504*					*395*	

Source: INE – National Institute of Statistics, Portugal.

3. Traditional carpool obstacles

Until recently, the central concept in carpool systems was the "ride-match" – that is, if somebody went "the same way", at "the same time of the day", he was a potential carpooler. This meant that when searching for a carpooler, besides searching for a common route one also searched for a common schedule. Now this might not be the best strategy, since a significant number of people are not willing to submit to a single travel time everyday without a choice, as shown in several reports that claimed the lack of schedules flexibility to be one of the major obstacles to carpool system's success (Dorinson et al, 2009), (US Agency, 2001), (Hope, 2001), (VTPI, 2003), (Denike, 2002). This should be one of the main reasons why carpooling was reported as a notoriously difficult activity to promote (Kaufman, 2002), that required a significant shift in people's attitudes to travel and major alterations to their lifestyle (Hope, 2001). A recent study (Deakin, 2011) reported that about one-fifth of commuters who drive alone to the campus would be interested in using dynamic ridesharing (varying one-time ride matches) at least occasionally and live in areas where matches could be found. So dynamic ridesharing is one of the forms of flexible arrangements for carpool.

More recently, a paper on carpool clubs confirmed this in its literature review and advanced the idea of complementing traditional rideshare with dynamic allocation of seats to account for changes in carpool arrangements (Correia, 2011). However, the proposal to introduce schedule flexibility determined an increase in the perimeter of the recruitment circles for the carpools, which, as the survey included in the same study showed, would cause a loss of trust in the system because carpoolers were not willing to travel with strangers (Correia, 2011). Also, the flexibility of dynamic ridesharing comes at the cost of not being able to guarantee transport whenever necessary, which means that there is room for a carpool scheme with guaranteed ride that introduces some flexibility.

This conflict between scale and trust is known for some time in the carpool literature. It has been reported that "an increase in (carpool) scale of participation, from companies to large-scale systems, has always been the objective of public policy making. Still, early research has shown that this is difficult to achieve due to the high probability of sharing the vehicle with a non-acquaintance, and the psychological effect that transporting persons who are not familiar can have in potential carpoolers (Duecker et al., 1977)" (Correia, 2011). Besides the empirical evidence, a theoretical social psychology view proposes that increasing group size has a negative impact on group member trust, cohesion, and commitment (Lawler, 2008). This theory builds on the idea that increasing group size likely reduces group members' awareness of one another, affecting cohesion and trust between them. So, beyond trust capital, we might even argue small groups are more likely to survive and succeed in carpooling.

Besides flexibility, the second major and often neglected obstacle to carpooling is the trust problem (Sievers, 2003). Trust is one of the core issues to be addressed to increase participation in ridesharing programs (Chaube, 2010). So far, dealing with the first obstacle to carpool 'flexibility' made society loose ground on the second obstacle 'trust'.
In our carpool approach, we propose a new way of obtaining some schedule flexibility with guaranteed ride without having to increase carpool scale. Therefore, this gain does not come at the expense of a loss of confidence or guarantees provided by the system. In our proposal every member of the carpool will meet each other before starting to carpool.

Our scale preserving approach to carpool flexibility abandons the strict idea of the ride-match concept to form carpools. Instead of being a strict restriction of our search (because if it did we would need more people to find coincidences), the time schedule for departure is now considered as a time interval comprising one, two, or even more hours. The new restrictions should look something like: “Willing to carpool from A to B with at least two departure times between 7 and 8”, or “Willing to carpool from A to B with at least three departure times between 7 and 9”. Incorporating these restrictions in the model means it must be possible to organize carpools in such a way that, for each journey, a small group of carpoolers will have at least two departure times available. At a first glance this might seem difficult to achieve. Probably that’s why these arrangements are not available so far.

In our model flexibility does not depend on the number of carpoolers (provided you have at least 4). For example while 7 carpoolers would hardly share the same departure time, requiring a match in a larger group, in our model you only need three cars for a 3 departure time mode (each car departing at a different time), which is possible and eventually satisfying for these 7 carpoolers, with a transport rate bigger than 2:1. So it is possible to have small and (relatively) flexible carpools.

Trust concerns usually have been taken care of once the ride-matches have been made on a database, through the use of information systems technology that submits every carpooler's identification to an intermediate organization. It would be possible, however, to address this problem previously, in the ride-matching process, as a restriction to the gathering of people in the same pool. In fact, trust (and trust concerns address) comes from knowledge, from people knowing each other previously. This is better achieved if the groups are grounded firstly on the basis of their professional or residential communities’ affiliation and vicinity. It might be argued that building groups from acquaintances could somehow limit the number of people available for carpool recruitment, but the fact is that the carpools coming out of such strategy should be more stable and stronger than the ones built through Internet ride-sharing sites.

These ideas are in agreement with the marketing argument that carpool development should be prudent and its growth determined by raising more members in a territory rather than expanding towards new territory (Hope, 2001). One reason for this is that “word of mouth“ will probably be the most effective marketing channel, making it critical that carpooling delivers high satisfaction levels (Scott, 1997).

According to the results of our second survey, and some data on Lisbon municipality’s car commuters, there seems to be room (at least in Lisbon) for our proposal of introducing flexibility in carpools while preserving this trust building approach. This is achieved by sticking to a small group carpool concept. Corresponding to the Portuguese smallest territorial units, the recruitment area is not very large (something like “within 10 minutes walk distance”), so some people will be acquaintances, and others will meet and get to know each other in advance. Groups are small for trust reasons, but this is also a consequence of having many carpools covering a small area each, to minimize distances to travel to meeting points, and avoiding large central hubs that would increase the amount of kilometres travelled.

4. A several departure time carpool model

The basis for the most convenient carpool model is the one that - while preserving carpool scale (maintaining small territorial units as the recruitment circles) - allows the maximum transport rate (per journey) and gives carpoolers a wider choice between different time schedules. A trade-off will have to be established between these two objectives. The following two carpool modes emerge, as the globally more convenient, each one representing a different preference:

- The two-departure time carpool mode (2DTM), providing a better transport rate
- The three-departure time carpool mode (3DTM), providing a wider choice in terms of time schedule

Following (Srivastava, 2012), in our model every carpooler is a potential driver that sooner or later will have to play that role. Besides its convenience for the carpool organization as we shall see, this guarantees a maximum benefit in terms of taking cars out of the roads.

As a simplification for a first study we assumed cars carry 5 people, which is quite common in Portugal. With 4 people cars, the attainable transport rate would decrease from 3:1 to 2,5:1 passengers per car in the 2 Departure Time Mode, and from 2,3:1 to 2:1 in the 3 Departure Time Mode.

In the 2DTM, a 3:1 transport rate is possible to obtain, i.e., in the best case scenario, each car of the pool will be able to transport, in average, three persons per journey. With 2 departures at different times and 5 people cars, discounting the 2 drivers, 4 occupants is the maximum number of people left that can find transport in any of the two departures, so 2+4=6 and we get 6:2 or 3:1 as the transport ratio. In order to achieve the maximum benefit, in this mode the carpool should be formed by a minimum of two cars and a number of carpoolers corresponding to three times a pair number of cars. The idea is quite simple. Taking the example of the carpool group made of 6 people and 2 cars (6/2), it is easy to see how this mode allows for any carpooler to take an alternative schedule whenever necessary, except for the days when he is a driver - 1 out of each 3 days[3]. In fact, once the driver is set for each journey, no matter what departure time each carpooler chooses, the remaining capacity of each car is always enough to transport the other persons (Figure 2).

