The Effectiveness of Decision Support Systems on Mobile Devices

Thomas Acton (corresponding author)
Dept of Accountancy & Finance
National University of Ireland, Galway
thomas.acton@nuigalway.ie

William Golden
Dept of Accountancy & Finance
National University of Ireland, Galway,
willie.golden@nuigalway.ie

Hans van der Heijden
School of Management
University of Surrey
UK
H.Vanderheijden@surrey.ac.uk

The Effectiveness of Decision Support Systems on Mobile Devices

Abstract: This paper reports the results of an experiment as part of a study assessing the impact of decision aid use on performance-based decision-making. We examine the effect of a single-user decision support mechanism for multi-attribute preferential choice in the context of large- and small-screen systems, in terms of measures of decision maker performance. The study gauges the effect of screen size on decision performance, and the moderating impact of a decision aid, through a single task scenario implemented on large 17" PC computer screens and small PDA screens. Results indicate that the decision aid significantly increases performance. Also, the decision aid directly influences the decision strategy employed to reach a decision, and reduces the cognitive effort associated with strategies traditionally considered more effortful, leading to faster decisions. Ultimately, results indicate that a decision aid can moderate the effect of diminished screen size on decision performance.

Keywords: decision aid, small screen, decision support systems, performance

1 Introduction

Decision aids designed for large screen devices may not have similar effects if applied by users accessing decision support systems using small devices. The familiar navigational aspects of large screen web browser software do not scale well to small devices, particularly where decision support systems have been designed for display on large screen monitors. If small devices are to become usable, ubiquitous and effective mobile gateways to decision support systems, there is a need for research into the design of dedicated and targeted decision aids to compensate and address inherent usability limitations of personal digital assistants (PDAs) and mobile phones.

This paper describes an experiment using a decision aid designed to assist in decision making on a mobile device. Based on research from the decision support literature and consumer behaviour, in particular research regarding consideration set membership, we derive features that should aid the consumer in a small-screen environment with respect to choosing a single alternative from a multiattributed tabular data grid. A decision aid was built with the following characteristics: the ability to create a consideration set as a subset of all alternatives, and a facility to reduce the effort in employing more accurate decision strategies to select one alternative from many. The study examines whether screen size affects decision performance, and whether the decision aid moderates this potential effect.

2 Theory

The theory in this paper is framed in the context of general behavioural decision making and decision support systems (see Todd and Benbasat (1992, 1999)). A decision strategy can be considered as a method (sequence) of operations for searching through a problem space (Payne et al., 1988, Todd and Benbasat, 1999). Decision strategies are influenced by the types of tools

or decision aids that might be available, and decision aids influence the selection of a particular strategy through their influence on the cognitive cost of using that approach. Decision strategies for multi-attribute preferential choice problems include *compensatory* and *non-compensatory* forms. A compensatory strategy is based on a comparison between attributes for alternatives. A non-compensatory strategy is based on a comparison of attribute values to some threshold level and the elimination of any alternative which does not meet the threshold level for any one of its attributes.

Decision makers alter and adapt their decision strategies in attempts to reduce the decision making effort and reach an acceptable decision (Benbasat and Todd, 1996). Studies have shown that there is an effort-accuracy tradeoff: where less effortful strategies are employed in decision making, the decision is less accurate (Benbasat and Todd, 1996, Johnson and Payne, 1985, Garrity et al., 2005). Whilst non-compensatory approaches to choosing one of many alternatives are less effortful, existing research indicates that compensatory strategies should lead to a better, more accurate, and higher quality choice. Where a decision involves the examination of a large amount of data, such as a large tabular grid, compensatory strategies carry too high a cognitive cost, and non- compensatory strategies dominate: consequentially alternatives can either be eliminated from further consideration, or else (at least temporarily) identified as possible choices. In any event, steps in decision making involving large amount of tabular data involve the exclusion of some alternatives and the inclusion of others for further examination: this produces a consideration set as a subset of all available alternatives (Häubl and Trifts, 2000). By providing a supporting decision aid which provides a mechanism in reducing the effort to employ compensatory rather than non-compensatory strategies to a consideration set, decision quality may be improved (Benbasat and Todd, 1996).

