Testing the improved PAS methodology

Implementation of a search algorithm

Hylke de Visser – Final report – June 2016

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Project information

Institution:	Delft University of Technology;
	Faculty of Architecture and the Built Environment;
	MSc track Management in the Built Environment
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Title:	Testing the improved PAS methodology
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Colophon

Project title:

Testing the improved PAS methodology
Implementation of a search algorithm.

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Preface

In front of you is the report that I wrote on the research and design project that I conducted the past year in order to demonstrate my academic competencies and so obtain my master degree from the department of Management in the Built Environment (formerly Real Estate & Housing), at the faculty of Architecture and the Built Environment at Delft University of Technology.

This process started when Monique Arkesteijn invited me to drink a coffee and discuss a potential subject for my graduation thesis once I started orienting for a graduation project. This didn't surprise me, because drinking coffee to connect with people is how it works at this faculty. With this invitation, she recalled a statement made by me a year before. I indicated that I was interested in the concept of systems thinking and planned to take a course in system-dynamic modelling, in order to apply this in some way in a more quantitative graduation project. Somehow she associated this course with her PhD research theme and saw a potential match. This is typically Monique. Once she is enthusiastic, she easily makes connections to make things work and she is good at that.

Part of my personal motivation for a research project was that I wanted to make a contribution to current research in order to be taken seriously and to work on something that is relevant in practice. The possibility of contributing to the Preference-based Accommodation Strategy (PAS) research covered al the aspects mentioned previously, so I agreed.

The process that I followed during the past academic year started with a thorough literature study to gain full understanding of the PAS procedure and its development. Ruud helped me in this phase to understand the mathematical principles of correct preference measurement and to explain it in such a way that other students are able to understand it.

At the end of this phase I made an early start experimenting with modelling in Matlab, something I had only heard of up to that point. A lot of friends started doing this in their first year in Delft, I started in my 6th year. However I learned surprisingly fast, particularly due to the help of Rein, with whom I met often to discuss my questions almost every other week. I learned that modelling can be very satisfactory, already when the smallest step works, its counterpart is the frustration when you cannot find out why something doesn't work like you expected.

I used this theoretical knowledge and modelling experience in a pilot study with the PAS for Oracle's Advanced Planning team. It took quite some time before I found a company with people willing to facilitate such a project that also had the time to do so. Both Carol Leipner-Srebnick and Katie Davenport were very enthusiastic and helpful during the entire process. The evaluation results from the pilot study were very positive and upfront I did not dare to think that people would really want to use the model I developed.

For the past ten months I have been collaborating closely with Monique Arkesteijn as my first mentor, towards the final result in this report. In the beginning you helped me to find the right focus in the research field and to make me understand what I was working on. Gradually this changed into more of a guiding role in the preparation and execution of the pilot study. All the time you were very enthusiastic and you faced the challenges we encountered in a positive way. Thank you for guiding me through this process.

My second mentor was Ruud Binnekamp. I want to thank you for your role in the structured formulation of my research questions and the accompanying research plan. In addition to this, the discussions and structured feedback on my attempts to explain

the mathematical language of the correct preference measurement paradigm in a chapter that can be understood by my fellow student in the future, were very helpful.

I also would like to thank Rein de Graaf for his efforts in my initial Malab experiments and his patience in explaining to me how I could best construct the model I was working on. Also in the development of the final model and the design interface your modelling expertise was priceless to me.

Hereby I would like to thank both Carol Leipner-Srebnick and Katie Davenport for the fruitful collaboration of the past four months, since they genuinely tried to understand the system and put a lot of time in the weekly meetings and the workshop sessions with the model.

Enjoy reading,

Hylke de Visser

Delft, 24 June 2016

Management summary

Introduction

Large, multinational companies often have vast real estate portfolios that are meant to support the core activities of the organisation. In order to manage such a portfolio properly, they have a real estate department with professionals solely dedicated to the management of the company's real estate. This is called corporate real estate management (CREM). This research and design project is focussed on the test and evaluation of a tool to improve CREM decision-making in order to increase the added value of the real estate to a company.

Alignment of corporate real estate (CRE) and corporate strategy has been a long-standing issue in CREM (Heywood, Kenley, & Waddell, 2009, pp. 5-7). This alignment is defined as *'[...] the bringing into harmony things that differ or could differ [...] by making them consistent or in agreement with each other'* (Heywood, 2011, p. 2). According to Den Heijer (2011, p. 91), the core of real estate management (REM) is the added value of real estate to the performance of an organisation. Added value can be realised by adjusting costs and revenues and by meeting more qualitative goals, this can be done through the alignment of CRE strategy and business strategy (De Jonge et al., 2009, pp. 9-10, 17; Heywood, 2011, p. 1). Generating this added value is an issue as practitioners indicate that they have trouble in achieving this alignment (Heywood, 2011, p. 11).

From the available alignment models, Heywood (2011, pp. 2, 3, 6) identified a total of 15 different components in the alignment activity, however none of the models employs the complete set (Heywood, 2011, pp. 5-6). As a consequence, none of them captures the full bandwidth of the alignment activity, which makes it hard to select one to apply in practice (Heywood, 2011, pp. 6, 10). This results in heuristics judgement (i.e. intuitive judgement) of the alignment, which is prone to errors (Heywood, 2011; Kahneman, 2011, pp. 7-17, 22-27) In addition to this, Arkesteijn, Valks, Binnekamp, Barendse, and De Jonge (2015) reviewed a selection of these alignment models. They conclude that most of them do not aggregate criteria ratings in an overall rating, are not transparent in generating alternatives and have no well-defined procedure to select the best alternative. Moreover, none of the methods incorporates correct measurement of the stakeholders' preferences (Arkesteijn & Binnekamp, 2013, p. 94; Arkesteijn et al., 2015, p. 103).

Arkesteijn et al. (2015) propose the preference-based accommodation strategy (PAS) procedure as a solution to the methodical issues above. In this procedure, the stakeholders define a set of decision variables and subsequently determine their preferences and assign weights to the variables. The preferences are established by assigning a preference rating between 0-100 to three physical values of the variable as (see figure i). The model uses the Lagrange curve fitted through these points to calculate the preference ratings of intermediate values (Arkesteijn et al., 2015, p. 104).

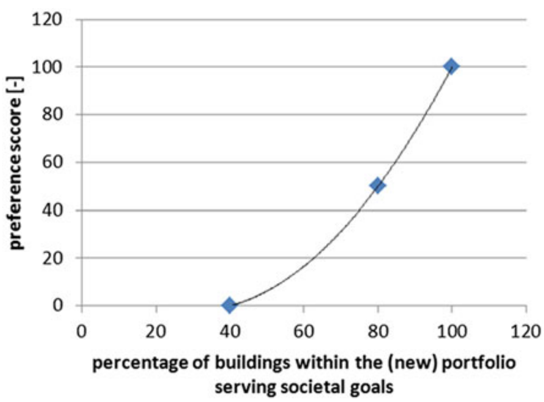


Figure i – Example of a Lagrange curve (Arkesteijn & Binnekamp, 2013, p. 96)

In an iterative self-design process, the stakeholders then manually design portfolio alternatives, while optimising the overall preference rating, which is generated using correct preference measurement. The alternative with the highest preference rating, i.e. the optimum design solution, is selected (Arkesteijn et al., 2015, p. 104). The principle of the process is visualised in figure ii. An advantage of this self-design process is that the stakeholders are able to gain insight into the effects of their input and improve it in order to increase the quality of the result (Arkesteijn et al., 2015, pp. 117-118).

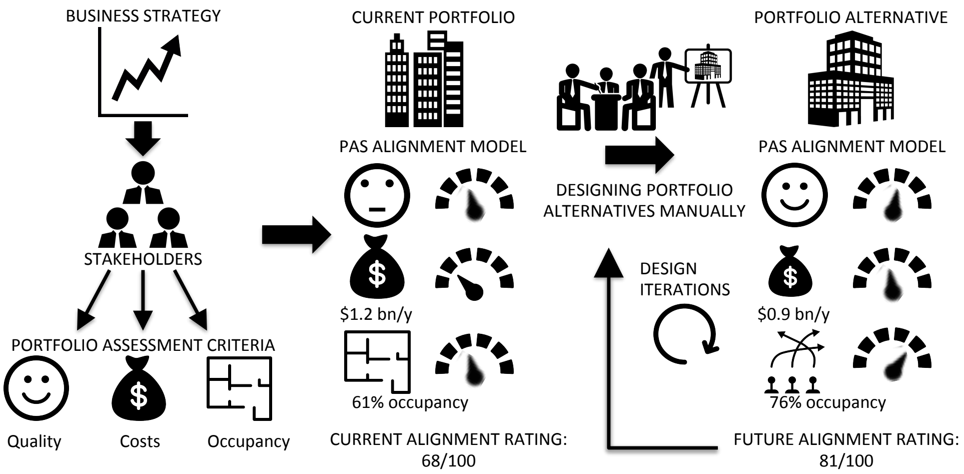


Figure ii – Basics of the PAS procedure (own illustration)

Earlier tests with the PAS have been successful and have shown that the iterative process of designing portfolio alternatives helps the users to develop insights in the effects of their input on the results. The possibility to adapt the input helps to improve the reflection of their preferences in the model, which increases the quality of the results (Arkesteijn et al., 2015).

However, this design process can be quite complex. Already in a simple case of 15 buildings and 3 possible interventions, the number of possible portfolio's is 3 to the power of 15 = 14.348.907. This means that it remains a question if the rating that is found by the stakeholders is the highest possible rating. In order to find out, previous research into the PAS suggest the implementation of a search algorithm that helps to find an optimum alternative in more complex cases (Arkesteijn & Binnekamp, 2013, p. 98; Arkesteijn et al., 2015, p. 118). However the algorithm has a limitation, because due to the nature of the problems in the PAS, it is confronted with a curve with multiple peaks that represents the preference rating. Once the algorithm finds a peak it will not search further. Therefore it is not certain if it found the highest peak, so this is called a local optimum, whereas a global optimum is certainly the best solution[1].

Currently this algorithm is available. Therefore, this research and design project is focussed on the implementation of the search algorithm in the PAS procedure, with special attention to discovering determinants for the successful implementation of such a tool in human decision-making processes. This research is important because it is assumed that it can find an alternative with an even higher preference rating compared to the self-design process, hence to achieve a higher added value for the organisation.

The main research question that is covered in this research and design project is: *How could an improved PAS be developed in such a way that the outcome of the algorithm closely reflects the stakeholders' preferences and what insights do a test and evaluation in practice provide?*

[1] Based on n.a. (2015). *Local Optima vs. Global Optima. Retrieved 22/02/16 from http://www.lindo.com/doc/online_help/lingo15_0/local_optima_vs__global_optima.htm*

The elements in this main question are summarised in the conceptual model in figure iii, it comprises of three main elements; the *Improved PAS procedure*, *Building & testing a Matlab model* and *Pilot study evaluation*. These three elements form the structure of this report.

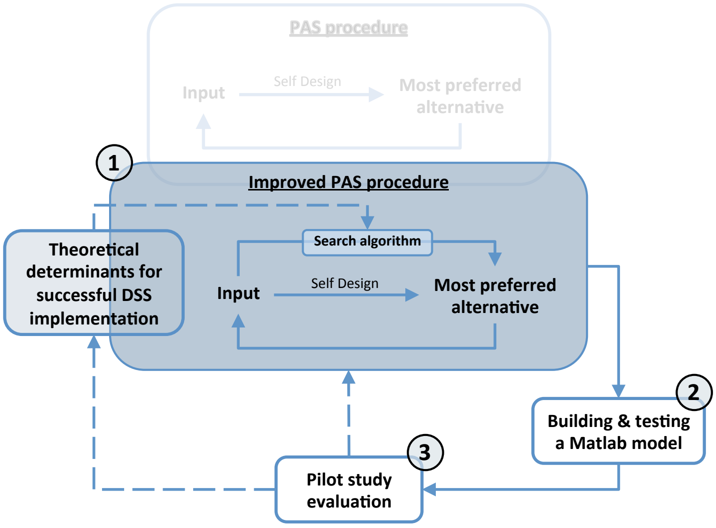


Figure iii – Conceptual model (own illustration)

Methods

The main question comprises of a so-called design problem, so the design of an artefact was required to properly arrive at a solution (Barendse, Binnekamp, De Graaf, Van Gunsteren, & Van Loon, 2012, p. 1). Therefore, the final result is a model of the PAS procedure that uses the algorithm and is tested and evaluated in a pilot study in practice.