TT	D	P	P	P	P
7h30	Car Number 1				
	1	**1**	**1**	**1**	**1**
8h30	Car Number 2				
	1				

Figure 2: Early arrive scenario in the 2 departure time carpool mode with 2 cars
(TT-Time Table; D-Driver; P-Passenger)

This maximum transport rate scenario naturally applies to multiples of the 6/2 combination between the number of people and the number of cars, making it possible to build 12/4 carpools, 18/6 carpools, etc. A 2DTM carpool with 12 people and 4 cars would work the same way, except that 2 cars would departure at the same time. Figure 3 scenario would occur if everybody were late on the same day.

[3]In two of the models presented later in the text - the car-share model and the flexible schedule model – this obligation is eliminated or made less inconvenient, respectively.

TT	D	P	P	P	P	D	P	P	P	P
7h30	Car Number 1					Car Number 2				
	1					**1**				
8h30	Car Number 3					Car Number 4				
	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Figure 3: Late arrive scenario in the 2 departure time carpool mode with 4 cars
(TT-Time Table; D-Driver; P-Passenger)

In the 3DTM, to attain its maximum benefit, the carpool group should be formed by a minimum of 3 departures and 7 people. Although this scenario apparently allows for more flexibility, this is only true for some of the carpool models to be described. In a carpool model built on the assumption that a driver is pre-defined for each journey this mode would imply that each person would have to stick to a time-table every 3 out of 7 days, as a driver, which means being obliged to one single departure time almost day in day out. This contradicts the purpose of flexibility that a three-departure time mode was supposed to fulfil.

To make the 3DTM mode effective, the time departure flexibility is extended to the drivers in the home to work journeys so that they don't have to be committed to a single predefined departure time anymore. This gives rise to the Flexible Schedule Carpool Model to be presented later. In fact, if every carpooler is a driver, and if there is a common meeting point, there is no obstacle to a late definition of each departure drivers. Only in their return home would each day's drivers be obliged to a single timetable[4], but in average this would only occur 3 times out of each 14 journeys (14 are each driver's journeys across 7 days, the total number of journeys 42 (in 3 DTM) divides by the number of drivers 7 to give 6 and dividing it by 2 to account only for returns one gets 3 times as a driver), which already seems quite acceptable.

Figure 4 shows the advantage of a late decision on who is the driver. Suppose the carpooler in car number 3 was supposed to be the driver at 7h15. The fact that he showed up late at 8h00 determined that unexpectedly another carpooler would have to be the driver at 7h15. This illustrates how driver flexibility benefits carpoolers.

7h15	D	P	P	P	P					
	Car Number 1									
	1									
8h00	P	P	D	P	P	D	P	P	P	P
	Car Number 2					Car Number 3				
	1	**1**	**1**	**1**	**1**	**1**				
8h45	D	P	P	P	P					
	No Car Departure									

Figure 4 – Driver replacement scenario in the 3 departure time carpool mode with 3 cars and variable driver (TT-Time Table; D-Driver; P-Passenger)

[4] In the car-share model presented later in the text even this obligation is eliminated

Both for 2 DTM and 3 DTM, besides the previous described scenarios, there are all the other non-optimal configurations with a different ratio number of carpoolers/number of cars per departure. For each number of carpoolers and each mode we have found the optimal number of cars departing and we present these later in tables 7 and 8.

- **New carpool models descriptions:**

As variations on the idea of the Several Departure Times Carpool, three other new slightly different carpool models have been identified, with the purpose of increasing carpool flexibility. So overall we have four possible configurations for a small carpool:

The Traditional Rideshare Model is the classic one where every carpooler travels everyday at the same predetermined time and with the same predetermined people. The only variable left is whether drivers are always the same for each journey or they rotate over a time period. Although less appropriate to the nowadays less predictable travel time schedule demands, this model enables car transport rates to reach their maximum and carpoolers to save as much money as possible.

The Alternative Schedule Carpool Model or Fixed Driver Carpool Model (2 DTM) is appropriate for people with a quite regular schedule but who desire to have a travel time alternative for each trip, or a tolerance margin for the departure time that guarantees transport in late arrival to departure occasions. This is the 2 DTM carpool, allowing for the economic and environmental expenditures to be at most one third of what they are now.

The Flexible Schedule Carpool Model or Variable Driver Carpool Model (>= 2 DTM) is the appropriate carpool model for people with less regular schedules, looking for a several departure time carpool mode that provides a maximum flexibility without having to share cars. In this system carpoolers might have available 2, 3 or 4 departure times available per journey, and still save between two thirds and one half of what they actually spend in their daily commutes. The only restriction is that once every six, five or four journeys (depending on the number of departure times mode) each carpooler will have to travel at a specified time as a driver. But even this is daily negotiable, i.e., most of the times a non-desirable obligation to drive might be postponed through an exchange with another carpooler.

The Car-share Carpool Model (>= 2 DTM) is a carpool model where one third of the carpoolers allow the other ones to drive their car whenever necessary. Although more difficult to implement due to obvious cultural reasons, this model is the one that provides the maximum schedule flexibility, since it delivers carpoolers the benefits of the Flexible Schedule Carpool Model without any need to periodically compromise as a driver. This model might require civil responsibility insurance extension.

The following diagram (Figure 5) tries to illustrate these differences:

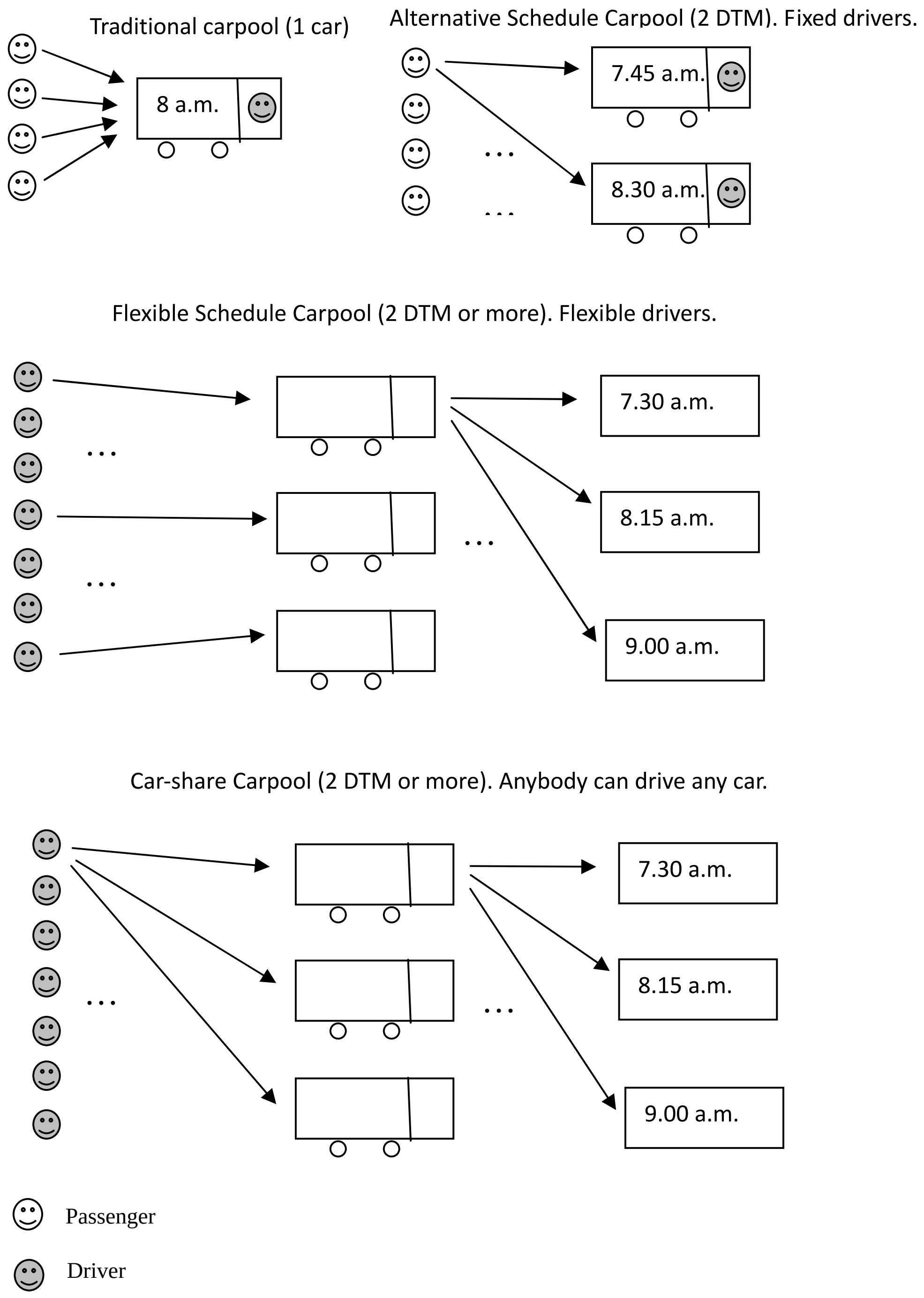

Figure 5: Differences between the new carpool models

Table 3 evidentiates the distinctive features of each one of these four model possibilities.

Table 3: Several Departure Time Carpool Models features comparison

Model	Drivers	DepartTime Modes	Periodic fixed schedule	Meeting points	Driver definition	Model target carpoolers
Traditional Rideshare	*Car Owners*	*1 DTM*	*Everyday*	*Usual car parking place*	*Pre-determined*	*Fixed schedule carpoolers*
Alternative Schedule Carpool	*Car Owners*	*2 DTM*	*Once every 3 days*	*Common parking zone[5] or usual car parking place*	*Pre-determined*	*Relatively regular schedule carpoolers or carpoolers with no common parking zones nearby*
Flexible Schedule Carpool	*Car Owners*	*2 DTM 3 DTM 4 DTM …*	*Once every 6, 5 or 4 journeys*	*Common parking zone[6]*	*On departure*	*Flexible schedule carpoolers*
Car-share Carpool	*Any carpooler*	*2 DTM 3 DTM 4 DTM …*	*None*	*Common parking zone[6]*	*On departure*	*One 3rd Carpoolers willing to share their car or every carpooler willing to share their car once every 3 days*

- **Comparison with previous approaches:**

Our model - Several Departure Times Carpool Model - seems to be the first to simultaneously guarantee a certain reasonable level of transport, flexibility and trust. Table 4 describes how it compares with others.

Table 4: Comparison of the new carpool model to prior approaches

		Guaranteed Ride	Flexibility	Trust level
Carpool model	*Traditional*	*Yes*	*None*	*Good (Lawler, 2008)*
	Dynamic ride-sharing (Deakin, 2011)	*No*	*Plenty (bigger scale allows for more match chances) (Deakin, 2011)*	*Bad (Lawler, 2008)*
	Hybrid (traditional and dynamic coexistence) (Correia, 2011)	*Yes*	*Plenty (bigger scale allows for more match chances) but not guaranteed (Correia, 2011)*	*Perceived as bad (Correia, 2011)*
	Several Departure Times Mode	*Yes*	*Some guaranteed*	*Good*

5 Parking zone where usually there are several available parking places that works as a meeting point where carpoolers leave their cars.

- **Other operational details:**

Following the recommendations resulting from similar experiences in Europe [16] and the USA (Scott, 1997), whenever possible the meeting points shouldn't be more than 10 minutes distance by foot (in average) from the carpoolers' residences and workplaces. This would allow non-drivers to reach the meeting points by foot in the models with pre-determined drivers, and minimize driving to get to the meeting points in the other cases, when the model requires availability of all cars.

An important feature of this model is that it will rely on a central system that forms the groups, ensures fairness and adherence to the rules (like punishment of cheating), manages changes in schedules and group members, and runs periodic group meetings to promote team spirit. Such system is funded through a monthly fee that carpoolers pay to be part of a group, quite smaller than the monthly savings for using the system. We expect carpoolers to find such investment worthwhile since nowadays transport needs dynamics ensures there will be frequent changes in group members and schedules, as well as potential conflicts, which need to be managed.

Unforeseen events are taken care of by such system for example through a guaranteed ride home, in a taxi. The organization guarantees a certain number of free taxi rides for each group, which is a common successful practice in carpool systems (VTPI, 2003), (Leibson, 1994).

In its first version this is a point to point transport system. It can have stops along the way but only when they are part of the most consensual itinerary towards the final destination.

- **Interplay with public transport options:**

Concerning the advantages of carpooling, one might argue, in particular in larger cities, that the space freed up by increasing occupancy is taken by new cars previously deterred by high congestion levels. This would eliminate all positive effects and potentially harm ecological benefits by adding weight carried by cars.

To clarify this, one can consider that roads are used at a level c (variable to designate capacity) which corresponds to a state of equilibrium between the willingness to drive and the discouragement of road congestion. We can consider that this capacity c is characterized by the number of cars on the road. Now on the long term we have the pessimistic scenario of an elastic procurement for driving, since traffic demand seems to follow travel time improvement (1% saving in travel time generates 1% increase in volume traffic in the long term (Goodwin, 1996)). This means that some time after the carpool system freeing up space on the road, that space will translate into an easiness of circulation and can be occupied from previous public transport users, with road usage at level c again, and cars will carry more people than they did before, so that from the ecological point of view things could look a little worse due to the extra weight carried by cars.

However, compared to car weight, extra passengers do not make much difference. Pollution costs for cars are computed as costs per passenger kilometre (European Commission, 2003), which means that global car pollution values are simply divided by average numbers of passengers to get their marginal pollution, suggesting that the more passengers cars take, the less they pollute, from the consideration of this indicator. So from the ecological point of view, overall, the same number of cars carrying more people is not something necessarily bad, and statistically, might even be interpreted as a change for the better.

From the economic point of view, in turn, in the new scenario there are clear and guaranteed benefits, since car occupancy increased and more people are getting transport for approximately the same car fuel consumption. Public transport has costs too (ecological and economical) and if users get to prefer carpooling it means they find it more beneficial. Since what we were looking for was global environmental impact optimization (not only ecological - see table 1) this led us to consider the scenario we propose here as better then the one without carpool.