In this study we examined the effect of a single-user decision aid in the context of a multi-attribute preferential choice problem using large- and small-screen systems. The decision aid promoted the use of compensatory strategies in finalising a selection from a consideration set formed through less effortful non-compensatory approaches. We measured decision performance in terms of quality and time to reach a decision. First, the study gauged the effect of screen size on decision performance. Second, taking screen size as independent variable, and decision performance as dependent variable, the study assessed the impact of a decision aid (as moderating variable) on task performance across these screen sizes (see figure 1). The central questions are: does screen size affect decision performance, and does the decision aid moderate the effect of screen size on decision performance?

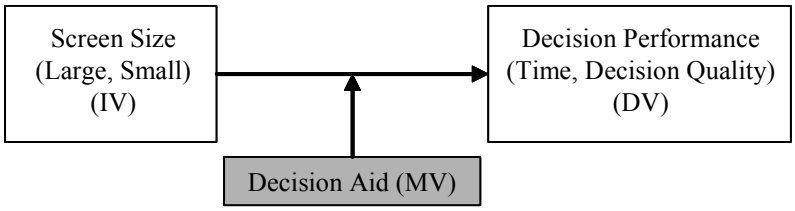

Figure 1: Conceptual Model

Cognitive strain, and thus effort, is increased as visually referenced alternatives, still possibly present on a large screen display, may not still be displayed on a small screen. With a higher cognitive strain together with a necessary higher degree of navigational wayfinding, decision making performance is impacted (Chalmers, 2003, Shneiderman and Chimera, 1994). Previous studies examining the time impact of a reduced screen area in task-related or goal-seeking scenarios also reduced decision performance (Marsden et al., 2002, Buyukkokten et al., 2000). We hypothesise:

H1: Decreasing screen size negatively influences decision performance.

Where a decision aid is introduced, and whilst there is conflicting evidence on whether such aids increase decision quality (Barr and Sharda, 1997, Montazemi et al., 1996, Turetken and Sharda, 2004), decision styles can be directly influenced to promote strategies that can minimise the effort expended in reaching a decision, thus impacting decision performance (Benbasat and Todd, 1996, Thomassin Singh, 1998, Todd and Benbasat, 1992). Further, more effortful strategies are generally more time-consuming (Kuo et al., 2004). A decision aid that enables the production of a quality consideration set, and promotes compensatory decision strategies within this subset by reducing the cognitive effort in their employment may increase decision quality and decrease the time taken to otherwise reach a decision. In this scenario, whilst all possible alternatives may initially be present simultaneously on screen as a data grid, the decision aid acts as a reducer of alternatives in facilitating the formation of a consideration set, and the consumer can more easily employ a compensatory strategy on the consideration set matrix to find their optimal alternative. We hypothesise:

H2: The decision aid positively influences decision performance.

A more moderate effect may result in the case of large screen systems, as users may identify 'best fit' decision alternatives visually in the decision matrix with only a relatively small impact on performance. For small screen devices such as PDAs and mobile phones, considering the reduced simultaneous visibility of a large number of decision alternatives with non-distorted data display, the effect of the decision aid in reducing decision effort by identifying potential 'best fits' for that user's choice may be more pronounced. Indeed the influence of the decision aid on performance may be increasingly evident with decreasing screen size. Therefore, we hypothesise:

H3: The decision aid moderates the influence of screen size on decision performance.

3 Method

Experimental design

The study involved a single decision scenario based on the apartment selection task similar to that employed by Payne (1976) and extended by Todd and Benbasat (1992), and involved a 2 x 2 laboratory experiment where students carried out a house selection task on large and small screens. Using tertiary data on local rental housing accommodation in a University city, student housing was categorised into a number of criteria such as rental price, proximity to city, proximity to University, number of bedrooms, and so on. Numerical data for each category was assigned, and tabulated in a matrix for 42 numbered houses with categories as column headings, using the method employed by Häubl and Trifts (2000), and identifying 6 non-dominated *superior* alternatives with 36 dominated *inferior* alternatives (see Appendix A). The single task was to select an apartment (house) from the table. Superior alternatives were positioned randomly in the matrix. This complete table occupied most of the available screen area on a large screen monitor, and was viewable and navigable without user scrolling. Presented at the same font point size, only a portion of the entire table was visible without scrolling on the small screen device. The large screen devices were laboratory PCs with 17" TFT monitors at 1024 * 768 pixel resolution. The small screen devices were colour screen PDAs at a resolution of 240 * 320 pixels.

Sample

101 participants were randomly allocated to one of the four groups. Participants were all volunteering undergraduate students following the same programme of study (age M=18.61,

SD=1.26, 38 male, 63 female). Post-task analyses resulted in the exclusion of 5 invalid cases, leaving a valid N of 96 for further analysis. The PC group without the aid comprised 27 participants, the PC group with the aid 23, the PDA group without the aid 25, and the PDA group with the aid 21.