This model was built in an iterative sequence of three interviews and two workshops in the following sequence; I-W-I-W-I. In each interview round, the stakeholders were invited to make adaptations to their input in the model. Also the PAS was evaluated based on the checklist that resulted from the literature study. Each of the elements was connected to acceptance or trust and to one of the three evaluation criteria suggested by Joldersma and Roelofs (2004):

1) Experiences with the method;
2) Attractiveness of the method;
3) Perception of effectiveness of the method (combined with the observer's perception of the effectiveness of the method).

Successful implementation of Decision Support Systems

Decision support systems (DSS) are computer-based information systems that support multi criteria decision-making problems by organising information to solve these semi-structured or unstructured problems (Razmak & Aouni, 2015, pp. 101, 113; Riedel et al., 2011, p. 232). DSSs are developed as interactive tools to assist in formal steps of problem solving, e.g. generating alternatives and selection of relevant options (Razmak & Aouni, 2015, pp. 102, 111; Riedel et al., 2011, p. 232). According to this definition, the PAS can be regarded as such a DSS.

Literature study revealed that creating acceptance of a system and trust in the system and its outcome is important for actual use of the system. A key element in establishing both acceptance and trust is participation and involvement of stakeholders in the development and implementation process. According to the model for creating acceptance, developed by Riedel et al. (2011, pp. 258, 266-267) participation and involvement helps the stakeholders to improve the representation of the actual decision making process in the characteristics of the model. Both lead to system acceptance, which leads to system use and satisfaction.

In the cases where a DSS is required, the system is too complex to fully understand so users need to rely on the system, which requires their trust in the system. Trust is made operational as the expectation the user has regarding the tasks the system will perform on his/her behalf. Trust is increased by system performance according to the expectations, insight in the backside of the system and low performance variability. Therefore, since participation and involvement helps to develop expectations and enables user influence on the system characteristics, this could bring in accordance the expectations and system performance. Therefore, to increase trust, participation should be a central element in the process.

This means that since an important part of the involvement is embedded in the iterative self-design process in the PAS, the algorithm in the improved PAS should be implemented in addition to the self-design, to create acceptance, trust and system use.

Moreover, the determinants for successful DSS implementation discussed above, resulted in a checklist that was used in this research and design project to prepare and to evaluate the model development process and the model itself. An interview with Monique Arkesteijn, who leads the PAS research project, showed that all elements were already more or less taken into account in previous pilot studies with the PAS.

Model building & tests

The improved PAS was applied in a pilot study at the Advanced Planning (AP) team of the real estate department of Oracle, a multinational ICT company. The AP team executes their global real estate strategy by maintaining close ties with the business. The team conducts so-called location studies in order to identify locations, i.e. cities or metropolitan areas, that a Line of Business (LOB) could choose from to expand its activities. The AP team uses a scorecard process in order to rank a selection of locations on a set of criteria with weights that are confirmed by the LOB. The LOB then selects a location.

The case used in this pilot study comprised of a location study conducted for LOB 1 in the region covering Europe, Middle-East and Africa (EMEA). In this pilot study, a selection of 22 of the original criteria was used, together with 32 locations among which are six current locations. Also, during the process four design constraints were established. The criteria are confirmed by a representative of LOB 1 and cover multiple perspectives from within the LOB. So effectively one stakeholder is involved that brought in criteria. In addition to this, two users from the AP team were involved. The aim of this pilot study was to provide a second opinion on the original study outcomes, since the final choice by the LOB was not in the top-10 of the ranking. Therefore the model was required to provide a ranking of the locations based on their individual preference rating and an overall preference rating for each portfolio design made by the users.

The model was written in Matlab, a mathematical calculation tool that enables a model based on interrelated functions, which makes it easy to add objects and alternatives. It is used because the search algorithm is written in Matlab. The final model meets the above requirements and was connected to a graphical user interface (GUI) that provided the users with all the required elements to design and compare portfolio alternatives, e.g. by providing visual feedback on the design constraints, easy comparison to the current portfolio rating and the possibility to save and recall alternatives (see figure iv).

However, according to correct preference measurement theory (Barzilai, 2005, 2010), the calculation of overall weighed preference ratings is problematic, since also when measured correctly, preferences do not allow operations of addition and multiplication (Binnekamp, 2010, pp. 33-35). It is only an approximation of the real value that was implemented because obtaining the real values through Tetra, a basic version of the algorithm, takes more time and was done outside of the workshops.

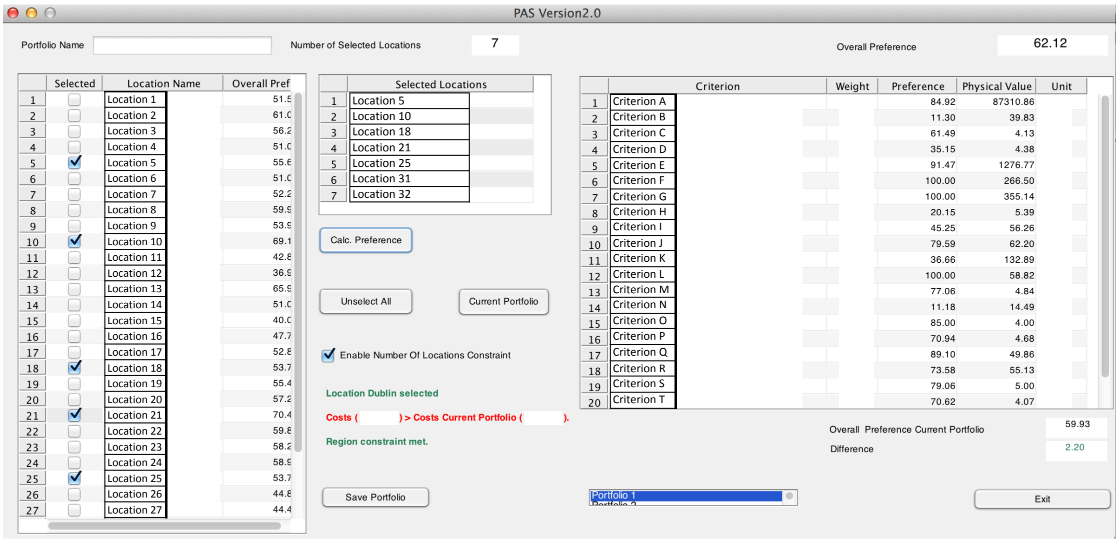


Figure iv – Final GUI impression with confidential information coded (own illustration)

Model outcomes

The outcomes of the pilot study after workshop two comprise of a ranking of all locations based on their preference rating and a set of portfolio alternatives from the self-design process and the optimum alternative from the brute force function.

Comparing location rankings

A ranking of locations was the main output from the original study, therefore the users compared the PAS ranking to the original ranking (see table i). The PAS ranking was checked in Tetra, which showed that only two locations switched one place. This is a confirmation of the close approximation that the weighed average calculation provides for the actual value.

The comparison showed that roughly 2/3rd of the top-15 locations in the original study returns in the top-15 of the PAS outcome. Moreover, location #13, which was selected by LOB 1 after the initial study, moves from place 17 to place 4 in the PAS ranking, which makes it the second most preferred location that is not included in the current portfolio. This is an initial indicator that the PAS model quite closely reflects the stakeholders' preferences in a more accurate way than the original scorecard procedure.

Output original study		Output PAS model		
Rank:	**Locations:**	**Rank:**	**Locations:**	***Overall weighted location rating:***
1	Location 21	**1**	Location 21	70,43
2	Location 10*	**2**	Location 10*	69,19
3	Location 22	**3**	Location 32*	66,41
4	Location 25*	**4**	**Location 13**	65,99
5	Location 23	**5**	Location 2	61,00
6	Location 32*	**6**	Location 8	59,98
7	Location 2	**7**	Location 22	59,84
8	Location 17	**8**	Location 24	58,93
9	Location 16	**9**	Location 23	58,26
10	Location 24	**10**	Location 20	57,28
11	Location 20	**11**	Location 3	56,21
12	Location 29	**12**	Location 5*	55,67
13	Location 18*	**13**	Location 19	55,48
14	Location 31*	**14**	Location 9	53,97
15	Location 26	**15**	Location 25*	53,75
16	Location 3	**16**	Location 18*	53,72
17	**Location 13**	**17**	Location 17	52,89
18	Location 27	**18**	Location 7	52,25
19	Location 15	**19**	Location 1	51,56
20	Location 8	**20**	Location 6	51,05
21	Location 19	**21**	Location 14	51,04
22	Location 14	**22**	Location 4	51,00
23	Location 5*	**23**	Location 29	48,49
24	Location 9	**24**	Location 16	47,78
25	Location 7	**25**	Location 26	44,88
26	Location 6	**26**	Location 31*	44,55
27	Location 28	**27**	Location 27	44,42
28	Location 1	**28**	Location 11	42,82
29	Location 30	**29**	Location 15	40,09
30	Location 4	**30**	Location 28	39,15
31	Location 12	**31**	Location 12	36,95
32	Location 11	**32**	Location 30	35,16

*Table i – Location ranking from the PAS model compared to the ranking from the original study (* = location in current portfolio)*

Generating alternatives and selecting the optimum alternative

The main portfolio alternatives generated during the pilot study are presented in table ii. The alternative Current & Location 13 is the portfolio with the actual location selected by the LOB.

Name:	*Current portfolio*	Current & Location 13	Optimum_alt_04	*Global optimum alternative*
Locations:	*Location 5*	Location 5	Location 8	Location 10
	Location 10	Location 10	Location 10	Location 13
	Location 18	Location 13	Location 13	Location 17
	Location 25	Location 18	Location 17	Location 21
	Location 31	Location 25	Location 25	Location 27
	Location 32	Location 31	Location 31	Location 31
		Location 32	Location 32	Location 32
Preference rating:	*59,93 (Tetra: 61,43)*	**61,36 (Tetra: 63,05)**	**62.48 (Tetra: 64,46)**	**64,01 (Tetra: 65,88)**
Difference	-	**3%**	**5%**	**7%**

Table ii – Comparison of optimum portfolio alternatives to the current portfolio and the actual choice by LOB 1

The portfolio alternative with the maximum preference rating designed by the stakeholders is the alternative Optimum_alt_04. It includes four of the six locations from the current portfolio. Three of those, location 10, 31, 32 are included to stay within the design constraints that require to include location 10 and Russia and the Middle-East, because in the latter two regions no other locations are available in the model. Also location 13 is included. This portfolio alternative provides an improvement of 5% in the preference rating over the current portfolio, based on the correct Tetra ratings.

After the pilot study a brute force function was used to generate and rank all feasible alternatives. The number one alternative is the Global optimum portfolio alternative. This has a higher preference rating than found by the stakeholders, which confirms the hypothesis that a portfolio alternative can be found with a better preference rating than the stakeholders are able to find. Moreover, the ranking showed that there are 78 alternatives with a better rating than found by the users through self-design.

The optimum alternative includes the minimum number of three of the six locations from the current portfolio, just to meet the regional design constraints. As such, it differs from the optimum found by self-design, which also included the current location 25. In addition to this, the location with the highest individual preference rating, location 21 and location 13, are included. The fact that location 21 is included is the most important difference with the alternatives designed by the users. At the same time it is a logical step in the design of the optimum portfolio, since this is the only way to increase the portfolio preference rating as much as possible. The global optimum portfolio alternative provides an improvement of 7% in the preference rating over the current portfolio.

Pilot study evaluation

In general the users evaluated the improved PAS very positively. They were especially positive about their involvement in the iterative model development process, which made them understand the PAS and model principles. One of the AP team users indicated that:

"she feels inclined to put more thought in fewer criteria, which means a choice for quality over quantity."