5. Carpool Model Optimisation

Operations research (OR) has already been used to support carpool decision making. See for example (Manzini, 2012), where clustering models helped group users in the same carpool. This research used the level of similarity between two users who want to carpool as a measure of the savings which encourage them to share a group. Another example of an OR approach to carpooling was the use of simulation to study the viability of carpooling clubs in a given region (Correia, 2009), based on census data. Carpooling studies traditionally have dealt with many-to-one (home-work) or one-to-many (work-home) problems. Another OR approach in the carpool research context comes from the novelty of modelling the carpool system as a network in a many-to-many scenario (Yan, 2011), (Vargas, 2008), and using integer linear optimization to determine the best vehicle timetable (Vargas, 2008). In (Agatz, 2010) we find the result that using sophisticated optimization methods instead of intuitive rules substantially improves the performance of ride-sharing systems. This conclusion is a strong support in favour of our Operations Research approach to try to introduce some flexibility into carpool systems while keeping them small.

Our focus however, is distinct from these applications. We focus on the optimization of the carpool functioning modes, once the number of carpoolers in each group is settled, under a one-to-one scenario.

5.1 Decision of the driver for each journey

The decision of the driver is connected with the costs division policy decision inside the group. Considering that in the new carpool concept every carpooler is a driver, each carpooler’s monthly costs with fuel, road tax and parking will be proportional to the number of times he or she drives his car in the carpool each month. Given the uncertainty around daily driver's definition in two of the models, the first obvious way to deal with this would be to register the number of times each carpooler is a driver, monthly elaborate an account sheet with each one's costs and redistribute expenses evenly between carpoolers, charging some of them and paying to the others. However, besides the bureaucracy involved, this would be costly to manage. Following (Srivastava, 2012), where the rotational driving role is considered as an incentive to carpool, and departing from our objective – keep the costs division simple – the causal relationships in Figure 6 motivated the search for a solution to enable driver rotation in every carpool model:

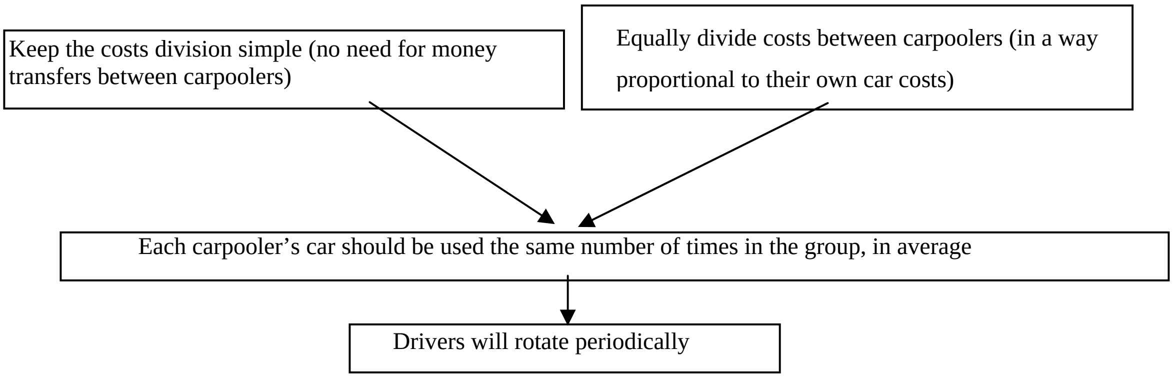

Figure 6: Causal relationships inducing the search for a drivers rotation solution

ι) <u>The models with predetermined drivers</u>

For the traditional and alternative schedule carpool models the solution is simple. One will simply have to settle a weekly or monthly scale to make sure driving responsibility is equally divided between carpoolers.

ιι) <u>The models with decision of drivers on departure</u>

For the flexible schedule and car-share carpool models - with a late decision of drivers - it will not be possible to predict who will show up in each departure. Therefore, an alternative strategy was developed to deal with this problem.

The basic idea is that a different number could be attributed to each carpooler, so that whenever they meet, the one holding the highest number would be the driver. Exchanging these numbers periodically and evenly between carpoolers would guarantee that, in average, each carpooler's car would be running the same number of times.

In fact, considering a group made of n carpoolers, with each carpooler holding a different number between 1 and n that increases one unit a day (until it reaches n to start again as 1), then the probability of each carpooler being a driver in a certain day equals to $\frac{i}{n}$ where i stands for the number the carpooler holds that day. Since numbers rotate evenly, the average probability across n days of being a driver can be obtained through the following expression:

$$\frac{\sum_{i=1}^{n} \frac{i}{n}}{n}$$

, being therefore the same for every carpooler.

This solution, however, would still oblige a group to keep a record of carpoolers numbers and rotate them periodically (daily or weekly). Carpoolers would also have to memorize their numbers each day.

A better solution is to let numbers rotate by themselves and associate a fixed number to each carpooler to be compared with the "rotating numbers". "Rotating numbers" could be month days, but not all months have 31 days and there is February, so comparing with these numbers could induce a systematic asymmetry.

Instead, we will take the "rotating numbers" to be "Number of the day of the week" (discarding weekends) concatenated to "last digit of month day". So we get the following possible combinations:

20,21,22,23,24,25,26,27,28,29,
30,31,32,33,34,35,36,37,38,39,
40,41,42,43,44,45,46,47,48,49,
50,51,52,53,54,55,56,57,58,59,
60,61,62,63,64,65,66,67,68,69

These numbers have two advantages over the day of the month:

-Although the numbers are still not all equally likely to occur (for example the termination '1' is sometimes possible for 4 days of the month while the termination '2' is only possible for 3) this effect is now less influent because the most significant digit (that settles the result of most comparisons) changes everyday, diluting the importance of slight asymmetries in the statistical occurrences of the last digit.

-There are also more numbers available (20 more) which makes it easier to deliver numbers to carpoolers (we do not expect carpools of more than 50 people)

If carpoolers fixed numbers were decided as equally spaced numbers between 20 and 69, starting from 20 for the first carpooler, summing the integer part of $50/n$ to this number to obtain the second and so on (n being the number of carpoolers in the group) then applying the following rule would guarantee a late definition driver rotation with minimum effort:

1. When two or more carpoolers meet for a departure, the driver will be the one whose number holds a greater difference (in absolute value) to the current "rotating number"

2. If the difference happens to be the same between drivers then just take the following rule: if the month day is pair, the highest number carpooler will drive, if not, the smallest number carpooler will.

This way each carpooler would only have to memorize one small number, make an easy subtraction and be able to recognize a pair number. It would not be too much to expect as a mathematics preparation to carpooling.

When new members join the carpool or others leave (and this can happen suddenly) one has to make sure that an even distribution is still applied. Dealing with such unforeseen events is the sort of work that the carpool management system people would be doing – managing changes on a daily basis, which would mean updating the numbers assigned to each carpooler and messaging them about it.

To prevent people from lying about their numbers for their own convenience, each carpooler would be able to know other carpoolers' numbers and check them (a message with this information should be made available to the group).

5.2 *Carpool groups model decisions*

i) <u>Carpool model alternatives</u>

Provided there are no special schedule flexibility requirements, the decision diagram in Figure 7 might help to decide on a carpool model adoption. If the same departing time is ok for everybody then the traditional model is the best because it leads to higher vehicle occupancy rates. Otherwise, there will be some flexibility in departure times, the extent of which depending on two factors:

-First, whether there are common parking zones available next to carpoolers homes and workplaces, so that they can meet there and allow for a late and convenient decision on who is the driver. If this is the case, the flexible schedule carpool becomes possible (2 DTM or more). If not, we have the alternative schedule carpool (2DTM), where drivers for different departures will have to be settled in advance, which places a periodical constraint on carpoolers departure times when they are playing driving roles.