Measurement

Decision performance was assessed through the following measures:

(i) Time taken to complete the task (seconds)

(ii) Quality of consideration sets

a. Number of distinct alternatives in participants' consideration set

b. Number of superior alternatives in participants' consideration set

The Decision Aid

In the large screen groups the table of 42 houses was visible in its entirety on the PC's monitor. The data was presented on a small screen PDA with the screen size displaying only a portion of the table, with other table cells visible through navigational scrolling (Figure 2). To ensure similar input mechanisms in each case participants navigated the screen through clicking button icons using the relevant pointing device to locate the criteria conditions leading to the identification of a best-fit house. A decision aid was not present in large- and small-screen control groups. The treatment participants performed the same task but on screens where a decision aid assisted in reducing the number of alternatives from the displayed 42 houses to create a consideration set from which the user could select a house: the decision aid presented the user of the device with the facility to add or remove particular houses to a consideration set as a

subset of the unordered original data (figure 3), to view only the contents of this subset, to navigate back and forth between this subset and the main table, and to make a final choice of house from this subset (figure 4). The aid did not act as a recommendation agent, rather it enabled the decision maker to 'mark' particular alternatives for further consideration later in the decision making process. The consideration set displayed each alternative in contiguous rows and alternatives were ordered according to the time they were added to the set, and not ordered or orderable by attribute. The reduced number consideration set provided a less effortful facility to employ a compensatory strategy on a reduced number of alternatives (figure 3). In all groups, where a user clicked on a house in the table, the entire row of data pertaining to that house was visually highlighted to aid horizontal navigation.

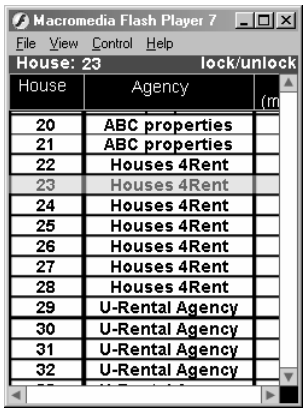

Figure 2: Entire table

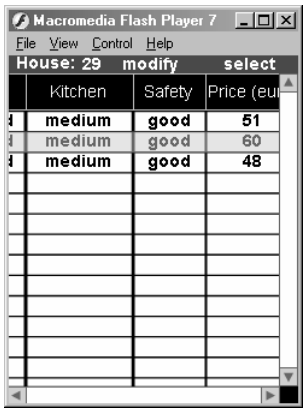

Figure 3: Consideration Set

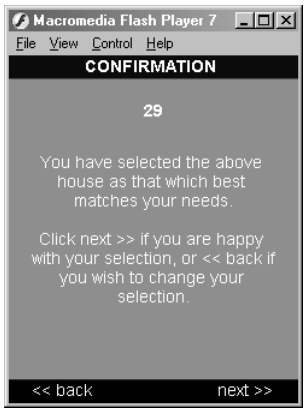

Figure 4: Choosing

4 Results

In general, two-way between groups analyses of variance were conducted to explore the impact of screen size and the presence of the decision aid on each of the dependent variables. With respect to the time taken to complete the task and reach a final decision (tables 1 and 2), there was a statistically significant main effect for the interaction between decision aid and screen size

[F(1, 92) = 11.627, p = .001], with a high effect size (partial eta squared = .112). There was a significant main effect for screen size [F(1, 92) = 5.032, p=.027], with a moderate effect size (partial eta squared = .052). Furthermore, there was a significant main effect for decision aid [F(1, 92) = 36.26, p=.000], with a high effect size (partial eta squared = .283). As expected, participants using the small screen devices took longer to complete the task than those using large screen devices. Also, participants with the decision aid took considerably less time to complete the task than did their counterparts using similar devices without the aid.

	Decision Aid Present		Decision Aid Absent	
	M	SD	M	SD
Large Screen	149.76	35.98	188.42	51.62
Small Screen	132.48	56.45	272.12	115.16

Table 1: Time taken to complete the task (M, SD in seconds)

Source	F	Partial Eta Squared	p
Aid	36.256	.283	.000
Device	5.032	.052	.027
Aid * Device	11.627	.112	.001

Table 2: Analysis of Variance for Time Taken to complete the task

The small screen negatively impacted the time performance measure by slowing the decision process. However, the relatively poor time performance of those lacking the decision aid on the small screen devices was positively compensated by the aid, to the extent that small screen users with the aid took a markedly shorter time to complete the task than small screen users without the aid, and large screen users with or without the aid.