They also indicated that the use of preference curves, the selection of criteria and the adaptations made in the design constraints, made the model reflect their preferences and the actual decision-making process very well. Also the model usefulness is rated highly by the stakeholders. The representatives of the AP team were specifically enthusiastic about the visual feedback and ease of use of the design interface.

The above evaluation results confirm that the users accept the model. Also from the evaluation interviews it followed that the users developed their expectations of the model performance during the model development process, while at the same time contributing to the input of the model. This brought the final model performance into accordance with their expectations, which resulted in trust in the model. Moreover, the users accept the outcomes of the brute force function as the final outcome of the pilot study. They regard it as a useful addition to the self-design process, which adds up to their positive perception of usefulness. However still, adding some criteria could improve the representation of their preferences in the portfolio alternatives.

These results imply a positive user experience with the PAS. Also they find the model very attractive, and would like to use it in their daily decision-making process. Moreover, the model is deemed effective in the decision-making process by the AP team. These results again confirm that the algorithm could be best implemented in addition to the self-design process, since this was evaluated very positively.

However, there are also suggestions for improvement. For instance one of the users asks for a more in-depth explanation of the backside of the model and to provide a manual with directions for each step of the PAS in order to be able to involve business users more easily. Also one of the users touched upon possible improvements of the graphical presentation of the output in order to present the results towards executives in order to take a decision.

Discussion & Conclusions

Results in perspective

Previous cases in which the PAS was tested showed an increasing level of complexity, compared to this, the case in this pilot study was less complex. Despite the aim for a more complex case suggested in previous research, to see the added value of the search algorithm, the outcome of this pilot shows that even in a more simple case there was a clear boundary to the preference rating found by the stakeholders. Also the brute force function provided added value. Moreover, it can be concluded that such a function is even more preferable as it finds a global optimum instead of a local optimum.

In comparison with the current scorecard system, the PAS provides the added value of a more fundamental incorporation of the stakeholders' preferences and a better representation by means of preference curves. Also it is more efficient in rating additional locations and in designing and comparing portfolio alternatives. Moreover it provides a goal oriented system for optimisation of the portfolio.

Conclusions

The main research question that is covered in this research and design project is: *How could an improved PAS be developed in such a way that the outcome of the algorithm closely reflects the stakeholders' preferences and what insights do a test and evaluation in practice provide?*

In this research and design project, an improved PAS has been developed based on the checklist developed from theory with determinants for successful DSS implementation. The PAS model was built in an iterative process where the stakeholders were closely involved from the start. This process followed the entire PAS procedure and for each of the steps, the principles, goals and expected results were explained to the users as insightful as possible. Together with the workshops, in which the users operated the model, they gained a good understanding of the effects of their input and the model itself. This helped them to make valuable improvements in the model, which increased the reflection of their preferences. The users confirmed this explicitly at the end of the second workshop.

The results of the pilot study showed an improvement in the representation of the users' location preferences in the final ranking of locations and in the self-design process, the users found an optimum alternative with an improvement in the alignment of 5% compared to the current portfolio. Moreover, the equivalent of the algorithm, the brute force function, was able to find an optimum portfolio alternative with an even higher preference rating with an increase of 7% in the preference rating that was accepted by the users as the final outcome of the pilot study.

The pilot study was evaluated very positively. The stakeholders felt very much involved in the process and indicated that they feel comfortable with the model and its output. Moreover, they indicated that they would like to use the model in their actual decision-making process because it better represents actual preferences, it works quite efficient and it is easy to design and compare alternatives. Furthermore, the evaluation showed that the process resulted in acceptance and trust in the model. As the LOB 1 representative put it,

"it is an excellent data driven tool to support the decision-making process."

The users evaluated the optimum alternative positively, although the second outcome, with an insignificant lower preference rating, felt somewhat more comfortable. Also one of the users indicated that some additional criteria would increase the reflection of the actual decision-making process in the optimum portfolio alternative. Still the users indicated that it improved their perception of the model usefulness.

The final outcome is the absolute optimum portfolio alternative in this case and shows an increase of 7% in the alignment between the real estate and the business of LOB 1. This means that the model is capable of increasing the added value of real estate to the organisation by improving the decision-making process. Even more so because the users indicated that they accept this outcome and would use the model in their actual decision-making process.

The significance of the findings in this pilot study is in the fact that Oracle is a very large, globally operating company and although their current process was already quite advanced, they still see the improvement of the PAS procedure and indicate that they would really like to use the tool in their daily work and to implement its outcomes.

Recommendations

The pilot study in this research and design project is evaluated very positively. Therefore an important recommendation for future research is to so use the improved PAS with the search algorithm implemented in addition to the self-design process. The modelling should take place in Matlab as the resulting model can be connected to the algorithm.

However, because this case included one stakeholder representative whom brought in criteria and one intervention, another recommendation for further research is to test the improved PAS in a complex case including multiple stakeholders involved in the pilot and multiple interventions. Such a case is expected to provide additional insight in the boundaries of the self-design process and the capabilities of the search algorithm. Nevertheless, it is recommended to use a less complex model to explain to the users how it works. The current pilot study has shown that this helps to make the stakeholders understand the model, which increases their acceptance of the model and trust in the model and its outcomes.

In this research and design project, the algorithm was substituted by a brute force function, which incorporates the important advantage that it finds the global optimum alternative. It could be valuable to find out in further research what the boundaries are for using such a function in terms of the number of feasible alternatives combined with the calculation time. In relation to this, it might be worthwhile test the performance and reliability of the algorithm by comparing the outcomes with a brute force function in cases with increasing complexity.

Reading guide

This report is comprises of five parts. Each part presents the results of a phase in this research and design project. The report starts off with the problem analysis, which is part one.

In *chapter 1 'Introduction to the problem field'* the reader gets an introduction to the problem faced in current CREM practice and the relevance of this research project from this perspective.

Chapter 2 'Research plan & methods' presents the objectives of this research and design project together with the research questions that result in a conceptual model that is used to structure the research. Also research methodology is discussed.

In *chapter 3 'Current state-of-the-art in research on the PAS procedure'* an overview is provided of the development of the PAS so far that led to the next step made in this project.

In addition to this, *chapter 4 'Multi criteria decision analysis'* and *chapter 5 'preference measurement'* provide additional relevant knowledge on the PAS as an MCDA tool and the paradigm of correct preference measurement to which this research and design project adheres.

Chapter 6 'Implications for the research project' summarises the lessons from the previous chapter.

Part II takes the first step towards an answer to the main research question and answers the first sub-question.

In *chapter 7 'Successful implementation of decision support systems'* based on literature study, a checklist is developed to guide the preparation and evaluation of the pilot study.

In *chapter 8 'Matlab modelling exercise'* the findings from the process of building a first Matlab model are presented.

In *chapter 9 'Lessons for implementation'* the first sub-question is answered.

Part III reports on the pilot study conducted in this research and design project and provides insights in the case used and the model that was built. This part is concluded by an answer to the second sub-question.

Chapter 10 'Current decision-making process' describes the current real estate alignment activity within Oracle.

In *chapter 11 'Writing the model in Matlab'* the model requirements are presented, together with the modelling process and the final model structure. The accompanying process is described in *chapter 12 'Testing & improving the model in practice'*, which also provides a reflection on some specific elements.

In *chapter 13 'model outcomes'* the results from the pilot study are presented in the form of a location ranking and an optimum portfolio design. Also this chapter answers the second sub-question.

In part IV the pilot study evaluation results are discussed and analysed in *chapter 14 'evaluating the pilot study'* and the implicaitons of this are presented in *chapter 15 'implications for further development of the PAS'*. Both chapters provide a partial answer to the third sub-question.

Part V provides a discussion on the results and concludes the report by combining the answers to the sub-questions into an answer to the main question.

Chapter 16 'The results in perspective' provides a reflection of this PAS pilot in relation to previous pilot studies and tries to explain the reason for the highest possible preference rating found in the study. Also it puts the PAS in perspective of the original scorecard process used in Oracle.

In *chapter 17 'Final conclusions'* the answers to the sub-questions are summarised and an answer to the main research question is formulated. This conclusion is complemented by a set of recommendations in *chapter 18 'Recommendations for further research'.*

Key terms list

Term/abbreviation	Explanation
BI	Behavioural intentions
Case	The case used in this research and design project comprises of a location study previously conducted by the Oracle Advanced Planning (AP) team, for one of their local LOB's. This use of the word 'case' should not be mixed up with its meaning in the context of the research method 'case studies'.
DSS	Decision support system
Feedback	*"the process of feeding information about the output of a process back into the process so it can be used to obtain better results"* (Dym & Little, 2004, p. 26)
Iteration	*"the repeated application of a common method or technique at different points in a design process"* (Dym & Little, 2004, p. 26)
MCDA	Multi criteria decision analysis
PAS	The Preference based Accommodation Strategy (PAS) comprises of three elements; 1. the procedural sequence of actions the PAS constitutes; 2. the process of performing these actions, which consists of a sequence of interviews and workshops to build the model; 3. the model itself that represents the procedure.
Positive/negative relation	*"A link between two variables A and B is considered positive if (i) an increase in A causes B to rise above what it would have been otherwise and (ii) a decrease in A causes B to fall below what it would have been otherwise. A link between two variables A and B is considered negative if* ***(i)*** *an increase in A causes B to fall below the value would have had otherwise and* ***(ii)*** *a decrease in A causes B to rise above what it would have been otherwise"* (Pruyt, 2013, p. 36).
Self-design	The activity of manually designing portfolio alternatives in the PAS procedure.

Table iii - List with key concepts used in this report

Table of content

Part I – Problem analysis

1. Introduction to the problem field

Real estate is often not at the heart of a company, real estate management is just one of the management processes that support the core business. However, real estate is an important precondition for a company to perform the core processes, its effect cannot be isolated. After all, employees need an office and machinery needs a roof over it, this means that real estate is connected to the people, the processes and the objectives of the organisation.

Large, multinational companies often have large real estate portfolios to manage. MasterCard, Phillips, Shell, they all have offices, factories and plants around the globe that have one goal; to support the core activities of the organisation. In order to manage this portfolio properly, they all have a real estate department with professionals solely dedicated to the management of the company's real estate. This is called corporate real estate management (CREM).

Real estate has the characteristics of being very cost intensive and rather static. Most buildings have a life span of more than 50 years and lease contracts generally span 10 to 20 years, although this is changing. This conflicts with the short-term orientation of a company that looks only a maximum of five years ahead. The challenge faced by CREM professionals is to align the real estate portfolio with the dynamic business strategy. In addition to this comes the complexity of the environment in which this should happen. Multiple stakeholders with different objectives and perspectives are part of the decision-making process, and all have to be taken into account.

There have been multiple attempts to aid this process, by providing procedures and models to guide it. However, those are mostly formal procedures from a business administrative point of view that lack structure. An approach based on designer thinking, as it is taught at the faculty of Architecture at Delft University of Technology, can help to think in terms of solutions. By designing alternatives together, the stakeholders can achieve a common understanding of the challenge, learn to understand each others' perspective and find common solution grounds. Moreover, professionals that graduated from the department of Management in the Built Environment (MBE), speak the same language as the real estate professionals and are able to bridge the language gap between these professionals and business professionals.

Therefore, a structured procedure to design a real estate portfolio strategy would be helpful. The preference based accommodation strategy (PAS) procedure could be a solution here. It enables the corporate real estate manager to incorporate all possible criteria and preferences of these stakeholders and to explore their effects on the resulting strategy design. The goal of the PAS is to improve the corporate real estate decision-making process by making the alignment measurable and providing tools to improve the alignment in the future. In order to better handle the complexity of such real estate decision-making problems, a mathematical algorithm is required to find an optimum solution. The implementation of this algorithm is the subject of this research project.

1.1. Problem definition

The general introduction provided insight in the perspective of this research within CREM practice. This paragraph describes the background of the problem and presents a brief analysis of the problem field. The goal is to establish the contribution of this specific research step in the current research into the PAS procedure.