-Second, whether besides the common parking zones there are also enough people letting all others drive their car. This is the most flexible model because nobody has to stick to a timetable as a driver, so you can always have 2, 3 or 4 departure times at your disposal without any constraints. We call this the car-share carpool model, which improves on the flexible schedule carpool model.

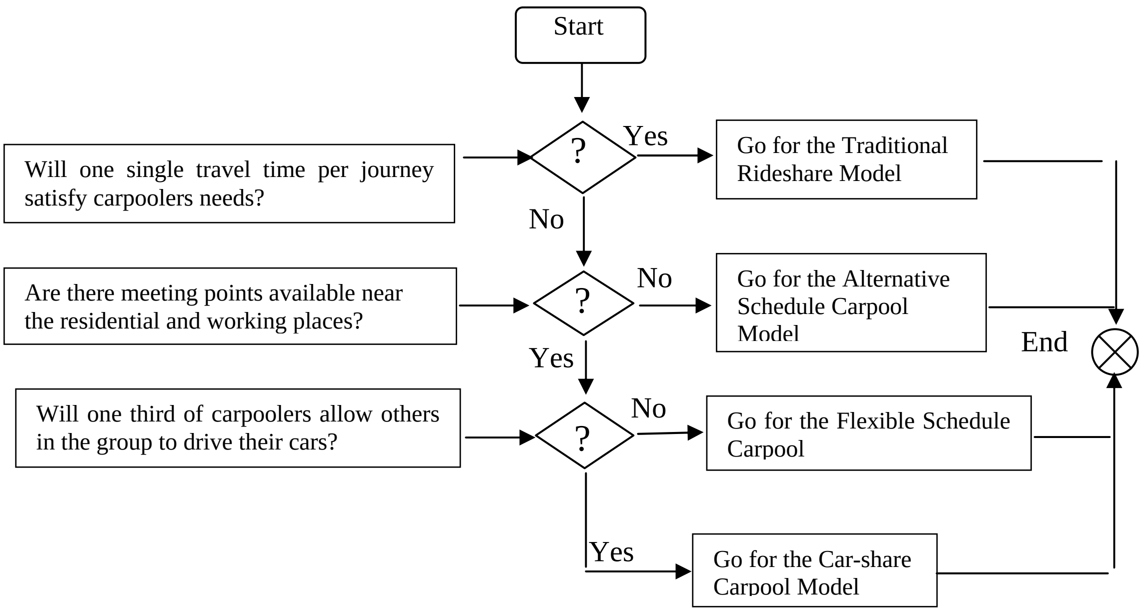

Figure 7: Decision rules to choose the appropriate carpool model for a group

ii) Carpool departure mode and number of cars alternatives

If the group is going to adopt the Flexible Schedule or the Car Share Carpool Model then the following reasoning applies:

Given a number of potential carpoolers (which we can't control) for a group sharing common routes and common journey schedules[6], the carpool optimisation problem reduces to finding out the right DTM (departure time carpool mode) and the right number of cars to use in each departure. Assuming that for the carpoolers preferences a 2DTM would already be acceptable, the problem can be quantitatively defined[7] the following way:

Taking the following variables:

na (problem data) -Number of potential carpoolers;
m (decision variable 1) - DTM (the number of departure times available)
ncp (decision variable 2) - Number of cars for each departure

Maximize[8] $\left(\frac{na}{ncp \times m} + \frac{1000}{1000 + \frac{1}{m}}\right)$

subject to the following restrictions:

$na \leq [(m \times ncp) - 1] * 5 + 1$ --> for 2 DTM guarantee seat available for every carpooler in every journey

or

$na \leq [(m \times ncp) - 2] * 5 + 2$ --> for 3 DTM guarantee seat available for every carpooler in every journey

$m \geq 2$ ---> for 2 DTM there should be at least 2 departure times available
or
$m \geq 3$ ---> for 3 DTM there should be at least 3 departure times available

$na \geq m \times ncp$ ---> the number of cars can't exceed the number of carpoolers
m *is* *Integer*
ncp *is* *Integer*
$ncp \geq 1$

The optimal solutions are the ones that maximize the number of carpoolers transported by car departing, but guarantee that there is always transport available on any departure time if necessary. Listed in Table 5 these optimal solutions have been found through the use of Excel Solver for groups with a number of carpoolers varying between 4 and 20. The maximum number of 20 carpoolers was used just as an example, for demonstration purposes. Numbers for larger groups can be easily computed as indicated. Anyway carpools are not very likely to

[6]such as departures between 7 a.m. and 9 a.m. for the home-to-work journey and between 5 p.m. and 7 p.m. for the return to home journey
[7]Some simplifications were assumed: there are 5 seats in each car and ncp is the same across group departures
[8]The 2[nd] term was added to award the solutions with higher m between those with the same product (m*ncp)

exceed this number because this is a point-to-point transport system, which decreases the likeliness of shared routes, and because there is a concern over trust issues which is handled by recruiting people to carpools on an acquaintance basis or by promoting this acquaintance prior to using the system. Large groups would harm this principle. Large groups would also make it more difficult to find common parking zones large enough for the group, and eventually become more difficult to manage.

Table 5: Optimal solutions ratio (nr. of people per car) for the number of departure times (m) and number of cars for departure time (ncp) given any number of carpoolers between 4 and 20 with a minimum of 2 DTM.

na	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
m	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
ncp	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*3*	*3*	*3*	*3*
nr./ car	*2*	*2,5*	*3*	*1,8*	*2*	*2,3*	*2,5*	*2,8*	*3*	*3,3*	*3,5*	*3,8*	*4*	*2,8*	*3*	*3,2*	*3,3*

If the carpoolers preferences required at least three departure times available (at the cost of a worse transport rate) then one would just have to enforce the minimum number of DTM restriction:

$m \geq 3$

, as well as change the restriction to guarantee seat available for everybody.

The optimal solutions under this scenario would now be different.

Table 6: Optimal solutions ratio (nr. of people per car) for the number of departure times (m) and number of cars for departure time (ncp) given any number of carpoolers between 4 and 20 with a minimum of 3 DTM

na	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
m	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
ncp	*1*	*1*	*1*	*1*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*
nr./ car	*1,3*	*1,7*	*2*	*2,3*	*1,6*	*1,5*	*1,7*	*1,8*	*2*	*2,2*	*2,3*	*2,5*	*2,7*	*2,8*	*3*	*3,2*	*3,3*

Lets suppose carpoolers were unable to decide which should be the minimum number of departure times available (2 or 3) given this objective's conflict with the transport rate associated cost. In that case, a simple relative preference order procedure would help to decide between the solutions obtained for each of these alternatives.

Considering 20 carpoolers, to compute the transport rate cost associated with the solutions in tables 7 and 8 one just has to divide the number of daily cars in use for the number of carpoolers (8/20 for the 1st solution and 12/20 for the 2nd).

