A disaggregate model of the effects of parking guidance systems

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A disaggregate model of the effects of parking guidance systems

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A Disaggregate Model of the Effects of Parking Guidance Systems

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1 Introduction

The effects of the provision of accurate and real-time information on driver behaviour is currently a central topic of dedicated transport research programs around the world (DRIVE in Europe, the IVHS-initiatives in the USA and similar research in Japan, Canada or Australia). It is therefore surprising that the effects of the second most widely implemented type of information system - real time parking guidance and information (PGI) systems - have not received more attention in the literature (See for example Polak, Hilton, Axhausen and Young, 1990, Axhausen, Polak, Boltze and Puzicha, 1994 or Smith and Philips, 1993). It shares that fate with the most widely implemented type of information system: radio-based information (for an exception see Polak, Vythoulkas and Chatfield, 1993). Recent reviews indicate that more than 100 PGI-systems have been installed, primarily in Europe and Japan (Polak *et al.*, 1990 and Körntgen, 1993). Using variable-message signs (VMS) a PGI-system provides the motorist with real-time/predictive information about the number and location of free spaces in the local off-street facilities.

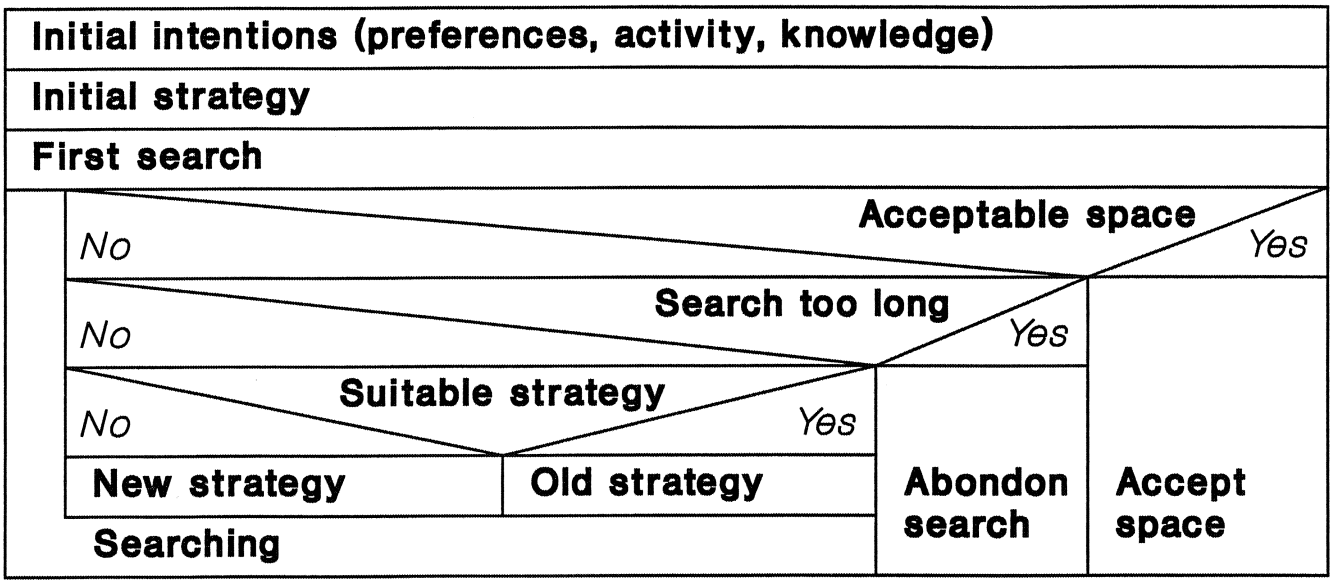
While aggregate impact analyses of different levels of sophistication have been performed in the past, disaggregate analyses of how the PGI-system influences behaviour had not been published. A recent before-and-after study of the impacts of the new PGI-system in Frankfurt/Main has allowed to start to fill this gap. The key concept of this analysis is the idea that drivers organize their parking search with the help of distinct *parking search strategies*. The purpose of the analysis is to try to understand through which behavioural shifts the aggregate effectiveness of the PGI-system is effected.

Figure 1 shows the behavioural framework of this study, which has been developed earlier on the basis of group discussions and other survey work (see also Axhausen and Polak, 1990). The driver starts out on his trip with a set of initial intentions about the location of the planned activities and their duration. These intentions are based on the driver's knowledge of the urban area, among other things with respect to the availability and costs of different forms of parking. Part of these intentions is the chosen parking search

strategy. The strategy defines the starting location of the search, the types of parking to be considered and the way in which to conduct the search; e.g. for someone who has decided to go straight to an off-street facility free on-street spaces are irrelevant, as are free off-street spaces for someone who is searching for on-street spaces by circling around the final destination. Encountering the first relevant free space the driver has to decide, if that space is acceptable with regards to price, distance to final destination, risk of theft, personal safety etc. The search ends, if the space is acceptable, otherwise the search continues.

The first question that the driver then has to answer is, if the search has taken too much time already. If the answer is yes, then the driver has to abandon the activity and replace it with a different one[1]. The next question is, if the strategy chosen is still suitable. The driver will have absorbed information about the current state of network from the search and the observation of the environment (speed, volume, origin and direction of traffic, queues for off-street parking facilities, extent of illegal parking, the location, number and type of spaces rejected, information from an existing PGI-system etc.), which will allow the driver to compare the original assumptions against his/her current assessment and naïve forecast of the situation. The driver will continue the search either with the current strategy or with a newly chosen one.

Figure 1 Behavioural framework



This view of the parking search process stresses the dynamic nature of it, in particular the interaction between the opportunities available, the search strategy and information collected by and available to the driver.

[1] The evidence about aborted trips is exclusively anecdotal, as non-completed trips have yet to be included in travel diaries (Axhausen, 1994) or time budget surveys.

The remainder of the paper will be structured in the following way. The next section discusses the data collected in Frankfurt, while the following section reports briefly on the aggregate results obtained from the data. The main section of the paper presents the disaggregate results in three parts: an analysis of individual parking search times and an analysis of the choice of parking search strategy. Conclusions highlight areas for future work.