95 (of 96) participants chose a superior alternative as the house which best matched their requirements. However, screen size and the aid were influential in affecting the remaining quality measures. In terms of identifying possible alternatives for consideration, irrespective of whether the alternatives considered were superior or inferior, there was a statistically significant main effect for screen size [$F(1, 92) = 9.451$, $p=.003$], and the effect size was high (partial eta squared = .093). Participants using the large screen devices considered significantly more alternatives than those using the small screen (Table 3). Further, the main effect for the presence of the decision aid was strongly significant [$F(1, 92) = 12.461$, $p = .001$] with a very high effect size (partial eta squared = .119). The decision aid resulted in significantly more alternatives being considered. As verification checks both Friedman's and Kendall's W tests were significant (in both instances Chi-Square = 147.646, $p = .000$). The interaction effect did not reach statistical significance [$F(1, 92) = .134$, $p = .716$].

	Decision Aid Present	Decision Aid Absent
Large Screen	6.96	5.74
Small Screen	5.76	4.20

Table 3: Number of Distinct Alternatives in the Consideration Set

However, the presence of the decision aid did not affect the number of distinct superior alternatives considered. Only the main effect for screen size was statistically significant in this regard (Table 4). Participants using the large screen device had a higher number of distinct superior alternatives in their consideration sets prior to making a final decision than did those using the small screen device irrespective of the presence or absence of the decision aid: those using the small screen device identified fewer superior alternatives (Table 5). Further,

participants with the decision aid considered a higher number of distinct alternatives than those lacking the aid, but this increased number comprised largely inferior alternatives.

Source	F	Partial Eta Squared	p
Aid	1.383	.015	.243
Device	20.502	.182	.000
Aid * Device	.467	.005	.496

Table 4: Analysis of Variance for Superior Alternatives in Consideration Sets

	Decision Aid Present	Decision Aid Absent
Large Screen	5.22	4.89
Small Screen	3.81	3.76

Table 5: Superior Alternatives in Consideration Sets

As such, we accept hypothesis 1 for all objective performance measures. We also accept hypotheses 2 and 3 for all measures with the exception of the influence of the decision aid on the identification of higher numbers of distinct superior alternatives.

5 Discussion

Overall, the experiment supports the hypotheses put forward in the theory section of this paper. Results show that the decision aid can moderate the negative effects of a diminished screen size on decision performance. The performance measures used here were the time taken to complete the task and choose a house, and the quality of the set of houses considered. Results show that decreasing screen size decreases decision performance. However, the decision aid strongly moderated these effects, with the impact of the aid more pronounced on the small screen devices. In particular the decision aid reduced the time taken to reach a decision. Further, the aid

facilitated the identification and consideration of a larger number of distinct alternatives, eased the employment of more accurate decision strategies, and resulted in a faster decision.

In the absence of the decision aid, participants using the small screen took longer to reach their decision. This is consistent with previous studies examining the time impact of a reduced screen area in task-related or goal-seeking scenarios (Marsden et al., 2002, Buyukkokten et al., 2000). While the decision aid positively moderated time-related performance on the large screens to a significant extent, its effect was more pronounced on the small screens. Not only did the decision aid compensate for the relatively poor time performances on small screens to a point nearing or equalling performance on large screens, it resulted in performance times which surpassed both the large screen performances where the aid was absent, and also where the aid was present. Participants using the decision aid on the small screen devices were significantly faster in reaching a decision than all other groups. As such, this experiment provides evidence of the moderating effect of the decision aid on the effect of small screen size on a traditional time-based measure of decision performance.

Participants with the decision aid employed (traditionally more cognitively effortful) compensatory decision strategies before making a final decision. This experiment indicates that the decision aid promotes the use of compensatory strategies. Considering that participants with the aid did not take longer to complete the task, it is possible that the decision aid reduced the cognitive effort associated with the employment of compensatory decision-making strategies. Indeed, considering that participants in the treatment groups took significantly shorter times to complete the task than control groups, and that their decision was no less 'accurate' than other groups in terms of choosing a superior solution, the decision aid may have reduced the effort

associated with using compensatory strategies to levels below that of non-compensatory alternatives. In agreement with Benbasat and Todd (1996) this suggests that the decision aid is effort-reducing, and through the promotion of compensatory strategies can potentially improve decision quality in shorter times.