Table 7: Cost comparison for two different DTM restriction values with a group of 20 carpoolers

Alternatives	*Total Departures*	*Total Carpoolers*	*Car usage cost compared to drive-alone behaviour (total car departures/total carpoolers)*
2 departures 4 cars per departure	*8*	*20*	*40%*
3 departures 4 cars per departure	*12*	*20*	*60%*

Now to order preferences one would just have to ask the following question to the group:

-Would you rather have <u>2 departure times available</u> a day and spend <u>40%</u> of what you do now,

<u>or</u>

-Would you rather have <u>3 departure times available</u> a day and spend <u>60%</u> of what you do now?

Considering that different carpoolers will probably have different preferences concerning the trade-off between departure time modes and costs, group decision aid methods might be of some help (Goodwin, 2004), (Tavares, 1996). Applying the same logic to the different possibilities of carpoolers numbers in a group, and eventually extending the carpool number of departures restriction to $m \geq 4$ (or more), one would arrive to appropriate solutions to the carpool mode and number of cars definition problem[9].

1.1 Carpool groups meeting points location

The problem of deciding where to locate a carpool group meeting point has some similarities with the traditional OR problem of facility location, with several particularities.

Table 8: Similarities between the facility location problem and the carpool meeting point location problem

OR Facility Location Problem	*Carpool Meeting Point Location Problem*
-How many facilities should be used and where should they be located?	*-How many meeting points should exist and where should they be located?*
-Which costumers should be served from which locations?	*-Which carpool members should use which meeting points?*

[9]One can't forget the "same number of cars for departure" assumption. To be precise on the number of cars in each departure requires the elimination of this assumption and making certain adjustments to the solutions (or refine the model). For example, with 19 carpoolers, having 3 cars in one departure and 4 on the other would be a better solution than the one provided.

Considering the usual parking difficulties in several municipalities in the metropolitan area of Lisbon (not only inside the city) there will not be many alternatives available for carpool groups meeting points. We will therefore start with a limited number of alternatives, and proceed to associate carpoolers to a certain meeting point. Consider for example a group of 17 carpoolers with its spatial distribution in a municipality being represented in Figure 8. Provided there is only one proper meeting point location alternative, the problem is solved. Carpoolers would meet in point A and then proceed sharing cars to reach point B, their common final destination.

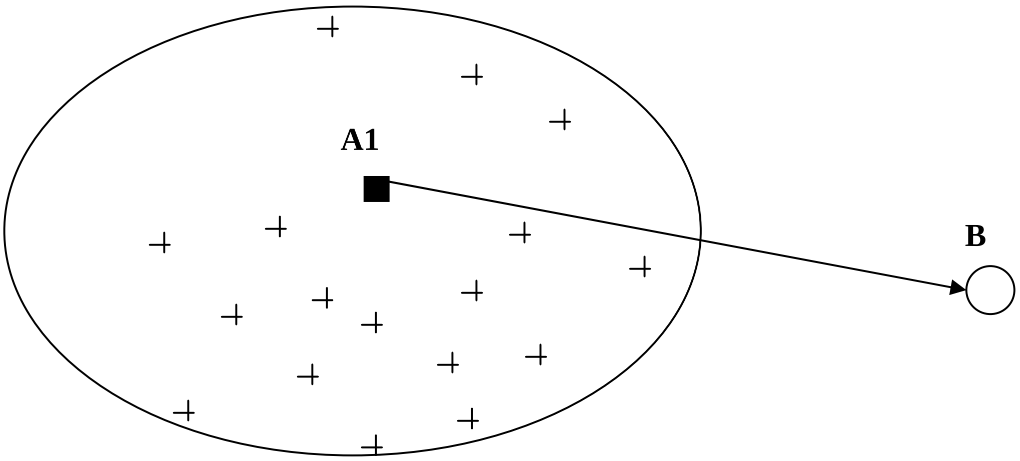

Figure 8: Carpool meeting point location decision with a single alternative (+ signs represent carpoolers)

But if instead of 1, there were 3 locations available (Figure 9), several questions arise, the first obvious one being which location alternative to choose, if we just wanted one. A3 seems an obviously sub-efficient alternative, but what about A1 and A2? Being closer to the "gravity centre" of all carpoolers locations, the total cost of carpoolers meeting in A1 would be less than meeting in A2. However, once the meeting takes place, the distance to travel from A1 to B would be greater (though at a lower cost since carpoolers would already be sharing cars). Computing the total miles driven by every car in each scenario, the location that minimizes them could be chosen (a simplification to compute this would be to assume full availability of roads with equal traffic between them and take the Euclidean distances).

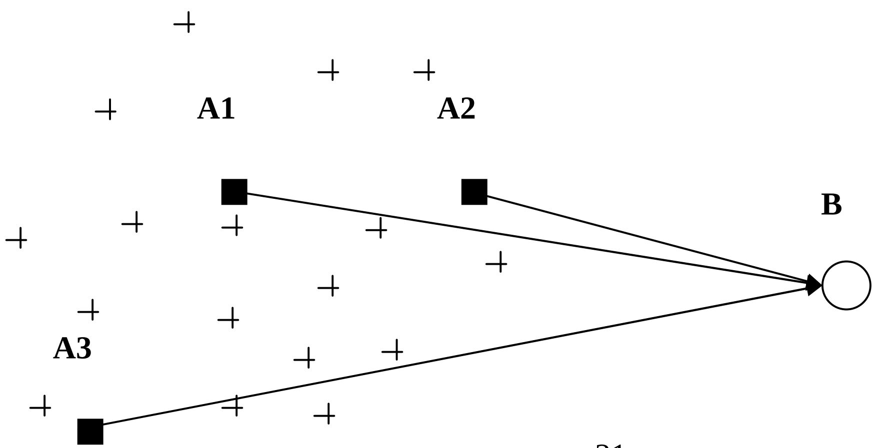

Figure 9: Carpool meeting point location decision alternatives (+ signs represent carpoolers)

But if several locations are possible, we don´t have to stick to one. Maybe a distribution of carpoolers between several meeting points would be better. For a certain number of carpoolers with coincident travel plans, several carpool groups partitions are possible. As we see in table 9, with 17 carpoolers we might have not only one but two or three carpool groups, served from different meeting points. Recalling table 5 results, the following group partition alternatives would be possible with no more than 2 departure times available:

Table 9: Group partition alternatives to organize 17 carpoolers in 2 DTM with coincident travel plans. The optimal ones are shaded.

Number of groups	*Group partition alternatives*	*Number of carpooolers*	*Nr. of departures*	*Nr. of cars per departure*
1	*17*	*17*	*2*	*3*
2	*11+6*	*11*	*2*	*2*
		6	*2*	*1*
	12+5	*12*	*2*	*2*
		5	*2*	*1*
	13+4	*13*	*2*	*2*
		4	*2*	*1*
	10+7	*10*	*2*	*2*
		7	*2*	*2*
	9+8	*9*	*2*	*2*
		8	*2*	*2*
3	*4+6+7*	*4*	*2*	*1*
		6	*2*	*1*
		7	*2*	*2*
3	*4+5+8*	*4*	*2*	*1*
		5	*2*	*1*
		8	*2*	*2*
3	*4+4+9*	*4*	*2*	*1*
		4	*2*	*1*
		9	*2*	*2*
3	*5+6+6*	*5*	*2*	*1*
		6	*2*	*1*
		6	*2*	*1*
3	*5+5+7*	*5*	*2*	*1*
		5	*2*	*1*
		7	*2*	*2*

Provided that $\sum m * ncp = 6$, as with just one group of 17 carpoolers, the solution could not be better, so we have the following optimal solutions, considering only the maximization of number of carpoolers per car:

17, 11+6, 12+5, 13+4, 5+6+6

So for example, in the 11+6 scenario, as represented in Figure 10, two groups of carpoolers could be “clustered to” two different meeting points. Considering the next decision of whom meets in which point, this now could be done in such a way as to minimize travelled distances. Considering now the miles driven, probably the 11+6 scenario could be better than the single group solution (17 scenario), since it minimizes the distances every carpooler has to travel sub-efficiently (alone) – the ones that contribute more to the total driven miles.