2 FRANKFURT/MAIN SURVEYS

Frankfurt/Main is the financial centre of the Federal Republic of Germany, a mayor centre of industry and the regional shopping centre. As part of its city centre strategy, the City of Frankfurt is implementing a PGI-system in three phases with the objective to reduce the amount of parking search traffic and to make better use of the spare capacities in the existing off-street facilities. The first phase of the system covering the historic centre of city became operational in November 1992. The second phase covering the remainder of the CBD was implemented at the end of 1993, while a third phase with variable message signs at the city limits providing also advice on Park+Ride will follow. The total investment cost is DM 14.1 million with an estimated running cost of DM 0.5 million annually (Körntgen, 1993).

As part of a wider study of the impacts of the PGI-system a series of one before and two after surveys were conducted on both a normal workday (Tuesday) and on a Saturday with late closure of shops at 18:00; in Germany the normal Saturday shop closing time is 14:00 (Boltze, Fischer, Puzicha, Axhausen and Polak, 1993). The brief surveys (around 4-5 minutes) focused on the parking search of the drivers, their experience with the PGI-system (after waves) and a small set of socio-economic and trip related background questions. The respondents were interviewed at their car either on arrival or just before departure. The crucial questions for the work reported here were:

- Duration of the parking search
- Parking search strategy used selected from a list of strategies
- Inquiry about any prior search for a different type of parking

Given the well known difficulties of defining what constitutes search and when it begins, compounded by the possibility of perceptual distortion in the recall and estimation of travel time, the results reported below should be interpreted only in a comparative context. Their value as an absolute assessment of the amount of time spent searching must remain doubtful, without an external validation, which was not part of this study.

The question concerning the parking search strategies proved to be very difficult for the respondents in Frankfurt in spite of earlier positive experiences with this question in other studies. A number of the original categories have therefore been combined for the analysis below.

A total of about 3500 drivers were interviewed, roughly equally distributed over the three waves. Table 1 gives a socio-demographic description of the sample, while Table 2 describes the characteristics of the trips. Whereas the Tuesdays and Saturdays samples are comparable in terms of gender, age distribution, car

availability and local knowledge, they do show significant differences for the other variables. In particular, on Saturdays there are more full time working respondents and there are fewer local visitors and a lower level of visiting frequency. This shift reflects an increase in out-of-town working shoppers on Saturdays.

3 AGGREGATE RESULTS

The results from these surveys allow the estimation of an expanded version of a simple non-linear relation between the total demand for parking off-street and the average search time for drivers arriving at off-street facilities in each half hour interval. The model form had been originally proposed by Bifulco (1991) and successfully applied to London data (Polak, Axhausen, Jones, Cook and Wofinden, 1993). The expanded model form allows the identification of the effects of the PGI-systems through the wave specific dummies:

$$t_i = \frac{\alpha(1 + \gamma_2\delta_2 + \gamma_3\delta_3)}{(1 - Occ_i/K)} \qquad [1]$$

where:

t_i	:	Average search time of drivers arriving at off-street facilities in the time interval i
Occ_i	:	Estimated occupancy of the off-street facilities during interval i
α	:	Structural parameter of parking performance relation
K	:	Total capacity of the relevant facilities (including facilities outside the study area and on-street spaces)
γ_j	:	Change in the structural parameter of the parking performance relation in wave j (j=2,3).
δ_j	:	Dummy variable equal to 1 for wave j and 0 otherwise.

In contrast to the Saturdays (see Figure 2) the demands on Tuesdays were not high enough to show any increase in search times as a function of off-street occupancy. The estimation of the model for the Saturdays showed that the introduction of the PGI-system had significantly reduced the search times in both waves (significant γ_j's of roughly equal magnitude) (see Table 3).

Whilst overall, the aggregate results are consistent with expectations, a closer examination of different user groups shows a more surprising picture. Table 4 shows the results of this analysis. Although search times are reduced on average, those who have actually used the PGI-system at some time after its introduction have significantly higher average search times than those who are aware of the system, but claim not to have used it. Those not aware of the system at all, most likely out of town visitors, have (in line with prior expectations) the highest average search times. Although it is difficult to draw firm behavioural conclusions from these results, they do suggest that there may be complex interactions taking place between drivers' familiarity with parking conditions in Frankfurt, their propensity to use the PGI system and it's consequent impact on their experienced parking search time. For example, it is possible to speculate that drivers who are very familiar with Frankfurt are likely to both have less need of a PGI and be able to find a parking space more easily than are drivers who are less familiar.

Table 1 Socio-demographic characteristics

Characteristic [%]	Tuesdays Off-street	Tuesdays On-street	Saturdays Off-street	Saturdays On-street
Gender				
Male	62.2	63.5	69.5	68.2
Female	37.8	36.5	30.5	31.8
Estimated age				
under 30 years	23.5	29.0	28.6	26.3
30 to 45 years	37.9	39.5	42.6	48.3
45 to 60 years	25.6	24.6	25.1	20.9
over 60 years	13.0	6.8	3.7	4.5
Work status				
Full time	65.4	60.6	85.4	75.5
Part time	8.0	17.6	4.8	10.2
Unemployed	1.2	3.2	0.3	0.3
Non working	25.4	18.6	9.1	14.0
Car availability				
Always	95.0	91.1	93.2	90.8
When required	4.6	8.9	6.0	8.3
Rarely	0.4	0.0	0.5	0.9
Car registered in				
Frankfurt	31.6	40.4	24.2	47.6
Immediate surroundings	53.8	52.6	60.8	45.9
Elsewhere	14.6	7.0	15.0	8.3
Frequency of visit				
Daily	28.5	25.5	21.0	27.4
Weekly	30.6	32.7	27.9	32.1
Monthly	23.1	30.6	26.1	25.6
Less frequently	17.8	11.2	25.1	14.6
Self-assessed local knowledge				
Very well	30.0	30.4	28.9	32.8
Well	51.6	49.6	46.7	48.7
Less well	11.2	15.0	13.9	12.5
Hardly	4.0	3.1	6.1	3.0
Barely	3.4	1.4	4.2	2.2

Values are the means of the three underlying daily values

The importance of familiarity with Frankfurt, as measured by self-assessed local knowledge, is also apparent in the next breakdown. Here, those with a self-assessment of "know the city less well" and "hardly" have the highest average search times, while those who know the city well have the lowest average search times.