Alignment of corporate real estate (CRE) and corporate strategy has been a long-standing issue in corporate real estate management (CREM) (Heywood et al., 2009, pp. 5-7). This alignment is defined as *'[...] the bringing into harmony things that differ or could differ [...] by making them consistent or in agreement with each other'* (Heywood, 2011, p. 2). According to Den Heijer (2011, p. 91), the core of real estate management (REM) is the added value of real estate to the performance of an organisation. Added value can be realised through adjusting costs and revenues and by meeting more qualitative goals, this can be done through the alignment of CRE strategy and business strategy (De Jonge et al., 2009, pp. 9-10, 17; Heywood, 2011, p. 1). This is an issue as practitioners indicate that they have trouble in achieving this alignment (Heywood, 2011, p. 11).

In the past twenty years multiple models have been developed to help improve alignment, these models approach alignment in different ways, e.g. as a process or a state (Heywood, 2011, pp. 2-3, 8). In order to be able to measure the alignment, it is most appropriate to look at it as a state (Arkesteijn et al., 2015, p. 100). From this perspective Arkesteijn et al. (2015) reviewed a selection of current alignment models and conclude that most of them do not aggregate criteria ratings in an overall rating, are not transparent in generating alternatives and have no well-defined procedure to arrive at the selection of the best alternative. Moreover, none of the methods incorporates correct measurement of the stakeholders' preferences (Arkesteijn & Binnekamp, 2013, p. 94; Arkesteijn et al., 2015, p. 103). Research into the models discussed above is important to achieve a better measurement of the state of alignment and consequently to be able to improve the added value of real estate management decisions to a corporation.

Arkesteijn et al. (2015) propose the preference-based accommodation strategy (PAS) procedure as a solution to the methodical issues above. In this procedure, the stakeholders define a set of decision variables and subsequently determine their preference values and assign weights to the different variables. In an iterative self-design process, the stakeholders then manually design portfolio alternatives, while optimising the overall preference rating, which is generated using correct preference measurement. The alternative with the highest preference rating, i.e. the optimum design solution, is selected (Arkesteijn et al., 2015, p. 104). The principle of the process is visualised in figure 1. An advantage of this self-design process is that the stakeholders are able to gain insight into the effects of their input and improve it in order to increase the quality of the result (Arkesteijn et al., 2015, pp. 117-118).

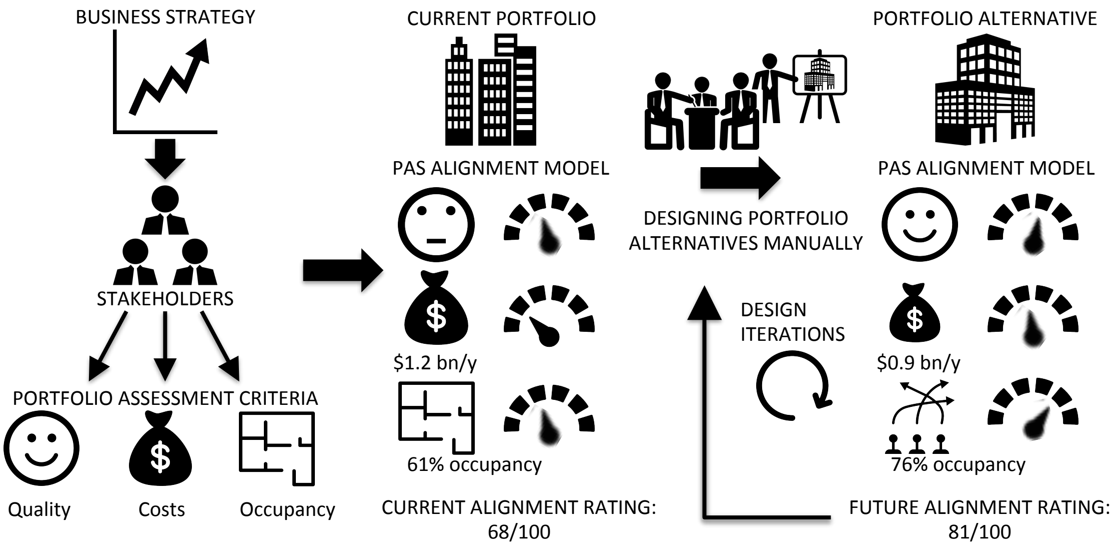


Figure 1 – Basics of the PAS procedure (own illustration)

However, already in a simple case of 15 buildings and 3 possible interventions, the number of possible portfolio's is 3 to the power of 15 = 14.348.907. In more complex cases in practice, generating alternatives in a self-design process and finding an optimum alternative, becomes both increasingly complex and time consuming. Therefore a search algorithm is required that searches for an optimum overall preference rating (Arkesteijn & Binnekamp, 2013, p. 98) (see figure 2). The expected advantage of only using the algorithm is that an optimum solution can be found, however this incorporates the disadvantage that the stakeholders do not gain as much insight in the effects of their input as in the self-design process.

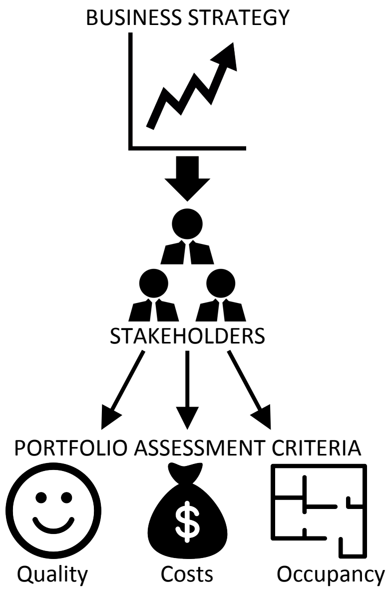


Figure 2 – Basics of the search algorithm (own illustration)

Currently this algorithm is available. Therefore, the next step in this research project is to implement the application of the algorithm in the PAS procedure. This is important because it is assumed that it can find an alternative with an even higher preference rating compared to the self-design process, hence to achieve a higher added value for the organisation. The algorithm could be implemented in two ways, substituting the entire process of self-design or in addition to the process of self-design.

Therefore, this research and design project focussed on the implementation of the search algorithm in the PAS procedure, with special attention to discovering determinants for the successful implementation of such a tool in human decision-making processes. It aimed to develop a theoretical basis for the implementation of the available search algorithm in the PAS procedure. The final result is a model of the PAS procedure that uses the algorithm. This model was tested and evaluated in a pilot study at a large multinational by means of several workshops where the stakeholders learned to operate the model.

1.2. Relevance

The PAS procedure is a tool to improve the corporate real estate decision-making process. In itself this could provide justification for the research, as the importance of it is supported by literature. However, in scientific research it is common to also establish the relevance in scientific and social terms.

1.2.1. Scientific relevance

As Heywood (2011) points out, there are rather few researchers worldwide that are dedicated to CREM. Also, models have been often developed from practical situations, possibly resulting in a lack of scientific foundation in the models (Heywood, 2011, p. 10). Therefore scientific research in the development of alignment models is relevant (Heywood et al., 2009, p. 9).

Furthermore, the previous paragraph showed that the models that have been developed, cover a variety of aspects of the alignment activity, however none of them seems to cover the complete set of components that was identified by Heywood (2011, pp. 6, 10). This could be the reason that they are not used in practice very often (Heywood, 2011, p. 10). Moreover, none of those methods incorporates correct preference measurement to obtain an optimum solution, although this is required to obtain meaningful results (Arkesteijn & Binnekamp, 2013, p. 94; Binnekamp, 2010, p. 29). Therefore, the PAS procedure is one of the first procedures that combines a structured approach towards the design of portfolio alternatives with correct preference measurement to rate the alternatives and select the best design (Arkesteijn & Binnekamp, 2013, p. 94; Arkesteijn et al., 2015, p. 103). This makes the research into the PAS relevant.

The previous paragraph also revealed that current models are mostly based on quantitative and financial criteria (Heywood, 2011, p. 5). This leaves a gap between the basis for the decision and the qualitative user perspective. This gap can be bridged by a perspective on this matter that takes into account the real estate specific and user experience perspective. This requires people that both speak the language of the user as well as the language of the business; something that belongs to the toolbox of professionals from the MBE department.

The current PAS procedure has been tested and is working (Arkesteijn et al., 2015, pp. 117-118). However, there have been several suggestions for optimising the PAS procedure by means of the use of a search algorithm, which is to find a better optimised solution than can be achieved in the current setup (Arkesteijn & Binnekamp, 2013; Arkesteijn et al., 2015). This provides additional scientific relevance to this research project.

With the above perspective on the PAS and its improvement, this research project into the PAS contributes to the PhD research of Monique Arkesteijn in the department of MBE at Delft University of Technology. The research aims to add to the current scientific knowledge in this field by bringing the research into the PAS procedure a step further. It focuses on the theoretically most optimal way to implement the algorithm in the procedure and to test and evaluate the resulting model in practice.

1.2.2. Societal relevance

The societal relevance of this research is related to the improvement of the decision-making process, which could lead to a better alignment of corporate strategies and real estate strategies. This could improve the efficiency in use of resources due to a more efficient use of space. The PAS procedure could help to maintain buildings in a real estate portfolio instead of divesting them and building/renting new accommodation, thereby leaving behind a lot of vacant space, which is rather unsustainable. This is enabled by the possibilities of the PAS procedure to incorporate more complex considerations between alternatives.

Better alignment of corporate real estate and business strategy will lead to more added value of the real estate to organisations. This might result in higher profitability of companies, which could increase their value. In the end this might lead to more prosperity in general.

1.3. Utilisation potential

The utilisation potential of a research subject is different for fundamental (or basic) research than for applied research. The former is focussed on the improvement of scientific theory, the latter is meant to solve a problem in practice. This research subject is part of the latter category; therefore it should contribute to solve the problem described previously.

The final result of the research project is a mathematical model of the PAS procedure using a combination of self-design by stakeholders and the search algorithm. The implementation of the algorithm has been done in a way that was theoretically deemed best. The improved procedure is tested on a case in practice and evaluated in terms of the model and the improved PAS procedure. The research also provides conclusions regarding the ability of the algorithm to find an alternative with a higher preference rating than the stakeholders did and regarding the satisfaction and usability of the improved procedure.

The model will be mainly usable by the company where it is developed, because it is customised to their preferences and because the development process is an important factor in the representation of the actual decision-making process. However, the conclusions from the evaluation of the pilot study can be used to improve the PAS procedure and the process of model building. These lessons can also be used to develop a basic alignment model that can be generically applied.

2. Research plan & methods

In order to clarify the paradigm in which this research and design project takes place, it is important to set up a research plan. This plan provides a structure to the selection and execution of appropriate research methods and the process of analysing the resulting data (Bryman, 2012, p. 45). Setting up this structure means that the researcher has to think about what to include and exclude from the research, where to place emphasis and to determine what the essence of the research and design project is. Such a research plan includes the objectives of the research and design and obviously a set of research questions that need to be answered in the end. In this study, the research questions are translated into a conceptual model that is used to structure the entire research and design project and the accompanying report. It is a structure that can be used to fall back on at any point during the process.

2.1. Research objectives

The PAS is meant to improve the corporate real estate decision-making process in order to reach better alignment between the real estate strategy and corporate strategy. This helps to increase the added value of real estate for the company. The objective of this research and design project is to bring the development of the PAS procedure a step further by testing and evaluating a model of this procedure that uses a search algorithm in order to find a better solution in complex decision-making processes. In this way, the project aims to improve the decision making process and thereby provide possibilities for corporate real estate managers to increase the added value of real estate for the company.

From this objective, it follows that a working mathematical model of the PAS procedure has to be built. This model is an improvement over the previous version, as it uses a search algorithm in order to find an optimum solution in these complex decision-making processes. The implementation of this algorithm requires knowledge of the determinants of successful design and implementation processes of tools that make use of such computer algorithms. Part of the results is therefore a literature study in this field that yields a comprehensive overview of the literature on the implementation of such search algorithms. This is used to implement the algorithm in the theoretically most optimal way, given the acquired knowledge.

A pilot study with the model will be held within a company's portfolio strategy decision-making process. The pilot will be evaluated in order to improve the PAS procedure and the process of building and operating the model and to make recommendations for further research.