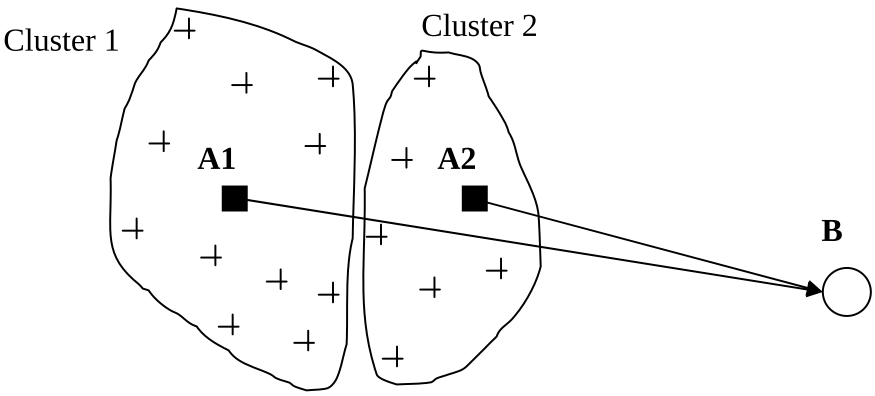

Figure 10: Optimal carpoolers clustering to different meeting point locations with 17 carpoolers

To combine our model with decision analysis on locations, and because we might divide a group into smaller ones assigned to several locations, we have to consider only the optimal configurations among the several carpool group partition alternatives for a certain number of carpoolers. This way, no matter what location decisions determines (from other factors), the benefits of the carpool model remain intact. This approach is important from a global optimization perspective, which avoids losing in other criteria (location optimization) what we gain from the carpool model transport rates. We can consider there is a certain modularity of the carpool groups, within the limits exemplified in tables 7 and 8, if when dividing a group in smaller pieces, one considers only the optimal partitions.

Given a certain number of carpoolers, with potential to share rides, one is free to build larger or smaller groups, with correspondent different numbers of location alternatives. With smaller groups we can adjust people to closer meeting locations than if they belong to one single group and are forced to converge from a wider area. But no matter what our location decision is, if our search space is confined to the optimal configurations within tables 7 or 8, the solutions are always efficient, irrespective of the minimum number of cars departing. So within these limits we can decide about locations independently, for example based on a criteria of distances travelled by the carpoolers to the different meeting points and from there to their destination.

6. Survey results

We have included two exploratory surveys, still not rigorous enough for final conclusions, as a first attempt to establish whether this carpool model deserves further consideration or not, namely, a wider appreciation from more rigorous surveys in future work.

6.1 First Survey

A first survey proved useful to shed some light over the uncertainty around the population adherence to the several departure time carpool system proposal. A survey was conducted in the municipality of Oeiras (Lisbon district) aiming to provide estimates of the driver's adherence to the system.

Fifty daily car drivers to Lisbon were interviewed by telephone after being randomly chosen from the Oeiras municipality telephone book. The interviews were conducted both during weekends and labour days, in the morning, during the day and at night.

In terms of sex, the sample is quite representative of the population. In 2006 we had 63% of men and 37% of women among commuters in Portugal (ANSR, 2006), which falls within a 5% error margin of the correspondent percentages in the sample. In terms of age we also find a reasonable correspondence with the sample distribution. In 2006 there were about 10% of drivers 24 years old or less (ANSR, 2006). In the sample we had 16% of drivers less than 30 years old. So we have a minority of young drivers, which follows the age profile of the Portuguese population where seniors are becoming more representative.

In our Survey we got the following distribution of the sample:

i) Sex:

20 women (40%)
30 men (60%)

ii) Age:

More than or equal to 30 years old - 42 people (84%)
Less than 30 years old – 8 people (16%)

For a Bernoulli population, and assuming a normal sample distribution, the obtained sample average for the population adherents proportion was 52%.

Results showed that between 38% and 66% of Oeiras drivers (19500) were willing to use such carpool system for commuting between home and work, that is, between 7.391 and 12.838 potential adherents, for a 95% confidence interval.

The respondents who were not interested have indicated the main reasons for not enrolling:

-8 drivers had different schedules everyday.
-4 drivers had different destinies everyday.
-4 drivers would not enrol for family reasons, mostly for already taking family members in their car with them.
-2 drivers needed their car during the day

In spite of some probable bias of the answers towards an adherence to the model, given the sympathy it naturally inspires, altogether, the results suggest a certain acceptance of the several departure carpool model here presented.

6.2 Second Survey

A second survey complemented the first for being more specific about the type of carpool flexibility the new model introduces, and about the schedule requirements of the respondents, to figure out whether these were compatible with the concept.

The respondents were targeted through an email chain. Therefore, the sample can not be considered random and we can not generalize the results to the population. However, it is useful as a preliminary test. To help us realize how far our sample might be from the population we have collected the following data on the respondents:

- The great majority (36 out of 38) of the asked persons commuted by car.
- 92% of the respondents were between 25 and 44 years old, while there are only 48% of Portuguese drivers in this age interval (ANSR, 2006).
- 92% of the respondents were graduated, against only 9% of Portuguese people with that degree.

Considering these data we observe a bias of the sample towards more educated people, and towards people in the early to middle stages of their career (relatively young people). If on one hand this means that the sample might contain a majority of people with environmental concerns, eventually more open to carpooling than the population, on the other hand more educated people might be economically better off, and less attracted by the savings potential of carpooling, which might balance the first effect.

We also realized that the profile of the interested carpoolers reveals something expected – their majority holds a profession with more stable schedules (public sector or other non-liberal professions):

Table 10: Carpoolers willing to enrol by profession

	Liberal professional	*Public Sector*	*Working for others*	*Other*	*Unknown*
Adherents Percentage	*0%*	*40%*	*10%*	*37%*	*13%*

Concerning respondents views on the main advantages of commuting by car we have found the following:

- Autonomy seems to be the major reason for commuters to avoid carpooling, which confirms the importance of approaches like our own that try to improve carpool flexibility.

- There is also a significant number of people considering travel time as the biggest advantage of car usage for commuting, against autonomy or comfort. Since our proposal relies on point to point routes (not more than 10 minutes away from the carpooler), it dispenses a transfer into more central locations where larger groups of people would show up. So we realize that avoiding a carpool scale increase holds the side benefit of decreasing travel time, by making travelling distances smaller. Therefore according to the second survey, our carpool system might improve the state of the art in two important advantages of car usage for commuting: autonomy and travel duration.