Table 2 Characteristics of the visit

Characteristic [%]	Tuesdays Off-street	Tuesdays On-street	Saturdays Off-street	Saturdays On-street
Purpose				
Work/Education/ Employers' business	36.1	36.2	6.4	5.9
Shopping	43.8	26.8	79.6	56.6
Private business	13.1	23.5	5.5	26.1
Other	6.9	13.2	8.3	11.6
Duration				
< 30 min	2.3	17.8	1.0	19.7
30 - 59 min	6.9	26.1	2.6	24.8
60 - 119 min	23.3	27.9	15.5	33.3
120-239 min	46.9	15.0	57.2	14.6
240-479 min	13.6	6.3	20.2	2.5
over 8 hours	6.9	7.0	3.5	5.2
Appointment				
Yes	35.7	45.0	12.0	20.1
No	64.1	55.0	87.7	79.9
Punctuality for appointments				
Required	61.0	25.6	51.9	14.1
Some leeway	33.4	70.9	37.6	81.3
Not essential	5.8	2.7	10.5	4.6

Values are the means of the three underlying daily values

The surprise are those who do not know the city, which have an average search time between the two other groups.

The patterns suggest that the search strategies adopted by the different groups based on their intentions and knowledge have a major impact on the search time experiences. They also indicate that the success of a parking guidance system will depend on the mixture of drivers in the managed area.

Figure 2 Saturdays: Average search time for off-street parkers as a function of estimated off-street occupancy [30 min intervals]

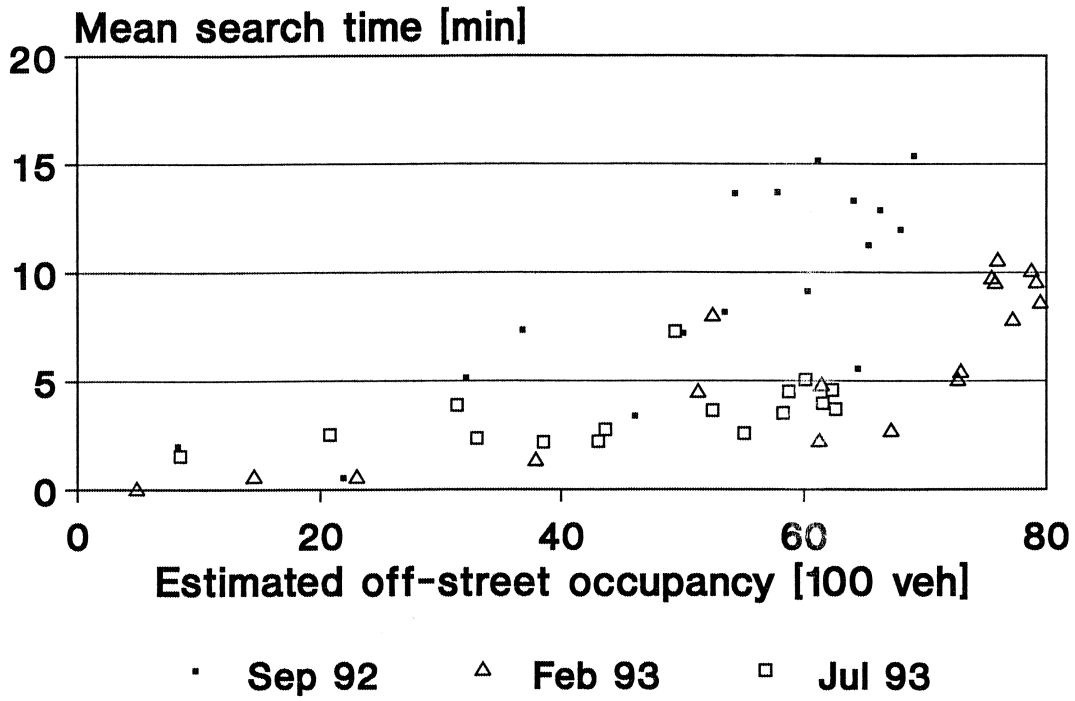


Table 3 Saturdays: results of the non-linear regression for off-street parking

Parameter	Value	Std. Error	t-statistic
α	3.555	0.396	8.98
γ_2	-0.605	0.062	9.76
γ_3	-0.564	0.073	7.73
K	92.219	4.231	21.80

SS Regression	2574.06
SS Error	232.56
R^2	0.91

Table 4 Average search times before and after the installation of the PGI-system

Characteristic	Average search time [min] Before	After
All	8.35	5.68
Aware, used	-	6.65
Aware, not used	-	3.76
Not aware	-	7.69
Good local knowledge	5.67	3.36
Medium local knowledge	12.15	7.65
Low local knowledge	8.50	7.00

4 DISAGGREGATE RESULTS

4.1 A model of search time

The first step of the disaggregate analysis is the construction of a model relating personal and trip characteristics to the search times experienced. The results shown in Table 5 were derived using linear regression. It should be pointed out that the residuals increase with increasing search times. This pattern could not be removed by any standard transformations of the search times. In the absence of any further information indicating a random response by the drivers, it was impossible to remove these outliers and this trend.

The explanatory power of the models in rather low (adjusted R^2's between 0.15 and 0.35). Searching for other types of parking first and employing a search strategy of circling around the final destination consistently increases the average reported search times of the drivers. So does a less then perfect knowledge of Frankfurt; the effect of not knowing the city and searching for on-street parking is quite dramatic on the Tuesdays. The general reduction in search times in the after waves is also captured by these disaggregate regression results The time of day effects are consistent across the four cases, even if only significant for the Saturday off-street parking experience. The overall results are consistent with expectations and earlier work reported by Polak *et al.* (1993). However, one surprising finding to emerge from this model is that the search strategy "Following the PGI" appears to lead to an *increase* in average search times, all other things being equal. This suggests, but does not establish, that in reality all others may not be equal, and that, in particular, the use of the PGI may be associated with changes in parking type or location. Unfortunately, however, our data do not allow us to explore these aspects further at a disaggregate level.