Participants using the large screens considered more distinct alternatives than did those using the small screens, and also that those with the decision aid considered more than those lacking the aid. Decision quality can be increased when larger numbers of alternatives are considered, where an increased number of considerations can lead to a higher quality consideration set deep into the decision-making process. In this experiment the decision aid directly resulted in the consideration of a larger number of possible choices of house. This, in conjunction with the decision aid's promotion of compensatory strategies in the decision-making process, provides an 'insurance' policy for decision quality.

Considering the relatively low times taken to reach a decision for those groups with the decision aid, through the consideration of more distinct alternatives the decision aid may have led to a higher quality decision without an increased burden of effort. As such, this experiment provides evidence for a decision aid which can increase the number of considerations in a task-based decision-making scenario on small screen devices without an associated time or effort burden. Benbasat and Todd (1996) showed that where such an aid reduces the effort in employing otherwise effortful decision strategies, these strategies are then preferred and used over less effortful but less accurate options. It follows that the decision aid here can lead to better decision-making through the use of 'quality' decision strategies.

Although the decision aid increased the total number of houses considered, it did not increase its non-dominated *superior* component. Participants using the large screens identified more superior solutions than those using the small screens, with the impact of the decision aid statistically insignificant. This is not unexpected, considering that a) participants have more information visible at any given time on the large screen devices, and b) participants can more easily scan all the attributes for a given house more easily on the large screens.

Overall, the decision aid raised the total number of distinct considerations for small screen users to a level surpassing those using the non-aid large screens, and to a point equalising that of the large screen aid users. In terms of providing a similar number of alternatives present in consideration sets prior to final decision choice, the decision aid fully compensated for the diminished screen size on the small devices, and essentially levelled the playing field.

This experiment contributes knowledge on the suitability and efficacy of a decision aid as a moderating influence on tabulated data accessed on small screen devices, and to identify the conditions under which such an aid can positively impact user performance with respect to decision making. The task in this experiment provides an internal validity in that student participants are not surrogates for a decision-making task in other domains, and the subject of the task has an important, immediate, and time-dependent relevance. The task is also one that maps and scales to generic and to management tasks involving time-centric decisions in situations involving remote access to information, possibly through PDA or mobile phone devices: such tasks may include team and project management, funds allocation, and flight reservations.

References

Barr, S. H. and Sharda, R. (1997) *Effectiveness of decision support systems: development or reliance effect?,* Decision Support Systems*,* 21 (2), pp. 133-146.

Benbasat, I. and Todd, P. (1996) *The effects of decision support and task contingencies on model formulation: A cognitive perspective,* Decision Support Systems*,* 17 (4), pp. 241-252.

Buyukkokten, O., Garcia-Molina, H. and Paepcke, A. (2000) *Focused Web searching with PDAs,* Computer Networks*,* 33 (1-6), pp. 213-230.

Chalmers, P. A. (2003) *The role of cognitive theory in human-computer interface,* Computers in Human Behavior*,* 19 (5), pp. 593-607.

Garrity, E. J., Glassberg, B., Kim, Y. J., Sanders, G. L. and Shin, S. K. (2005) *An experimental investigation of web-based information systems success in the context of electronic commerce,* Decision Support Systems*,* 39 (3), pp. 485-503.

Häubl, G. and Trifts, V. (2000) *Consumer Decision Making in Online Shopping Environments: The Effects of Interactive Decision Aids,* Marketing Science*,* 19 (1), pp. 4-21.

Johnson, E. J. and Payne, J. W. (1985) *Effort And Accuracy In Choice,* Management Science*,* 31 (4), pp. 395-414.

Kuo, F.-Y., Chu, T.-H., Hsu, M.-H. and Hsieh, H.-S. (2004) *An investigation of effort-accuracy trade-off and the impact of self-efficacy on Web searching behaviors,* Decision Support Systems*,* 37 (3), pp. 331-342.

Marsden, J. R., Pakath, R. and Wibowo, K. (2002) *Decision making under time pressure with different information sources and performance-based financial incentives--Part 1,* Decision Support Systems*,* 34 (1), pp. 75-97.

Montazemi, A. R., Wang, F., Khalid Nainar, S. M. and Bart, C. K. (1996) *On the effectiveness of decisional guidance,* Decision Support Systems*,* 18 (2), pp. 181-198.

Payne, J. W. (1976) *Task Complexity and Contingent Processing in Decision Making: An Information Search and Protocol Analysis,* Organizational Behavior and Human Performance*,* 16 (2), pp. 366-387.