Part of the research into the PAS procedure is the aim to develop a tool that can be used as much as possible without the help of the developer (Arkesteijn et al., 2015, p. 101). However, as this specific research and design project is mainly focussed around testing and evaluating the improved PAS procedure, it will at most provide a first step towards this. The complete model will mainly be useful for the company where it is developed, because it reflects their decision variables with specific preference ratings and incorporates their portfolio characteristics. Because the portfolio alternatives are based on this, another company cannot use the product one-on-one. However, the inductive research approach that is applied to the development of the model, aims to find elements that are more generally applicable (Bryman, 2012, pp. 26-27). The result could be that a part of the model's core mathematical formulations and decision variables are found to be generally applicable and could therefore easily be translated to a more general basic portfolio design model. Also this inductive strategy is applied to the knowledge about the development process, the procedure and its outcomes.

2.2. Research questions

Research questions are formulated based on an initial literature survey and discussion with professionals in the research field. Based on the findings of the in-depth literature study, the questions have been structured and formulated more precisely.

The main research question that is covered in this research and design project is: *How could an improved PAS be developed in such a way that the outcome of the algorithm closely reflects the stakeholders' preferences and what insights do a test and evaluation in practice provide?*

The question comprises of three parts that constitute the core of this research and design project and are used to structure it. Part one concerns the improved PAS, the second part the reflection of the stakeholders' preferences in the outcome of the PAS and third, the insights of a test and evaluation in practice. The three elements result in the following three sub-questions.

2.2.1. Sub-questions

1. *What is theoretically the best way to implement the search algorithm in the PAS?*
2. *Does the outcome of the algorithm reflect the stakeholders' preferences?*
3. *What is the judgement of the improved PAS by the stakeholders in practice, and what implications does this have?*

The answers to the sub-questions together will form the basis for the answer to the main question. The first sub-question is meant to establish a theoretical basis to start the modelling process. Finding an answer to the second sub-question requires several iterations in the model development process, whereby the stakeholders provide the model builder with feedback in order to improve the model's representation of the real decision-making process and stakeholder preferences. The answer to the third sub-question will be based on the evaluation results of a pilot study with the model.

2.3. Conceptual model

Figure 3 presents the conceptual model, based on the structure provided through the main and sub-questions.

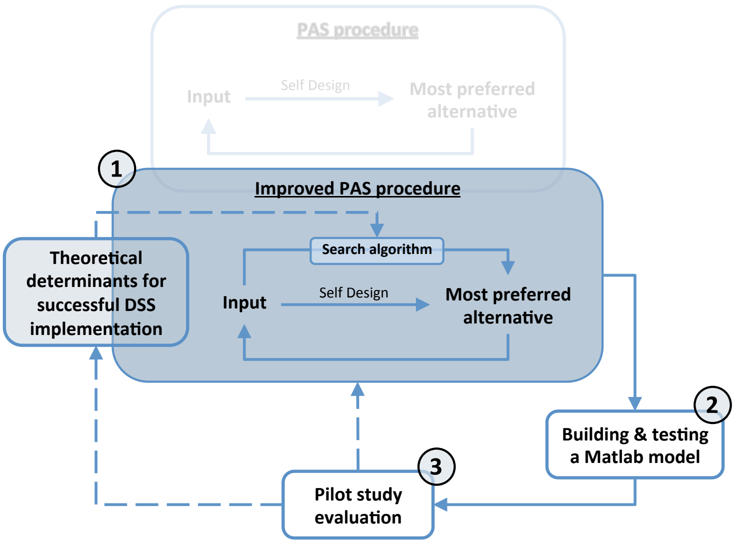


Figure 3 – Conceptual model (own illustration)

The conceptual model comprises of three main elements; the *Improved PAS procedure, Building & testing a Matlab model* and *Pilot study evaluation*. These elements are lent to the main research question and they all represent one of the sub-questions. In this way the conceptual model structures the research and design project and the final report, which will elaborate on each element in a separate part.

The first element is the *Improved PAS procedure*, which is related to sub-question one. It comprises of the original PAS procedure with the addition of the search algorithm. The original PAS procedure is the starting point of this research and design project. Based on the outcomes of a literature study into the *determinants for successful DSS implementation*, it is improved with the search algorithm. This improved procedure is the basis for the second element in the conceptual model; *Building & testing a Matlab model* of the improved PAS procedure. This step is related to the second sub-question and will be performed using a case from practice. The Matlab model will be developed in a pilot study with the improved PAS procedure, preferably at a company. This *pilot study will be evaluated* and the results of this evaluation will be used to make improvements in the procedure and possibly also to the theory on successful DSS implementation. This third part is related to the last sub-question. Each part of the model will be explained in further detail in each of the following parts of the report.

The PAS procedure actually comprises of three elements. First, the procedural sequence of actions the PAS constitutes. Secondly the process of performing these actions, which consists of a sequence of interviews and workshops to build the model. Third is the model itself that represents the procedure. In the remainder of this report “the PAS” refers to these three elements together, except when this is stated otherwise.

2.4. Research methodology

From the research questions posed in this chapter follows a research plan and a set of research methods that are suggested to be employed to answer the main question. This paragraph discusses the research approach and the methods to be used in detail.

2.4.1. Research approach

The main question of this research and design project comprises of a so-called design problem. It is aimed at making operation related improvements towards the future, i.e. an improvement in the PAS. In order to solve such problems in general, the design of an artefact is required to properly arrive at a solution (Barendse et al., 2012, p. 1). From the previous it follows that to provide an answer to the main question, a design process should be followed.

A structure for such a process is shown in figure 4. It shows an iterative process towards the development of an artefact.

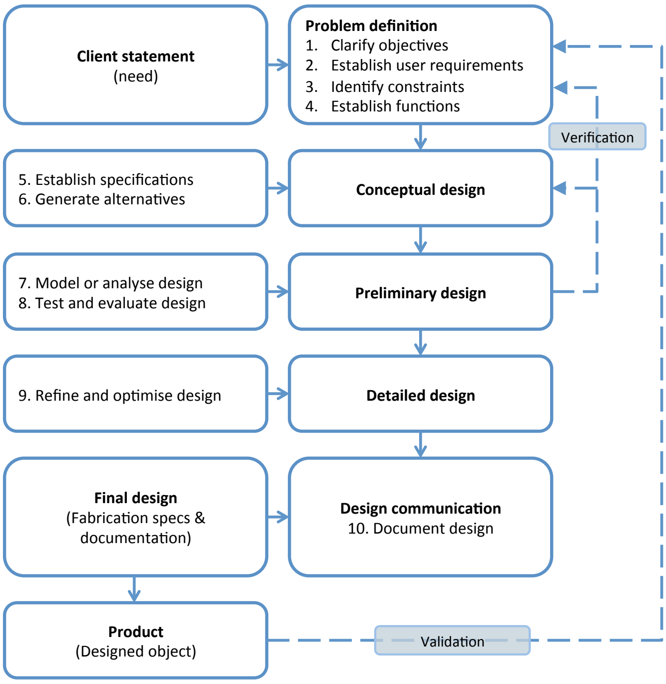


Figure 4 – The design process (own illustration based on Dym & Little, 2004, pp. 24, 26)

The scheme above shows five stages in the design process. Each of these stages comprises of a set of tasks that are performed using the provided input. However, the design process implies the use of empirical research as a basis for the conceptual design, e.g. to establish user requirements and identify constraints, but it is also required to evaluate the design tests (Dym & Little, 2004, pp. 24-25). In order to answer the sub-questions and hereby the main question, a hybrid model is needed that comprises of both the design process and empirical process.

Both processes have a cyclical character. The design process incorporates two feedback loops. Feedback in this case is defined as *"the process of feeding information about the output of a process back into the process so it can be used to obtain better results"* (Dym & Little, 2004, p. 26). The first feedback loop describes the verification of the model designs in the first three stages of the process in order to improve the design's representation of reality, the second one is that of comparing the evaluation results with the problem definition after testing the final design (Dym & Little, 2004, p. 26). Dym and Little (2004) also indicate a second crucial characteristic of the design process: iteration. Iteration is *"the repeated application of a common method or technique at different points in a design* process" (Dym & Little, 2004, p. 26). In the design process, the first four steps are iteratively applied in each design phase, just like step seven and eight.

In order to emphasise the cyclicality of the design process and to establish the interrelationship between the two processes, Barendse et al. (2012) represents the design approach in a different way and combines it with the empirical research process (e.g. Kumar, 2011, p. 22) (see the figure below).

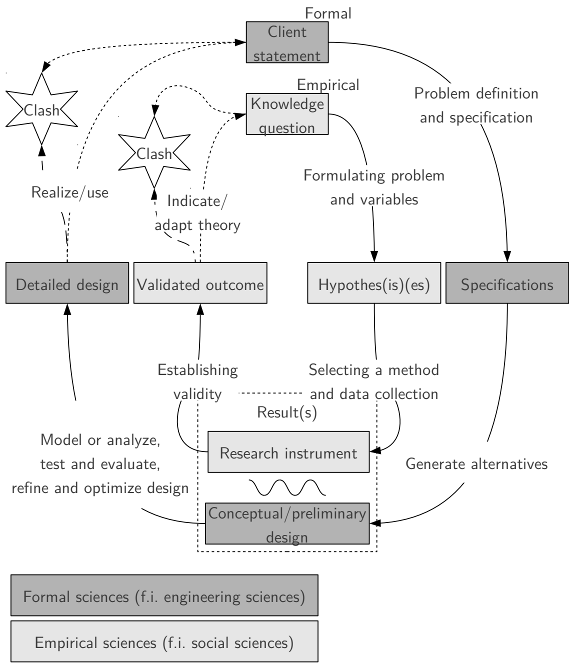


Figure 5 – The formal and empirical cycle combined (Barendse et al., 2012, p. 6)

The resulting model provides a good starting point to set out the structure and plan of this research and design project. Basically, this cyclical model is applied in two different ways in this project. Firstly it applies to the general plan of the project; improving the PAS by means of building and testing an artefact and employing the results to improve the PAS. However it will also be used to guide the process of building the mathematical model of the PAS. The five steps of the cycle are described below; first for the research and design project in general and secondly for the model design process.

Step 1

This step was used to define the problem; the implementation of a search algorithm in the PAS and testing and evaluating the improved procedure. This problem definition is based on an initial literature review and discussion with professionals in the research field. From the problem statement, a main research question was derived, supported by several sub-questions. The main question and second sub-question are answered in the formal cycle by building and evaluating a model of the improved PAS, applied to a practical case. The first and last sub-question are empirical questions and will be answered in the empirical cycle together. The answer to the first will be based on a literature study, the third sub-question will be answered based on the evaluation of the PAS.

Step 2

In order to specify the problem statement, a literature study into the development of the PAS procedure so far, was conducted. This yielded several specifications for the model design, regarding e.g. multi criteria decision analysis (MCDA) and correct preference measurement. In the empirical cycle, the first hypothesis is that the algorithm will yield a better result than the stakeholders are able to achieve through self-design. This hypothesis is mainly based on previous pilots with the PAS and its predecessors. Related to the first sub-question, the second hypothesis is that it would be best to implement the algorithm in addition to the self-design.

Step 3

Based on the specifications from the previous step, the mathematical model of the PAS will be developed in step three, in the second application of the cycle, which is described below. In this process, the conclusions from the literature study conducted in the empirical cycle into the first sub-question will be applied to the implementation of the algorithm. This is also the step where the evaluation results of the model building process and the PAS procedure from the formal cycle, form the input for the empirical cycle.

Step 4

In the formal cycle, this step comprises of connecting the final model of the PAS, which is developed in the modelling cycles, to the search algorithm to find an alternative with a higher preference rating. In the empirical cycle, the first hypothesis will be tested by comparing the outcome of the algorithm to the preference rating achieved through the self-design process. The evaluation of the implementation process of the algorithm is confronted with the second hypothesis. This yields the validated result. This result comprises of a full evaluation of the PAS in terms of procedure, process and model and two hypotheses that are confirmed or disapproved to some extent.

Step 5

In the formal cycle, the model will be judged upon its practical applicability for the company that provided the case. From the empirical perspective, the outcomes of the evaluation on the PAS procedure, process and the model are compared to previous research in order to improve the PAS and possibly add conclusions to the existing knowledge regarding the implementation process of the algorithm. Also conclusions regarding the extent to which the approach can be generalised are applicable here.