Table 5 Regression analysis: parking search times

Characteristic	Tuesday Off-street	Tuesday On-street	Saturday Off-street	Saturday On-street
Intercept	4.41	5.91	9.69	2.93
Type of Parking				
Searched for other type	1.42	5.08	3.38	4.17
Free parking	.	.	.	.
Metered parking	.	-	.	-
Illegal parking	.	-3.76	.	-
Time of Arrival in Frankfurt				
Between 11 and 13	-	-	2.24	-
Between 13 and 15	-	-	3.75	-
After 15:00	-	-	2.46	-
Familiarity				
Know Frankfurt	1.44	1.81	2.26	3.80
Know Frankfurt hardly	2.98	12.82	-	4.98
Survey Wave				
February 1993	-	-3.80	-5.00	-
June 1993	-2.77	-2.49	-9.55	-
Search Strategy				
Search in vicinity	1.85	4.25	2.89	3.80
Other search strategies	-	2.79	-	5.97
Followed PGI	-	.	2.44	.
N	557	384	1127	363
adjusted R^2	0.23	0.32	0.35	0.19

. Not applicable
- Not significant at alpha=0.05

4.2 Choice of parking search strategy

The choice of parking search strategy is central to the parking search experience of the drivers. Ideally the parking search survey would have collected the drivers' assessment of these different strategies in terms of expected costs and search times. As this was not possible, values were imputed for the choice models from the responses of the other drivers. The expected costs and search times were calculated as the average values for each strategy, day and two hour interval. This average should reflect the expectations of the drivers as formed over earlier experiences with the different strategies. The remaining variables describe the background of the driver or the specific trip.

Only the results for Saturday will be presented, as the Tuesday results are similar in their structure. Table 6 and Table 7 present the results of the multinomial logit analysis[2] for the before and after case. They were estimated with (mostly) generic and alternative-specific coefficients. The explanatory power of the models is rather low and mostly concentrated in the constants.

The results for the expected search times and costs seem counterintuitive, as they indicate an increasing likelihood of choice with increasing search times and costs. It is possible that these variables are picking up time-of-day effects interacting with lack of knowledge.

Table 6 Choice of parking search strategy: Saturday, before wave

Variable	Alternative specific coefficients				Generic
	Direct with search	Search in vicinity	Other	Direct without search	
Constant - ASC model	-2.196	-3.024	-2.536	.	.
Constant - Generic	-	-	-0.927	.	.
Arrived between 13-15:00	.	.	.	-	-0.883
Arrived after 15:00	.	.	.	-0.785	-1.101
Expected costs	0.000	-0.001	-	.	0.000
Expected search time	0.101	0.174	0.174	.	0.051
Male	0.380	-	-	.	-
Weekly visits	-	-	-	.	-
Less then weekly visits	-0.453	-	-0.581	.	-4.362
Purpose: Other private	-0.628	-	-	.	-
Purpose: Work	-	-	1.23	.	-
Know Frankfurt	0.478	1.050	-0.536	.	-
Know Frankfurt hardly	0.939	0.485	-	.	-
Market shares	23.6%	17.4%	22.0%	37.1%	
N	691				
$\varrho^2_{bar}(\mathbf{0})$	0.076				0.054
$\varrho^2_{bar}(\mathbf{C})$	0.054				0.025
Sample reconstitution test	43.99%				40.09%

. Not applicable
- Not significant at α=0.05

The effects of local knowledge are noteworthy. They indicate that, in general, there is an increasing likelihood of search intensive strategies with decreasing knowledge of Frankfurt. An exception, however, is the choice of "Following the PGI", but here the influence of awareness and prior use seem to be counterintuitive. Again, these variables may be picking up interactions with knowledge of the city centre, rather than actual dissatisfaction with the PGI system as such.

[2] The estimation was performed with the HIELOW-package of the University of Namur.

Table 7 Choice of parking search strategy: Saturdays, after waves

Variable	Alternative specific coefficients					Generic
	Direct with search	Search in vicinity	Other	Followed PGI	Direct without search	
Constant - ASC model	1.072	-	1.208	4.139	.	.
Constant - Generic	-	-1.891	-0.525	-	.	.
Arrived between 13-15:00	.	.	.	.	-	-
Arrived after 15:00	.	.	.	.	0.713	1.210
Punctual	.	.	.	.	0.870	.
Expected costs	0.001	-	-	.	.	0.001
Expected search time	-	-	0.064	.	.	-0.211
Duration	-	-0.002	-	.	.	-
Male	0.407	0.569	0.514	.	.	0.391
Weekly visits	-0.581	-0.735	-0.465	.	.	-0.447
Less then weekly visits	-1.040	-0.699	-0.535	.	.	-0.486
Purpose: Other private	-	1.302	0.945	.	.	1.220
Purpose: Work	-	-	-	.	.	0.912
Know Frankfurt	-	1.764	0.451	-	.	0.793
Know Frankfurt hardly	0.642	1.035	-	2.307	.	0.581
Noticed PGI before	.	.	.	-1.157	.	-*
Used PGI before	.	.	.	-3.155	.	-3.432*
Market shares	30.1%	16.2%	34.8%	4.0%	15.0%	
N	1262					1262
$\varrho^2_{bar}(\mathbf{0})$	0.171					0.149
$\varrho^2_{bar}(\mathbf{C})$	0.071					0.046
Sample reconstitution test	42.47%					39.14%

. Not applicable
- Not significant at α=0.05
* Only for alternative "Followed PGI"

5 CONCLUSIONS

The results report above show that further work will be required before we can fully understand parking search behaviour. While the results give us a first insight, especially into the importance of local knowledge and its interaction with trip purposes and time of day, it is not possible to draw very firm conclusions at this stage, due to limitations in the data available to the study.

The main areas of research required are the following:

- Research into methods of capturing the parking search process in an interview. Topics here are among others: unambiguous, but simple definitions of parking search strategies for interview use;

capturing the switch between search strategies; capturing the expectations about other search strategies and other types of parking

- Research into the naive forecasting of drivers: Drivers continuously update their assessment of their environment based on the information they receive, be it from the observation of the traffic around them or from VMS or similar sources. Their integration of this information together with their past experiences needs to be explored, before we can confidently predict the effects of external information, such as provided by PGI-systems.

The authors hope that the work reported here provides a stimulus for such, more fundamental work.

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Running title:

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ABSTRACT

A disaggregate model of the effects of parking guidance systems

Presenter: KW Axhausen

Topic number 9

Parking guidance systems are currently amongst the most widely implemented advanced transport telematics (ATT) technologies. Recent surveys have indicated that over 100 such systems are now installed in Europe and the Far East. There is therefore considerable interest in the measurement and modelling of the effects of these systems on travel demand and traffic patterns.

A recent before-and-after study of the parking guidance system in Frankfurt/Main provides a suitable database for the aggregate and disaggregate analysis of the effects of such systems. An on-street interview survey of about 1000 drivers was performed in each wave. The respondents were asked about their trip to Frankfurt, their parking search time and parking search strategy, their use and assessment of the PGI system (2. and 3. wave). The survey also established the basic socio-economic details of the respondents.