Payne, J. W., Bettman, J. R. and Johnson, E. J. (1988) *Adaptive Strategy Selection in Decision Making,* Journal of Experimental Psychology: Learning, Memory, and Cognition*,* 14 (3), pp. 534-552.

Shneiderman, B. and Chimera, R. (1994) *An exploratory evaluation of three interfaces for browsing large hierarchical tables of contents,* ACM Transactions on Information Systems*,* 12 (4), pp. 383-406.

Thomassin Singh, D. (1998) *Incorporating cognitive aids into decision support systems: the case of the strategy execution process,* Decision Support Systems*,* 24 (2), pp. 145-163.

Todd, P. and Benbasat, I. (1992) *The Use of Information in Decision Making: An Experimental Investigation of the Impact of Computer-Based Decision Aids,* MIS Quarterly*,* 16 (3), pp. 373-393.

Todd, P. and Benbasat, I. (1999) *Evaluating the Impact of DSS, Cognitive Effort, and Incentives on Strategy Selection.,* Information Systems Research*,* 10 (4), pp. 357.

Turetken, O. and Sharda, R. (2004) *Development of a fisheye-based information search processing aid (FISPA) for managing information overload in the web environment,* Decision Support Systems*,* 37 (3), pp. 415-434.

Appendices

House	Agency	City (minutes)	University (minutes)	Single Rooms	Facilities	Kitchen	Safety	Price (€)
01	KMG Houses	35	16	3	medium	medium	good	75
02	KMG Houses	29	25	1	good	medium	good	78
03	KMG Houses	20	31	1	medium	medium	good	63
04	KMG Houses	26	13	2	very good	medium	good	69
05	**KMG Houses**	**5**	**10**	**3**	**very good**	**medium**	**good**	**51**
06	KMG Houses	14	10	2	good	medium	good	81
07	KMG Houses	38	37	2	good	medium	good	66
08	Realty Rentals	29	22	2	good	medium	good	60
09	Realty Rentals	17	19	2	medium	medium	good	57
10	**Realty Rentals**	**8**	**4**	**3**	**very good**	**medium**	**good**	**54**
11	Realty Rentals	32	34	1	good	medium	good	54
12	Realty Rentals	23	28	1	good	medium	good	69
13	Realty Rentals	23	13	2	good	medium	good	78
14	Realty Rentals	11	31	1	very good	medium	good	72
15	ABC Properties	32	16	3	medium	medium	good	75
16	ABC Properties	17	37	2	very good	medium	good	81
17	ABC Properties	20	28	1	medium	medium	good	60
18	ABC Properties	29	19	1	very good	medium	good	63
19	ABC Properties	38	10	2	medium	medium	good	66
20	**ABC Properties**	**8**	**10**	**3**	**very good**	**medium**	**good**	**48**
21	ABC Properties	35	22	1	good	medium	good	72
22	Houses 4Rent	14	34	2	medium	medium	good	57
23	**Houses 4Rent**	**11**	**4**	**3**	**very good**	**medium**	**good**	**51**
24	Houses 4Rent	26	25	3	good	medium	good	78
25	Houses 4Rent	38	19	2	good	medium	good	72
26	Houses 4Rent	32	22	1	medium	medium	good	69
27	Houses 4Rent	11	13	3	medium	medium	good	75
28	Houses 4Rent	17	16	3	very good	medium	good	81
29	U-Rental Agency	35	34	3	very good	medium	good	60
30	U-Rental Agency	23	37	2	medium	medium	good	54
31	U-Rental Agency	20	28	2	good	medium	good	57
32	U-Rental Agency	14	31	1	medium	medium	good	66
33	U-Rental Agency	29	22	3	medium	medium	good	78

34	**U-Rental Agency**	**5**	**7**	**3**	**very good**	**medium**	**good**	**54**
35	U-Rental Agency	26	25	1	good	medium	good	63
36	Property People	38	37	3	good	medium	good	60
37	Property People	14	16	1	good	medium	good	72
38	Property People	20	19	2	medium	medium	good	75
39	**Property People**	**11**	**7**	**3**	**very good**	**medium**	**good**	**48**
40	Property People	35	34	1	very good	medium	good	57
41	Property People	26	28	1	very good	medium	good	63
42	Property People	17	13	2	medium	medium	good	66

Appendix A: Data grid (Entries in bold are non-dominated superior alternatives)