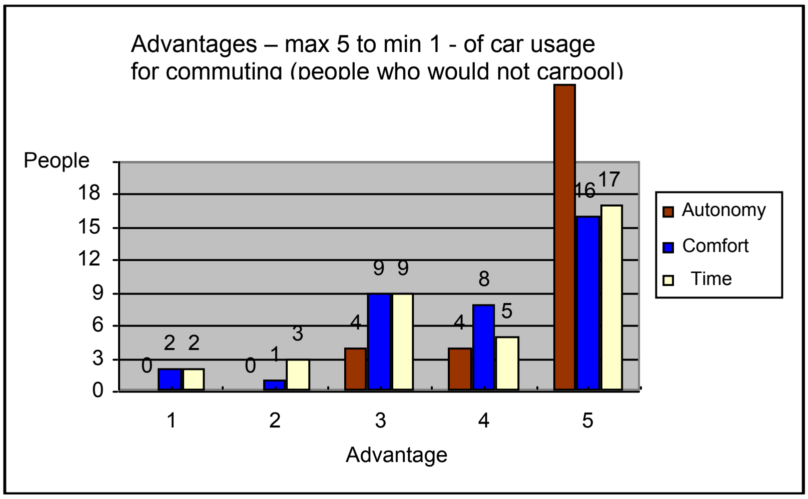

Figure 11: Advantages of commuting by car according to people who would not carpool

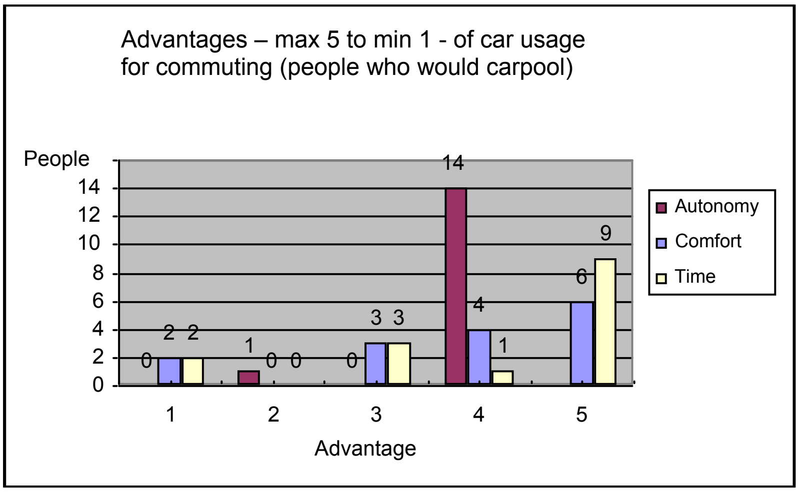

Figure 12: Advantages of commuting by car according to people who would carpool

In the main core of the survey the question was:

“Would you be willing to enrol in a carpool that provided 3 departure times distributed along a two hour time interval containing your usual departure times?”

And the results were:

From 38 respondents among a few more, 12 of them (32%) said they would enrol in a carpool functioning this way. And one third of these (10 %) had schedule preferences compatible to build a carpool they could form together.

- **Survey Analysis:**

The second survey suggests that approximately one third of potential carpoolers were effectively willing to enrol in the new carpool system proposed, with its particular kind of flexibility. Since our system is a point to point transport system, which assumes a great dispersion of potential carpoolers across regions and does not try to bring them to common places more than 10 minute away (by foot) from their houses and jobs, we have tried to check - in a very preliminary and heuristic way - whether in the Metropolitan area of Lisbon the “travel plan coincidence potential” could be enough to justify this alternative model.

So we obtained data for the number of people commuting to Lisbon as drivers coming from the different municipalities around. The average number for municipality was of 10157 people in 2001, considering 19 municipalities (INE, 2003). Dividing this number by the average number of 9 residential areas inside each municipality, and afterwards by 25 residential areas in Lisbon, we get approximately 45 people (in average) per route, i.e. travelling from every specific small residential area outside Lisbon to every specific small residential area in Lisbon. If about one third of these people is willing to enrol in the carpool system functioning under the new model, as the survey suggests, then in average we would have something around 15 carpoolers available for every route point to point.

However, according to another section of the survey, only a part (about a third) of the interested carpoolers had schedules compatible with the model features. The others demanded several departures at too early or too late hours, or a flexibility across a too long time window (3 hours or more) and it was not possible to deliver a solution compatible to the proposal each carpooler was willing to accept. Then we would be left with 5 carpoolers in average, which is perfectly enough for a carpool.

Therefore, further work could be worth to explore the viability of this approach, since in average several residential areas from municipalities in the Metropolitan area of Lisbon (as an example) might be eligible to choose point to point routes towards Lisbon for the new carpool system – particularly if the residential areas are contained within a 10 minute walk radius.

The more promising routes are the ones that involve more populated municipalities, because they are more likely to exhibit travel plans coincidence. Anyway, if one is suspicious about the model's viability, given the possible scarcity of carpoolers for many routes, it is easy to propose a simple aggregation of some residential units as a solution to that, without disregard for the principles of “small carpool” and “small distance to meeting point”.

We tried to be conservative in the analysis of the survey, for example by taking non-responses to some questions as a negative response. For simplicity, in this brief analysis we have left out the routes linking two different municipalities outside Lisbon. Those are, however, promising routes. Given their length, they will allow greater cost savings, and carpoolers here have fewer alternatives available (in terms of public transportation).

7. Conclusions

From an environmental and economical point of view, carpool is beneficial mostly in a context of car travel plans coincidence, particularly if the 'volume' of this coincidence is large enough to account for the possibility of some variation in schedules. To achieve this flexibility, which is recognized as a critical success factor of carpooling, practitioners usually enlarge the recruitment area for the carpools, so that is easier to find somebody sharing the same schedule needs. But this scale increase determines sharing rides with somebody one doesn't know, which undermines trust and compromises carpooling, according to theory and experience. Also, such “dynamic” ride-sharing schemes depend on the availability of ride-matches, which are not guaranteed on a daily basis.

We have found a way of introducing some flexibility in departure times without increasing scale or loosing guaranteed rides. We did this by relaxing the schedule match restriction. Within our model carpoolers with some differences in schedules can still belong to the same group. They share a schedule made of a time interval comprising each carpooler's usual departure time, and making several departure times available within that period.

We are aware that the scale and rigour of the surveys is not enough to reach conclusions but we find them interesting as means of showing this model deserves further study, screening and testing, and this was the reason why we have included them in the study.

The surveys results seem to point to the viability of the system. Though we can't be sure because the sample was not random, results seem to point to about 32% of potential carpoolers willing to enrol in a carpool system like the one we present. These respondents have stated that they would be willing to use a system that guarantees three possible departure times within a two hour time window containing their usual departure time. The percentage of interested carpoolers reduces to about 10 % if one takes into account the fact that the real schedule demand preferences these carpoolers indicated were not all compatible between themselves (we also assumed they were not negotiable).

As an approximate value, these 10% seem promising enough to anticipate the possible use of this system as an alternative to traditional carpooling, for example in the Metropolitan Area of Lisbon. According to our exploratory analysis, numbers for many of the routes linking small residential areas outside and inside Lisbon show they could be viable for this means of transport.

Overall, our several departure time carpool model, that preserves scale, trust and guaranteed rides while introducing some flexibility, seems to deserve further study and pilot implementation.

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