An earlier aggregate analysis was able to show that the introduction of the parking guidance system led to a reduction in search times on days with high overall demand (Axhausen, Polak and Boltze, 1993). However, this analysis also showed that the beneficiaries of those reductions did not necessarily belong to the expected groups, i.e. local drivers or drivers with a good knowledge of Frankfurt.

This paper explores in detail the mechanisms by which the individual users benefit from the system. Special emphasis will be given to the modelling of the choice of search strategy, which strongly influences the experienced search times. The paper will identify those groups, which have switched to a PGI-based search strategy. The paper will assess the benefits of that switch in strategy through models of expected search times.

The conclusions will discuss the design implications of the disaggregate results and provide guidance about the gains possible with PGI systems.

1 INTRODUCTION

The effects of the provision of accurate and real-time information on driver behaviour is currently a central topic of dedicated transport research programs around the world (DRIVE in Europe, the IVHS-initiatives in the USA and similar research in Japan, Canada or Australia). It is therefore surprising that the effects of the second most widely implemented type of information system - real time parking guidance and information (PGI) systems - have not received more attention in the literature (See for example Polak, Hilton, Axhausen and Young, 1990, Axhausen, Polak, Boltze and Puzicha, 1994 or Smith and Philips, 1993). It shares that fate with the most widely implemented type of information system: radio-based information (for an exception see Polak, Vythoulkas and Chatfield, 1993). Recent reviews indicate that more than 100 PGI-systems have been installed, primarily in Europe and Japan (Polak *et al.*, 1990 and Körntgen, 1993). Using variable-message signs (VMS) a PGI-system provides the motorist with real-time/predictive information about the number and location of free spaces in the local off-street facilities.

While aggregate impact analyses of different levels of sophistication have been performed in the past, disaggregate analyses of how the PGI-system influences behaviour had not been published. A recent before-and-after study of the impacts of the new PGI-system in Frankfurt/Main has allowed to start to fill this gap. The key concept of this analysis is the idea that drivers organize their parking search with the help of distinct *parking search strategies*. The purpose of the analysis is to try to understand through which behavioural shifts the aggregate effectiveness of the PGI-system is effected.

Figure 1 shows the behavioural framework of this study, which has been developed earlier on the basis of group discussions and other survey work (see also Axhausen and Polak, 1990). The driver starts out on his trip with a set of initial intentions about the location of the planned activities and their duration. These intentions are based on the driver's knowledge of the urban area, among other things with respect to the availability and costs of different forms of parking. Part of these intentions is the chosen parking search strategy. The strategy defines the starting location of the search, the types of parking to be considered and the way in which to conduct the search; e.g. for someone who has decided to go straight to an off-street facility free on-street spaces are irrelevant, as are free off-street spaces for someone who is searching for on-street spaces by circling around the final destination. Encountering the first relevant free space the driver has to decide, if that space is acceptable with regards to price, distance to final destination, risk of theft, personal safety etc. The search ends, if the space is acceptable, otherwise the search continues.

The first question that the driver then has to answer is, if the search has taken too much time already. If the answer is yes, then the driver has to abandon the activity and replace it with a different one[1]. The next question is, if the strategy chosen is still suitable. The driver will have absorbed information about the current state of network from the search and the observation of the environment (speed, volume, origin and direction of traffic, queues for off-street parking facilities, extent of illegal parking, the location, number and type of spaces rejected, information from an existing PGI-system etc.), which will allow the driver to compare the original assumptions against his/her current assessment and naïve forecast of the situation. The driver will continue the search either with with the current strategy or with a newly chosen one.

This view of the parking search process stresses the dynamic nature of it, in particular the interaction between the opportunities available, the search strategy and information collected by and available to the driver.

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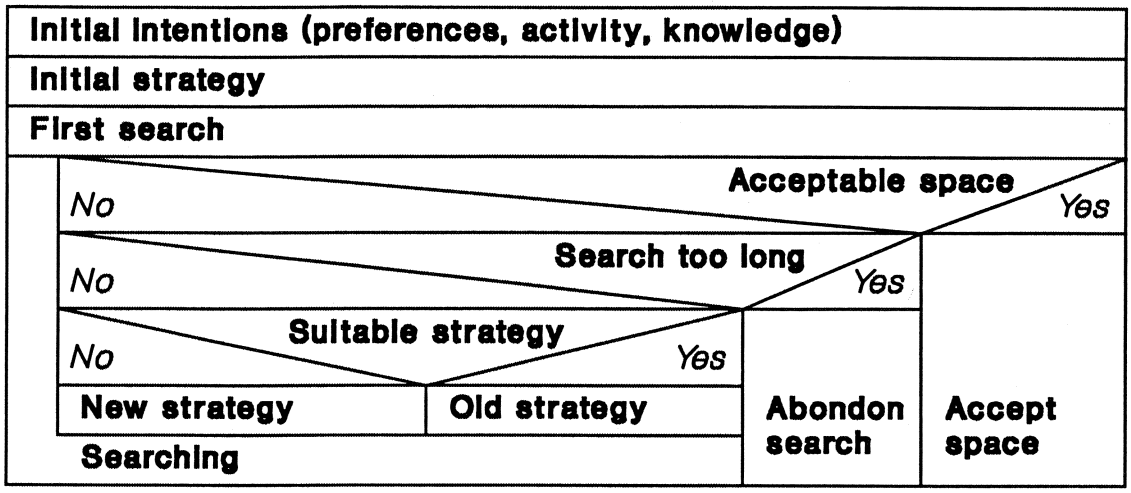
[1] The evidence about aborted trips is exclusively anecdotal, as non-completed trips have yet to be included in travel diaries (Axhausen, 1994) or time budget surveys.

Figure 1 Behavioural framework



The remainder of the paper will be structured in the following way. The next section discusses the data collected in Frankfurt, while the following section reports briefly on the aggregate results obtained from the data. The main section of the paper presents the disaggregate results in three parts: an analysis of individual parking search times and an analysis of the choice of parking search strategy. Conclusions highlight areas for future work.