2.4.2. Model development

The model design process takes place in step 3 of the cycle applied to the research approach. This is the point where the first feedback loop from the design process is applied. In a way, the entire formal cycle is run-through at least two times within the design stage. This process of modelling a real life portfolio case is illustrated in figure 6. It starts with a client statement regarding the current alignment of the portfolio with the business (step 3.1). The stakeholders specify their wishes for the future state of the portfolio in terms of decision variables, preference ratings and design boundaries that are translated to model specifications in step 3.2. These elements are based on the business strategy. Based on this statement, a first model is built that will be tested in a workshop where the stakeholders design portfolio alternatives themselves (step 3.3). The systems engineer is the one responsible for building the model and explaining it in the workshops. Also he or she operates the model during the workshops if necessary. The workshops are evaluated in an interview afterwards, comparing the model outcome with the knowledge of the process in real life, in order to improve the model's representation of reality. This is done by identifying adaptations to the client statement (step 3.4). Step 3.5, comprises of confronting the modelling process and the PAS procedure with the expectations of the stakeholders in order to be able to make improvements in the future. After this, the second iteration starts where the specifications of step 3.2 may have to be changed according to the evaluation of the model in step 3.4. This results in an adapted model of the PAS, which is tested, evaluated and improved again until the stakeholders are satisfied.

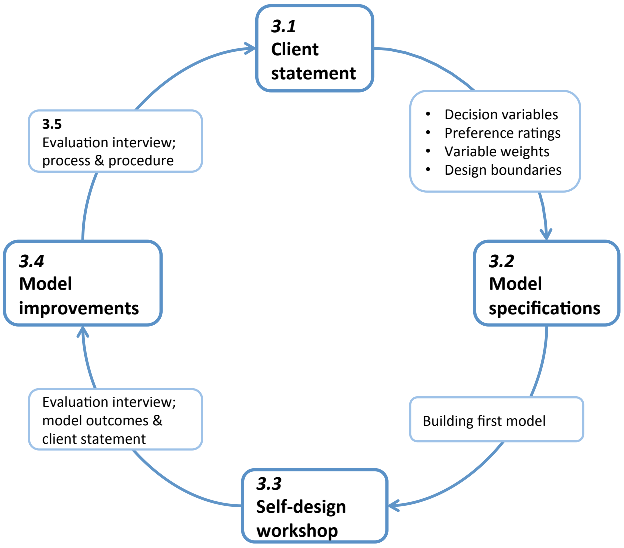


Figure 6 – Model design iterations in the formal cycle (own illustration based on Barendse et al., 2012, p. 6)

2.4.3. Research methods

The research methods that are used in this research and design project to answer the main question are both formal and empirical. The model building belongs to the former category, the literature study and interviews belong to the latter. The literature study is used to construct a theoretical framework prior to the building of the model. The interviews are used to acquire the data that is required to build the model and are used to evaluate the PAS after the test of the model.

Literature study

The literature study that was conducted can be roughly divided in two parts, one on the development of the PAS so far, and the other on the determinants of successful implementation of decision support systems. An exploratory literature review is used to analyse the problem and explore the research field. It is also used to set up the main research question and conceptual model. The final literature study is used to construct a theoretical framework on the topic of research.

The literature study on the development of the PAS has been conducted based on the publications that are suggested by the two mentors in this research and design project who developed the procedure. The combination of this literature provides an overview of the steps in the development of the PAS so far, and the next step that is made with this research and design project.

The literature search on the determinants of successful implementation of the search algorithm is started with search queries in Scopus, based on the following set of keywords.

	← AND →			
	Aspect 1	Aspect 2	Aspect 3	Aspect 4
↑ OR ↓	• Decision support system • Decision support systems • DSS • Decision making • Multi criteria decision making • Man-machine interaction	• Computer aided • Implementation	• Trust • Credibility • Acceptance	• Review • Literature review • Meta analysis

Table 1 – Literature search keywords

However, this approach mainly delivered rather dated reports and none of them comprised of a structural review of the literature on acceptance and implementation of decision support systems or equivalent systems to that date.

Therefore, the approach was shifted towards selecting interesting articles from the reference lists of the most recent articles. The articles were selected based on their keywords, of which at least one had to resemble the keywords under “aspect 1” in table 1. Furthermore the function “cited by” in Scopus was used to find publications that cited the publications found through the search queries. This process yielded about seven relevant publications. Among these publications there were only two recent literature reviews, one of which focuses on the field of implementation of the search algorithm. This is a research paper by Riedel et al. (2011).

The literature study discovering determinants for successful implementation of the search algorithm in the PAS is mainly based on this research paper by Riedel et al. (2011). The authors published a broadly oriented research paper on the acceptance of such algorithms in decision-making. They performed multiple literature studies on human factors in design and implementation of this kind of algorithms, focused around the model development process and the role of trust in the entire process. The findings from this paper are combined with other publications that were selected.

Model building
The model will be built in an iterative sequence of interviews and workshops as described above. The process will at least comprise of three interviews and two workshops in the following sequence; I-W-I-W-I. This method of building the model is also used in a previous test with the PAS and was evaluated positively (Arkesteijn et al., 2015, pp. 107, 118). The iterative sequence in the model building process is also supported by the findings from the literature study into the successful implementation of decision support systems. Therefore it will also be used in this research and design project.

The interviews are meant to acquire the information needed to build the model and are held with each stakeholder individually. In the first interview, the following elements are discussed:

1. Specify decision variable(s);
2. Assign the stakeholder's preference rating to each variable;
3. Assign the stakeholder's weight to each variable;
4. Determine design constraints;

The output of this interview is used to develop and test an initial model in the first workshop. The following interview discusses these same elements in order to identify additions in decision variables and/or adaptations in either of the elements. These topics are part of step three of the formal cycle as described above.

Evaluation interviews
In each interview round, the stakeholders are invited to make adaptations to the four elements mentioned in the previous paragraph, but more important is that the PAS will be evaluated. This will be done according to the four assessment criteria as suggested by Joldersma and Roelofs (2004). They use four criteria. The first one is *experiences with the method*; this criterion measures the impact of the method based on the user's experience. The *attractiveness of the method* as second, is related to confidence in the method and its outcomes which translate into satisfaction. The third criterion is *participants' perceptions of effectiveness of the method* and inquires on the extent to which the method contributes to the results. This is combined with the *observers' perceptions of the effectiveness of the method* in order to achieve a more balanced view of the quality of the results (Joldersma & Roelofs, 2004, pp. 697-698). Three of these criteria are based on the input of the stakeholders in the pilot, this results in the following interview elements:

1. Describe experiences with the method;
2. Describe the attractiveness of the method;
3. Describe perception of effectiveness of the method.

Table 2 provides a checklist to be used during the modelling of a DSS in order to evaluate both the process (P) and the system (S) itself. It is composed of the findings from the literature study into the determinants for successful implementation of DSSs and provides a set of important characteristics that, when taken into account, will lead to system acceptance and trust in the system. Both lead to system use and satisfaction.

Each characteristic is connected to one of the three evaluation elements that will be discussed with the stakeholders. This is done, by matching the description of the criteria by (Joldersma & Roelofs, 2004), with the characteristics concepts from literature. The table shows that most of the characteristics that are related to the process seem to be indicators for the users' experience with the method under the first interview element. This fits with the type of characteristics, as the process typically results in a certain user experience. The characteristics of the system, mostly seem to be indicators for the attractiveness of the method because they reflect the acceptance of the system and its outcomes, which is incorporated in the second interview element (Joldersma & Roelofs, 2004, pp. 697-698).

Process (p)/ system (s)	Characteristic	Evaluation category (Joldersma & Roelofs, 2004)	Resulting effect (Riedel et al., 2011)
P	Participation & involvement of users (Riedel et al., 2011); user consultation (Van Loon, Heurkens, & Bronkhorst, 2008)	Experience	System acceptance
P	Stakeholder interaction (Van Loon et al., 2008)	Experience	System acceptance
P	Iterative system development (Van Loon et al., 2008)	Experience	System acceptance
P	Perceived control (Riedel et al., 2011)	Attractiveness	System acceptance
P	Familiarise with backside of the system (Riedel et al., 2011)	Experience	Trust in the system
P	Clear system goal (Van Loon et al., 2008)	Effectiveness	System acceptance
S	Complexity (Riedel et al., 2011)	Attractiveness	System acceptance
S	Calibrated variables (Van Loon et al., 2008)	Attractiveness	Trust in the system
S	Perceived usefulness (Riedel et al., 2011)	Attractiveness	System acceptance
S	Purpose (Riedel et al., 2011)	Attractiveness	Trust in the system
S	Perceived ease of use (Riedel et al., 2011)	Attractiveness	System acceptance
S	Performance reliability (Riedel et al., 2011)	Effectiveness	Trust in the system
S	Justification of outcome (Riedel et al., 2011)	Attractiveness/ Effectiveness	Trust in the system

Table 2 – Checklist for evaluating DSSs and their development process (based on chapter 7)

The interview elements are part of the empirical cycle that is used to improve the PAS. In each intermediate interview these elements are discussed and in the end of the pilot they are used to make an overall evaluation where they are combined with the observer's perception of the effectiveness of the method in order to arrive at a validated outcome in step 4 of the research structure.

2.5. Validity and generalisation of conclusions

In research, biases can occur during the entire process from starting the research to drawing conclusions. These biases affect the validity of the conclusions and the extent to which they can be generalised.

Publications are easily interpreted as presenting a complete view on the research subject. However, in conducting research it is unavoidable that the values of the researcher influence the research to some extent, because during the research process there are multiple points where the personal bias of beliefs and values of the researcher could materialise. This might already occur at the start of the project with the choice of the research topic and the research method and design, but also later on in the interpretation of data and drawing conclusion (Bryman, 2012, p. 39). For this reason, it is important to take into account the perspective and the purpose of the author when analysing the information. When doing so, biases in the interpretation can be avoided. Moreover, in order to avoid taking over the personal biases of the author of a publication, a comparison with other research publications should be made.

Regardless of these precautions, the validity of research findings in psychological science should be questioned. Reproducibility is the most important factor in the validity of science, however research projects are seldom reproduced because research stimuli are focussed on new research subjects. Recently the "Reproducibility project" started with the reproduction of a hundred psychological studies that were published in high ranked psychology journals, to find out where science stands (Open Science Collaboration, 2012, p. 1). The results are shocking, from the 97% significant results in the original studies, only remains 36% after replication (Nosek, Cohoon, & Kidwell, 2015, p. 1). This is a huge decrease, which urges to be cautious relying on double or even single sources.

According to Bryman (2012, p. 47) validity covers the quality of the conclusions of a research project. He distinguishes two types of validity; internal and external. Internal validity *"is concerned with the question whether a conclusion that incorporates a causal relationship between two or more variables holds water"* (Bryman, 2012, p. 47). In this research and design project, it will be evaluated whether the theoretical findings for the implementation of the algorithm in the PAS result in actual reflection of the stakeholders' preferences in the model and its outcomes. In other words, the outcome will provide a reflection on the internal validity of these findings. The question whether conclusions can be generalised beyond this specific project is covered by the external validity. This is defined as *"the question of whether the results of a study can be generalised beyond the specific research context"* (Bryman, 2012, p. 47). The model will be built specifically for the case at hand, therefore the external validity of this specific model will be limited. The lessons leaned in terms of the process and the procedure, on the other hand, are expected to have a higher external validity because they help to improve the general approach the PAS provides towards the improvement in corporate real estate strategy decisions.

This research and design project is approached from the inductive perspective. This means that the research starts from observations and tries to formulate laws from the findings that can be generalised towards other situations (Bryman, 2012, pp. 26-27). More specifically, this means that from the data that is generated in the evaluation of the model tests, general lessons will be formulated that can be incorporated in the PAS in order to be applied in other cases too.

3. Current state-of-the-art in research on the PAS procedure

This chapter discovers the development of the PAS so far. The relevance of the development of the procedure is found in the history of model development in the field of CREM. Other models are presented as well and compared to the PAS. Furthermore, the procedure is explained elaborately, together with the results of the first pilots. This elaborate version of the PAS is fitted in the conceptual model in the figure below.