2 FRANKFURT/MAIN SURVEYS

Frankfurt/Main is the financial centre of the Federal Republic of Germany, a mayor centre of industry and the regional shopping centre. As part of its city centre strategy, the City of Frankfurt is implementing a PGI-system in three phases with the objective to reduce the amount of parking search traffic and to make better use of the spare capacities in the existing off-street facilities. The first phase of the system covering the historic centre of city became operational in November 1992. The second phase covering the remainder of the CBD was implemented at the end of 1993, while a third phase with variable message signs at the city limits providing also advice on Park+Ride will follow. The total investment cost is DM 14.1 million with an estimated running cost of DM 0.5 million annually (Körntgen, 1993).

As part of a wider study of the impacts of the PGI-system a series of one before and two after surveys were conducted on both a normal workday (Tuesday) and on a Saturday with late closure of shops at 18:00; in Germany the normal Saturday shop closing time is 14:00 (Boltze, Fischer, Puzicha, Axhausen and Polak, 1993). The brief surveys (around 4-5 minutes) focused on the parking search of the drivers, their experience with the PGI-system (after waves) and a small set of socio-economic and trip related background questions. The respondents were interviewed at their car either on arrival or just before departure. The crucial questions for the work reported here were:

- Duration of the parking search
- Parking search strategy used selected from a list of strategies

- Inquiry about any prior search for a different type of parking

Given the well known difficulties of defining what constitutes search and when it begins, compounded by the possibility of perceptual distortion in the recall and estimation of travel time, the results reported below should be interpreted only in a comparative context. Their value as an absolute assessment of the amount of time spent searching must remain doubtful, without an external validation, which was not part of this study.

The question concerning the parking search strategies proved to be very difficult for the respondents in Frankfurt in spite of earlier positive experiences with this question in other studies. A number of the original categories have therefore been combined for the analysis below.

A total of about 3500 drivers were interviewed, roughly equally distributed over the three waves. Table 1 gives a socio-demographic description of the sample, while Table 2 describes the characteristics of the trips. Whereas the Tuesdays and Saturdays samples are comparable in terms of gender, age distribution, car availability and local knowledge, they do show significant differences for the other variables. In particular, on Saturdays there are more full time working respondents and there are fewer local visitors and a lower level of visiting frequency. This shift reflects an increase in out-of-town working shoppers on Saturdays.

3 AGGREGATE RESULTS

The results from these surveys allow the estimation of an expanded version of a simple non-linear relation between the total demand for parking off-street and the average search time for drivers arriving at off-street facilities in each half hour interval. The model form had been originally proposed by Bifulco (1991) and succesfully applied to London data (Polak, Axhausen, Jones, Cook and Wofinden, 1993). The expanded model form allows the identification of the effects of the PGI-systems through the wave specific dummies:

$$t_i = \frac{\alpha(1 + \gamma_2\delta_2 + \gamma_3\delta_3)}{(1 - Occ_i/K)} \qquad [1]$$

where:

t_i	:	Average search time of drivers arriving at off-street facilities in the time interval i
Occ_i	:	Estimated occupancy of the off-street facilities during interval i
α	:	Structural parameter of parking performance relation
K	:	Total capacity of the relevant facilities (including facilities outside the study area and on-street spaces)
γ_j	:	Change in the structural parameter of the parking performance relation in wave j (j=2,3).
δ_j	:	Dummy variable equal to 1 for wave j and 0 otherwise.

In contrast to the Saturdays (see Figure 2) the demands on Tuesdays were not high enough to show any increase in search times as a function of off-street occupancy. The estimation of the model for the Saturdays showed that the introduction of the PGI-system had significantly reduced the search times in both waves (significiant γ_j's of roughly equal magnitude) (see Table 3).

Table 1 Socio-demographic characteristics

Characteristic [%]	Tuesdays Off-street	Tuesdays On-street	Saturdays Off-street	Saturdays On-street
Gender				
Male	62.2	63.5	69.5	68.2
Female	37.8	36.5	30.5	31.8
Estimated age				
under 30 years	23.5	29.0	28.6	26.3
30 to 45 years	37.9	39.5	42.6	48.3
45 to 60 years	25.6	24.6	25.1	20.9
over 60 years	13.0	6.8	3.7	4.5
Work status				
Full time	65.4	60.6	85.4	75.5
Part time	8.0	17.6	4.8	10.2
Unemployed	1.2	3.2	0.3	0.3
Non working	25.4	18.6	9.1	14.0
Car availability				
Always	95.0	91.1	93.2	90.8
When required	4.6	8.9	6.0	8.3
Rarely	0.4	0.0	0.5	0.9
Car registered in				
Frankfurt	31.6	40.4	24.2	47.6
Immediate surroundings	53.8	52.6	60.8	45.9
Elsewhere	14.6	7.0	15.0	8.3
Frequency of visit				
Daily	28.5	25.5	21.0	27.4
Weekly	30.6	32.7	27.9	32.1
Monthly	23.1	30.6	26.1	25.6
Less frequently	17.8	11.2	25.1	14.6
Self-assessed local knowledge				
Very well	30.0	30.4	28.9	32.8
Well	51.6	49.6	46.7	48.7
Less well	11.2	15.0	13.9	12.5
Hardly	4.0	3.1	6.1	3.0
Barely	3.4	1.4	4.2	2.2

Values are the means of the three underlying daily values

Table 2 Characteristics of the visit

Characteristic [%]	Tuesdays Off-street	Tuesdays On-street	Saturdays Off-street	Saturdays On-street
Purpose				
Work/Education/ Employers' business	36.1	36.2	6.4	5.9
Shopping	43.8	26.8	79.6	56.6
Private business	13.1	23.5	5.5	26.1
Other	6.9	13.2	8.3	11.6
Duration				
< 30 min	2.3	17.8	1.0	19.7
30 - 59 min	6.9	26.1	2.6	24.8
60 - 119 min	23.3	27.9	15.5	33.3
120-239 min	46.9	15.0	57.2	14.6
240-479 min	13.6	6.3	20.2	2.5
over 8 hours	6.9	7.0	3.5	5.2
Appointment				
Yes	35.7	45.0	12.0	20.1
No	64.1	55.0	87.7	79.9
Punctuality for appointments				
Required	61.0	25.6	51.9	14.1
Some leeway	33.4	70.9	37.6	81.3
Not essential	5.8	2.7	10.5	4.6

Values are the means of the three underlying daily values

Whilst overall, the aggregate results are consistent with expectations, a closer examiniation of different user groups shows a more surprising picture. Table 4 shows the results of this analysis. Although search times are reduced on average, those who have actually used the PGI-system at some time after its introduction have significantly higher average search times than those who are aware of the system, but claim not to have used it. Those not aware of the system at all, most likely out of town visitors, have (in line with prior expectations) the highest average search times. Although it is difficult to draw firm behavioural conclusions from these results, they do suggest that there may be complex interactions taking place between drivers' familiarity with parking conditions in Frankfurt, their propensity to use the PGI system and it's consequent impact on their experienced parking search time. For example, it is possible to speculate that drivers who are very

familiar with Frankfurt are likely to both have less need of a PGI and be able to find a parking space more easily than are drivers who are less familiar.

The importance of familiarity with Frankfurt, as measured by self-assessed local knowledge, is also apparent in the next breakdown. Here, those with a self-assessment of "know the city less well" and "hardly" have the highest average search times, while those who know the city well have the lowest average search times. The surprise are those who do not know the city, which have an average search time between the two other groups.

Figure 2 Saturdays: Average search time for off-street parkers as a function of estimated off-street occupancy [30 min intervals]

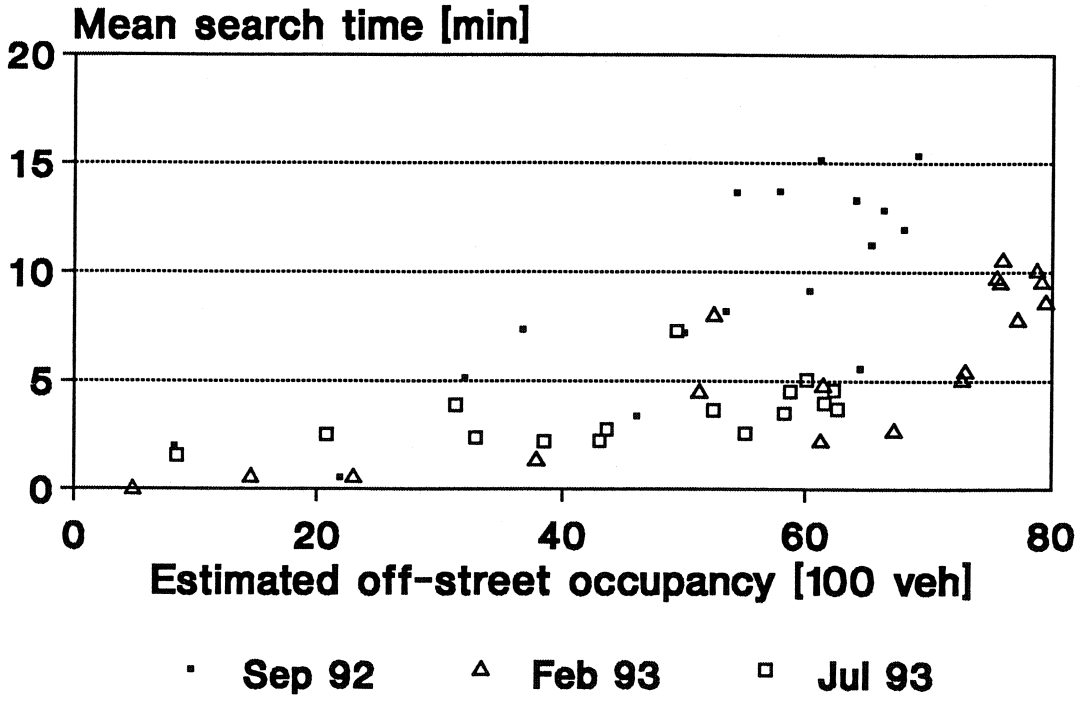


Table 3 Saturdays: results of the non-linear regression for off-street parking

Parameter	Value	Std. Error	t-statistic
α	3.555	0.396	8.98
γ_2	-0.605	0.062	9.76
γ_3	-0.564	0.073	7.73
K	92.219	4.231	21.80

SS Regression	2574.06
SS Error	232.56
R^2	0.91

Table 4 Average search times before and after the installation of the PGI-system

Characteristic	Average search time [min]	
	Before	After
All	8.35	5.68
Aware, used	-	6.65
Aware, not used	-	3.76
Not aware	-	7.69
Good local knowledge	5.67	3.36
Medium local knowledge	12.15	7.65
Low local knowledge	8.50	7.00

The patterns suggest that the search strategies adopted by the different groups based on their intentions and knowledge have a major impact on the search time experiences. They also indicate that the success of a parking guidance system will depend on the mixture of drivers in the managed area.

4 DISAGGREGATE RESULTS

4.1 A model of search time

The first step of the disaggregate analysis is the construction of a model relating personal and trip characterstics to the search times experienced. The results shown in Table 5 were derived using linear regression. It should be pointed out that the residuals increase with increasing search times. This pattern could not be removed by any standard transformations of the search times. In the absense of any further information indicating a random response by the drivers, it was impossible to remove these outliers and this trend.

The explanatory power of the models in rather low (adjusted R^2's between 0.15 and 0.35). Searching for other types of parking first and employing a search strategy of circling around the final destination consistently increases the average reported search times of the drivers. So does a less then perfect knowledge of Frankfurt; the effect of not knowing the city and searching for on-street parking is quite dramatic on the Tuesdays. The general reduction in search times in the after waves is also captured by these disaggregate regression results. The time of day effects are consistent across the four cases, even if only significant for the Saturday off-street parking experience. The overall results are consistent with expectations and earlier work reported by Polak *et al.* (1993). However, one surprising finding to emerge from this model is that the search strategy "Following the PGI" appears to lead to an *increase* in average search times, all other things being equal. This suggests, but does not establish, that in reality all others may not be equal, and that, in particular, the use of the PGI may be associated with changes in parking type or location. Unfortunately, however, our data do not allow us to explore these aspects further at a disaggregate level.

4.2 Choice of parking search strategy

The choice of parking search strategy is central to the parking search experience of the drivers. Ideally the parking search survey would have collected the drivers' assessment of these different strategies in terms of expected costs and search times. As this was not possible, values were imputed for the choice models from the responses of the other drivers. The expected costs and search times were calculated as the average values for each strategy, day and two hour interval. This average should reflect the expectations of the drivers as formed over earlier experiences with the different strategies. The remaining variables describe the background of the driver or the specific trip.

Only the results for Saturday will be presented, as the Tuesday results are similar in their structure. Table 6 and Table 7 present the results of the multinomial logit analysis[2] for the before and after case. They were estimated with (mostly) generic and alternative-specific coefficents. The explanatory power of the models is rather low and mostly concentrated in the constants.