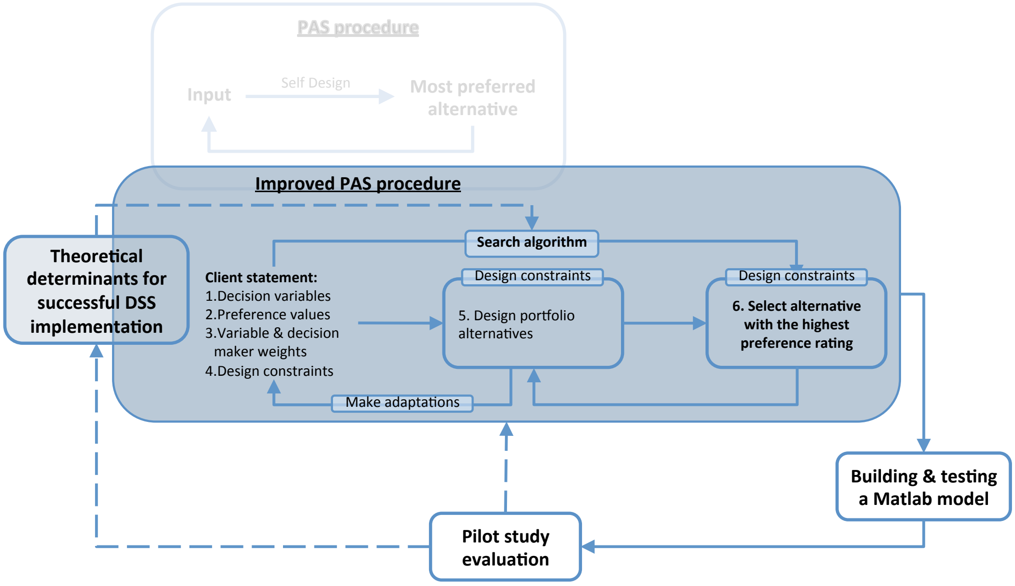


Figure 7 – Conceptual model with elaborate PAS procedure (own illustration)

3.1. Development of a preference based portfolio design procedure

Heywood (2011, pp. 2, 3, 6) points out several possible causes of the alignment problem that is presented in the problem analysis. In the models that have been developed so far, two main approaches prevail: single criterion alignment and algorithm based models. The first one is not suitable for multi criterion decision-making as it is only able to optimise one variable. However, the second type is able to accommodate this (Arkesteijn & Binnekamp, 2013, p. 98; Heywood, 2011, p. 6). Nevertheless, it seems that the models that have been developed in the past, are hardly used in practice. This could be due to the differences in the number and type of components that they employ (Heywood, 2011, p. 10). Heywood (2011, pp. 5-6) identifies a total of 15 different components in the available alignment models, but none of them uses the complete set. As a consequence, none of them captures the full bandwidth of the alignment activity, which makes it hard to select one to apply in practice (Heywood, 2011, pp. 6, 10).

As a consequence of the lack of useful models, Heywood (2011) argues that it seems that current alignment processes are ruled by heuristics, i.e. intuitive judgement of the state of alignment. Kahneman (2011) puts this way of thinking in perspective by making a distinction between two systems in our brain. The first system works intuitive and is able to quickly assess situations around us and provides a solution almost instantly. It is used to associate between thoughts and to sense changes in social situations. This is the system responsible for heuristics. System two is able to solve more complex problems in a structured way and helps us to make decisions in situations where intuition is not sufficient. However, the latter system requires more effort and continuous attention. Therefore, most of the time it is in stand-by mode (Kahneman, 2011, pp. 7-17). Only when system one stalls, system two is invoked in order to solve the problem in a more elaborate way. Because system one is good at what it does, this division of tasks is very efficient. However, system one also knows errors that occur in specific situations. One important element in this context is that it sometimes misses obvious information because the brain is focussed on something else (Kahneman, 2011, pp. 22-27). Yet, when using system one to assess the state of alignment, mistakes are easily made. It also hampers transparency, because the assessment cannot be reproduced. Due to this lack of transparency, the alignment cannot be measured (Heywood, 2011, p. 6). Therefore, this asks for a more structured and measurable approach towards alignment.

Another aspect of CREM that induces the need for decision support tools is the increasing complexity of the decision-making process. The involvement of an increasing number of stakeholders, which requires weighing of (conflicting) requirements, together with the increasing amount of information, ask for structured support (Den Heijer, 2011; Razmak & Aouni, 2015, p. 101). This is in line with Van Loon et al. (2008, p. 72) stating that: *'new instruments need to be developed (for urban planners) in order to support planning issues that are becoming more and more complex'*.

Currently, multiple decision-making tools are available to improve this situation towards better alignment. One of those is the DAS frame (designing an accommodation strategy). The framework structures the process of determining the current state of alignment by means of expert opinions of real estate professionals and professionals that know the business. In an iterative process, the framework helps to design a real estate strategy to achieve future alignment. This strategy design consists of a number of interventions in each of the buildings in the subject portfolio (De Jonge et al., 2009, pp. 35-44). Another example is the Scenario planning model developed by Dewulf et al. (as cited in De Jonge et al., 2009, pp. 52-55, 80-81). This model starts off with a stakeholder analysis and the translation of the corporate mission into real estate related objectives. Future portfolio demands are determined based on the needs of the core business. The next step is to design portfolio strategies by translating the corporate strategy into a real estate strategy while taking into account the long-term uncertainties in the business. Also the influence of future scenarios is taken into account. In order to make the strategy operational, an object policy plan is developed (De Jonge et al., 2009, p. 80).

Within the aforementioned models, alternative portfolio designs are generated and the best design is to be selected. However, this selection process is characterised by multiple stakeholders that have different views on which set of interventions suits the goal best. In order to overcome this situation, the most suitable way is to use Multiple Criteria Decision Analysis (MCDA) (Arkesteijn & Binnekamp, 2013, pp. 89, 93). This is a term for problem structuring methods that explicitly take account of multiple, often subjective and conflicting, criteria in order to reach a well-substantiated decision (Belton & Stewart, 2002, p. 2). Such tools combine the preference ratings of stakeholders on different criteria to generate a total rating for each alternative. This allows the stakeholders to select the best alternative, i.e. the one with the highest overall preference rating (Arkesteijn & Binnekamp, 2013, p. 93). MCDA will be discussed more elaborately in chapter 4.

The problem of the DAS frame and other tools used in corporate and public real estate management is, however, that they show little transparency because of two reasons. Firstly, these frameworks have no well-defined procedure to arrive at the overall portfolio preference rating, i.e. the total rating of all interventions in all buildings in the portfolio, given the preferences. This means that they cannot be used without the help of the model designer (Arkesteijn et al., 2015, pp. 101, 103). Secondly, no proper preference measurement is used in the procedures, i.e. the models make use of preference scales that do not allow mathematical operations of calculus and linear algebra (Arkesteijn & Binnekamp, 2013, p. 89; Arkesteijn et al., 2015, p. 103). These findings support the need for a well-defined procedure.

Barzilai (2005, pp. 173-174; 2010, p. 1) contends that due to the lack of proper preference measurement, the numbers that are generated by many of the models discussed before are meaningless. Proper measurement scales, in turn, can be achieved trough the use of the preference function modelling (PFM) procedure (Arkesteijn & Binnekamp, 2013, pp. 90-91; Barzilai, 2005; Binnekamp, 2010, p. 81). This will be discussed in more detail in chapter 5.

The PFM procedure however, is meant for evaluation purposes with known alternatives, hence it is not useful in design situations where the alternatives are not known beforehand (Binnekamp, 2010, p. 3). Therefore Binnekamp (2010) developed the preference-based design (PBD) procedure to make it suitable for design purposes. In this procedure the stakeholders determine decision variables, which are given preference ratings. Tests with the procedure at building level turned out to be successful (Arkesteijn & Binnekamp, 2013, p. 91; Binnekamp, 2010).

Still, the PBD procedure is not suitable for designing alternatives for an entire portfolio. In order to be able to solve this issue, the PBD procedure is further developed into the preference-based portfolio design (PBPD) procedure (Arkesteijn & Binnekamp, 2013). This procedure is designed such that the PFM algorithm can be used to evaluate the generated portfolio alternatives (Arkesteijn & Binnekamp, 2013, p. 97). This procedure is later on referred to as the PAS procedure (Arkesteijn et al., 2015, p. 103).

3.2. The procedure in detail

The PBPD procedure comprises of the following six steps (Arkesteijn & Binnekamp, 2013, pp. 91, 95):

1. *Step 1*: Specify the decision variable(s) the decision-maker is interested in.
2. *Step 2*: Rate the decision-maker's preferences for each decision variable as follows:
    a. Establish (synthetic) reference alternatives, which define two points of a Lagrange curve:
        i. Define a "bottom" reference alternative, the alternative associated with the value for the decision variable that is least preferred, rated at 0. This defines the first point of the curve (x0, y0).
        ii. Define a "top" reference alternative, the alternative associated with the value for the decision variable that is most preferred, rated at 100. This defines the second point of the curve (x1, y1).
    b. Rate the preference for an alternative associated with an intermediate decision variable value relative to the reference alternatives. This defines the third point of the curve (x2, y2).
3. *Step 3:* To each decision variable, assign decision-maker's weight.
4. *Step 4*: Determine the design constraints.
5. *Step 5*: Generate all design alternatives (using the number of buildings and allowed interventions). Then use the design constraints to test their feasibility.
6. *Step 6*: Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

Figure 8 shows an example of a list of decision variables as defined in step one, together with the assigned weight in step three. Assigning weight to each decision variable in a single decision-making problem represents the relative importance assigned to the variables. However in case of multiple stakeholders this would implicitly incorporate the power of the decision makers (Arkesteijn et al., 2015, p. 105). This process requires negotiation between the decision makers regarding the importance of their variables. In this process the actor with most power will be able to realise a higher weight for his/her variables. This contradicts the claimed transparency of the procedure. This is solved in the next version of the PAS procedure, presented below.

Decision variable	Weight
1. Percentage of buildings serving societal goals	10
2. Percentage of buildings scoring ≥40 on user satisfaction	10
3. Percentage of buildings scoring ≥40 on technical state	10
4. Percentage of buildings for which rent covers costs	10
5. Gross floor area	40
6. Additional yearly rent due to renovation interventions	20

Figure 8 – Example list of decision variables with assigned weights (Arkesteijn & Binnekamp, 2013, p. 97)

In establishing the preference ratings in step two, the procedure makes use of a Lagrange curve. This curve is fitted through a top and a bottom reference alternative, supplemented with a third alternative that determines the shape of the curve (see figure 9). This shape is represented by a formula that enables the computer model to also determine the preference rating for intermediate input values (Arkesteijn et al., 2015, p. 104). It should be noted that a distinction can be made in types of preferences, i.e. stated preferences and revealed preferences. The first category comprises of known preferences, explicitly stated by people. The second category is the type of preferences resulting from observations of peoples' actual behaviour. The PAS is mostly about stated preferences.

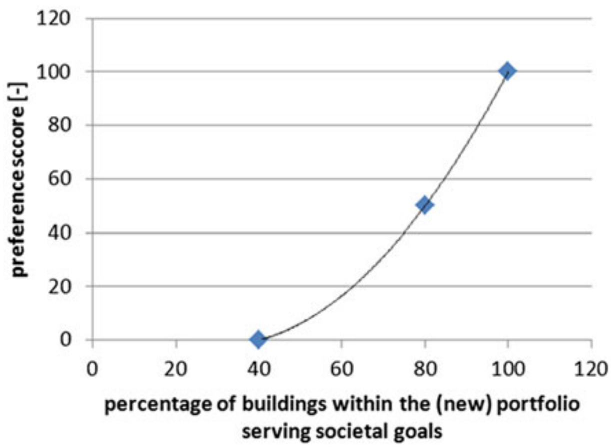


Figure 9 – Example of a Lagrange curve (Arkesteijn & Binnekamp, 2013, p. 96)

A possible outcome of step five is shown in the table below. It shows the top-ten portfolio design alternatives with the highest overall preference rating. In order to calculate these scores, firstly all possible portfolio designs have been generated in step five, i.e. the combinations of interventions 1-3. Only when these alternatives were available, the PFM algorithm is used in step six to calculate the accompanying preference scores.