The results for the expected search times and costs seem counterintuitive, as they indicate an increasing likelihood of choice with increasing search times and costs. It is possible that these variables are picking up time-of-day effects interacting with lack of knowledge.

[2] The estimation was performed with the HIELOW-package of the University of Namur.

Table 5 Regression analysis: parking search times

Characteristic	Tuesday Off-street	Tuesday On-street	Saturday Off-street	Saturday On-street
Intercept	4.41	5.91	9.69	2.93
Type of Parking				
Searched for other type	1.42	5.08	3.38	4.17
Free parking	.	.	.	.
Metered parking	.	-	.	-
Illegal parking	.	-3.76	.	-
Time of Arrival in Frankfurt				
Between 11 and 13	-	-	2.24	-
Between 13 and 15	-	-	3.75	-
After 15:00	-	-	2.46	-
Familiarity				
Know Frankfurt	1.44	1.81	2.26	3.80
Know Frankfurt hardly	2.98	12.82	-	4.98
Survey Wave				
February 1993	-	-3.80	-5.00	-
June 1993	-2.77	-2.49	-9.55	-
Search Strategy				
Search in vicinity	1.85	4.25	2.89	3.80
Other search strategies	-	2.79	-	5.97
Followed PGI	-	.	2.44	.
N	557	384	1127	363
adjusted R^2	0.23	0.32	0.35	0.19

. Not applicable
- Not significant at alpha=0.05

The effects of local knowledge are noteworthy. They indicate that, in general, there is an increasing likelihood of search intensive strategies with decreasing knowledge of Frankfurt. An exception, however, is the choice of "Following the PGI", but here the influence of awareness and prior use seem to be counterintuitive. Again, these variables may be picking up interactions with knowledge of the city centre, rather than actual dissatisfaction with the PGI system as such.

Table 6 Choice of parking search strategy: Saturday, before wave

Variable	Alternative specific coefficients				Generic
	Direct with search	Search in vicinity	Other	Direct without search	
Constant - ASC model	-2.196	-3.024	-2.536	.	.
Constant - Generic	-	-	-0.927	.	.
Arrived between 13-15:00	.	.	.	-	-0.883
Arrived after 15:00	.	.	.	-0.785	-1.101
Expected costs	0.000	-0.001	-	.	0.000
Expected search time	0.101	0.174	0.174	.	0.051
Male	0.380	-	-	.	-
Weekly visits	-	-	-	.	-
Less then weekly visits	-0.453	-	-0.581	.	-4.362
Purpose: Other private	-0.628	-	-	.	-
Purpose: Work	-	-	1.23	.	-
Know Frankfurt	0.478	1.050	-0.536	.	-
Know Frankfurt hardly	0.939	0.485	-	.	-
Market shares	23.6%	17.4%	22.0%	37.1%	
N	691				
$\varrho^2_{bar}(0)$	0.076				0.054
$\varrho^2_{bar}(C)$	0.054				0.025
Sample reconstitution test	43.99%				40.09%

. Not applicable
- Not signifcant at α=0.05

5 CONCLUSIONS

The results report above show that further work will be required before we can fully understand parking search behaviour. While the results give us a first insight, especially into the importance of local knowledge and its interaction with trip purposes and time of day, it is not possible to draw very firm conclusions at this stage, due to limitations in the data available to the study.

The main areas of research required are the following:

- Research into methods of capturing the parking search process in an interview. Topics here are among others: unambiguous, but simple definitions of parking search strageties for interview use; capturing the switch between search strategies; capturing the expectations about other search strategies and other types of parking

Table 7 Choice of parking search strategy: Saturdays, after waves

Variable	Alternative specific coefficients					Generic
	Direct with search	Search in vicinity	Other	Followed PGI	Direct without search	
Constant - ASC model	1.072	-	1.208	4.139	.	.
Constant - Generic	-	-1.891	-0.525	-	.	.
Arrived between 13-15:00	.	.	.	.	-	-
Arrived after 15:00	.	.	.	.	0.713	1.210
Punctual	.	.	.	.	0.870	.
Expected costs	0.001	-	-	.	.	0.001
Expected search time	-	-	0.064	.	.	-0.211
Duration	-	-0.002	-	.	.	-
Male	0.407	0.569	0.514	.	.	0.391
Weekly visits	-0.581	-0.735	-0.465	.	.	-0.447
Less then weekly visits	-1.040	-0.699	-0.535	.	.	-0.486
Purpose: Other private	-	1.302	0.945	.	.	1.220
Purpose: Work	-	-	-	.	.	0.912
Know Frankfurt	-	1.764	0.451	-	.	0.793
Know Frankfurt hardly	0.642	1.035	-	2.307	.	0.581
Noticed PGI before	.	.	.	-1.157	.	-*
Used PGI before	.	.	.	-3.155	.	-3.432*
Market shares	30.1%	16.2%	34.8%	4.0%	15.0%	
N	1262					1262
$\varrho^2_{bar}(0)$	0.171					0.149
$\varrho^2_{bar}(C)$	0.071					0.046
Sample reconstitution test	42.47%					39.14%

. Not applicable
- Not significant at α=0.05
* Only for alternative "Followed PGI"

- Research into the naive forecasting of drivers: Drivers continuously update their assessment of their environment based on the information they receive, be it from the observation of the traffic around them or from VMS or similar sources. Their integration of this information together with their past experiences needs to be explored, before we can confidently predict the effects of external information, such as provided by PGI-systems.

The authors hope that the work reported here provides a stimulus for such, more fundamental work.

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The problem is that, at the end, the models fail to show very much. We end up with speculation and a call for more research / better data.

Date & Signature P Bonsall 24/4/95

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EVALUATION FORM FOR FULL PAPERS

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SUB-TOPIC: Parking Information Systems

PAPER No: P 823

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AUTHOR(S): Axhausen and Polak

REFEREE:

NAME: Nick Hounsell

ADDRESS: TRG Southampton

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SPECIFIC COMMENTS:
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Very good paper. Some aspects of disaggregate modelling approach/results a little unclear.

Date & Signature N. B. Hounsell, 01.05.95

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Charlie, F. H. and M. B. Routh (1966). The chemical determination of toxins. *J. Am. Chem. Soc.*, **66**, 267-269.

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