Portfolio	Bulding Numbers															Rating
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
9388514	1	2	2	1	2	2	2	2	2	1	2	1	2	0	2	75.6
9388502	1	2	2	1	2	2	2	2	2	1	2	1	0	2	2	75.6
9387773	1	2	2	1	2	2	2	2	1	1	2	1	0	2	2	75.5
9387785	1	2	2	1	2	2	2	2	1	1	2	1	2	0	2	75.5
9033491	1	2	1	2	2	2	2	2	1	1	2	1	2	0	2	75.4
9033479	1	2	1	2	2	2	2	2	1	1	2	1	0	2	2	75.4
8857073	1	2	1	1	2	2	2	2	2	1	2	1	2	0	2	75.2
8857061	1	2	1	1	2	2	2	2	2	1	2	1	0	2	2	75.2
8856344	1	2	1	1	2	2	2	2	1	1	2	1	2	0	2	75.1
8856332	1	2	1	1	2	2	2	2	1	1	2	1	0	2	2	75.1
Current	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17.7

0 = remove, 1 = keep, 2 = renovate

Table 3 – Example list of portfolio design alternatives (Arkesteijn & Binnekamp, 2013, p. 97)

3.3. Tests and results

The first test with the procedure, described above, was performed with a simple theoretical case of 15 buildings and three possible interventions. As a result of the large number of possible portfolios to be generated (3^15 = 14.348.907) already in this simple case, one of the recommendations is to develop a search algorithm to find the most preferred alternative in more complex cases (Arkesteijn & Binnekamp, 2013, p. 98).

The first practical pilot study of the procedure is executed and reported by Arkesteijn et al. (2015) and Valks, Arkesteijn, Binnekamp, Barendse, and De Jonge (2014). Due to the complexity of this case, it was not possible to generate all alternative portfolios and because a search algorithm was not available yet, the procedure was altered. Also this had to increase the transparency. Major changes took place in steps 5 and 6, which were substituted for a process of manual design of portfolio alternatives. Also in step 3 changes took place. In order to explicitly incorporate the role of power, the subject owner now needs to assign weight to each decision maker as well. The result is that negotiation does not take place so much in the first four steps, but merely during the design process regarding possible portfolio alternatives.

The following procedure is the result (Arkesteijn et al., 2015, pp. 105-106):

1. *Step 1*: Each decision-maker specifies the decision variable(s) that he/she is interested in.
2. *Step 2*: Each decision-maker rates his/her preferences for each decision variable as follows:
    a. The decision-maker establishes (synthetic) reference alternatives, which define two points of a Lagrange curve.
        i. A "bottom" reference alternative is defined, which is the alternative associated with the value for the decision variable that is least preferred, rated at 0. This defines the first point of the curve ($x0$, $y0$).
        ii. A "top" reference alternative is defined, which is the alternative associated with the value for the decision variable that is most preferred, rated at 100. This defines the second point of the curve ($x1$, $y1$).
    b. The preference for an alternative associated with an intermediate decision variable value relative to the reference alternatives is rated. This defines the third point of the curve ($x2$, $y2$).
3. *Step 3*: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.
4. *Step 4*: Each decision-maker determines the design constraints he/she is interested in.
5. *Step 5*: The decision-makers generate design alternatives group wise and use the design constraints to test the feasibility of the design alternatives. The objective is to try to maximise the overall preference score by finding a design alternative with a higher overall preference score than in the current situation.
6. *Step 6*: The decision-makers select the design alternative with the highest overall preference score from the set of generated design alternatives.

The pilot study shows that participants are able to determine their preferences and improve the portfolio preference rating compared to the current rating from 58 to 69, based on their conjunct preferences. In this pilot, the stakeholders operate the procedure iteratively. This iteration has two components; one whereby they design alternative portfolio designs themselves in order to optimise the overall preference rating. This process of self-design enables the participants to develop insights in the effects of their preferences on the overall rating and the interventions in the portfolio. In order to incorporate those insights, stakeholders are allowed to adjust their preferences, which is the second iterative element. The pilot study shows that these iterations help to increase the quality of the results, i.e. a higher overall preference rating and better representation of stakeholder preferences in the model (Arkesteijn et al., 2015, pp. 117-118).

However, the question is if the rating that is found by the participants is also the highest possible rating, given the stakeholders' preferences and constraints imposed on the outcome. In order to find out, all possible alternatives would have to be generated, but the more complex the case the more complex and time consuming this becomes. An algorithm could be of help here, as it searches for an optimum overall preference rating and generates only this portfolio alternative (Arkesteijn & Binnekamp, 2013; Valks, 2013; Valks et al., 2014).

As such, a search algorithm could substitute step five and six of the PAS procedure. This could result in a serious increase in the efficiency of the process, as those steps are most time consuming (Valks et al., 2014, p. 12). However, Arkesteijn et al. (2015, pp. 117-118) make the recommendation, not to completely substitute the self-design of portfolio alternatives. The reasons for this are that these design iterations help the stakeholders to gain insight in the effects of their preferences and to understand how the backside of the model works. Moreover, without self-design, the freedom to adjust preferences would have less value. These elements increase the quality of the result, and improve the stakeholder's acceptance of this result (Arkesteijn et al., 2015, pp. 117-118).

Regardless of the time efficiency this algorithm could achieve, its importance is captured in finding portfolio alternatives with a higher preference rating. The optimum portfolio alternative is able to achieve better alignment and provide more added value to the organisation. However, as can be concluded from the previous paragraph, the implementation of the algorithm should not comprise of simply substituting step five and six of the procedure. Before conducting a pilot study with the improved PAS, it is important do determine in what fashion the implementation of the algorithm would theoretically yield the highest stakeholder acceptance. Substituting the self-design of alternatives, or in addition to this.

3.4. Basics of the algorithm

As a result of the type of the problems approached with the PAS the algorithm is not able to find the optimum portfolio alternative with certainty, it has its limitations. In some problems, the constraints that demark the solution space are represented by linear relationships, in such cases the solution is optimised by maximising the value using an objective function. Such a problem can be solved in a linear optimisation model. An example is shown in figure 10. In this figure, the feasible solution space is determined by the functions A, B and C, which is the area in the middle. By moving the objective function from the bottom-left to the top-right over the feasible solution space, the optimum solution is found at the intersection of the functions A and C. This solution has a value higher than all other feasible solutions; in mathematics this is called a global solution or global optimum. Only when the objective function runs parallel to e.g. function A, an infinite number of feasible solutions is available.

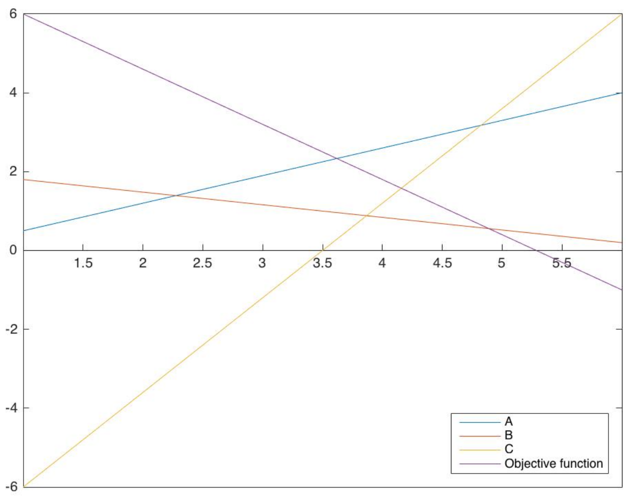


Figure 10 – Example of a linear programming problem (own illustration)

In case of the decision-making processes in this study, which are characterised by many objects, stakeholders and preferences, it is not possible to build a linear optimisation model. Instead, the model will be non-linear.

Within this non-linear model, the algorithm searches for a feasible optimum, without a better feasible result in the direct neighbourhood. This is called a local optimum, because there might exist other optima that are further away but have better values, of which the algorithm is unaware. An example of this is shown in figure 11 representing the preference rating found by the algorithm. Assume that the algorithm starts to search for a maximum value from x = 2,5. It will move towards x = 2 as this leads up-hill, at this point it finds the local optimum y = 2. However, it is unaware of the optimum at x, y = [4, 4][2].

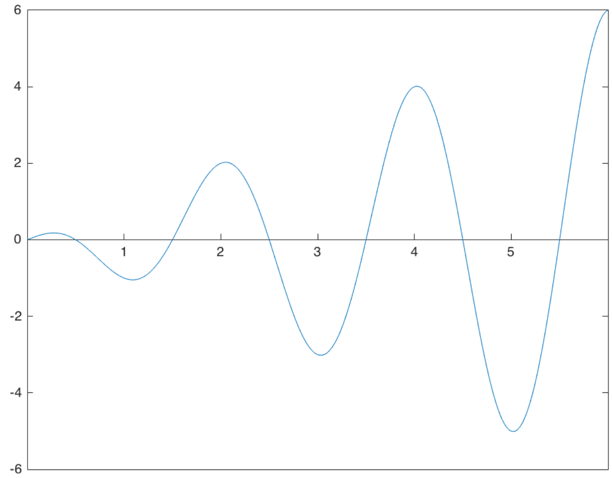


*Figure 11 – Graph of x * cos(π * x) (own illustration)*

The figure shows that it is possible that the algorithm finds a solution with a preference rating that is higher than the value found by the stakeholders in the self-design process, but that is still not the highest preference rating possible in the particular model. However, this last statement can only be falsified by finding an optimum with an even higher preference rating. Therefore it cannot be said that the algorithm will find "the" optimum, it finds "an" optimum.

During the implementation of the PAS procedure, the outcomes of each step are translated into a mathematical model that calculates the overall preference rating per alternative. The implementation of the algorithm in the procedure then means that the algorithm is connected to this model, to use the data in the model to find an optimum alternative.

3.5. PAS in perspective

Compared to other models, the PAS procedure stands out by combining quantitative data with qualitative assessment by means of preference curves, and the translation of both elements into one single preference rating (Arkesteijn et al., 2015, p. 103; Valks et al., 2014, p. 2). Most other models, like the ones mentioned earlier this chapter, rely for a great deal on qualitative assessment. The model by Dewulf et al. (as cited in De Jonge et al., 2009, pp. 52-55), is strongly based on the scenario planning technique. A set of scenarios is used to determine the consequences of different futures for a set of possible strategies. This results in an assessment of each strategy, which is used to define the final portfolio strategy (Dewulf et al. as cited in De Jonge et al., 2009, pp. 52-55). Compared to this, the PAS procedure uses the business strategy to define a set of criteria to assess the real estate portfolio and to construct portfolio alternatives that incorporate a real estate strategy based on a specific set of interventions per object. The difference is in the selection of the best strategy. In the PAS, this is included in the structure of the procedure. The best solution is the portfolio alternative with the highest preference

[2] Based on n.a. (2015). *Local Optima vs. Global Optima. Retrieved 22/02/16 from http://www.lindo.com/doc/online_help/lingo15_0/local_optima_vs__global_optima.htm*

rating. However, in the Scenario planning model this selection process is not well structured, therefore it is not clear what is the best alternative.

Other models are more financially driven, like the Strategy Alignment Model developed by Osgood (as cited in De Jonge et al., 2009, pp. 73-75). Just like the PAS, this method starts from the business strategy to define a real estate strategy. This happens through the development of a "strategy alignment map", which connects certain elements of the business strategy to characteristics of the real estate portfolio that should be assessed in order to increase the alignment (Osgood as cited in De Jonge et al., 2009, pp. 73-75). Despite the fact that the model also incorporates qualitative aspects, the resulting overall portfolio performance rating is only based on financial elements (Arkesteijn et al., 2015, pp. 102-103). As mentioned before, in the PAS these elements are all incorporated into one single rating.

In fact, the PAS is a tool that is implemented in the context of the DAS framework (Designing an Accommodation Strategy), which is a method to identify the key elements in the real estate strategy-making process (De Jonge et al., 2009, p. 35). Therefore the PAS has the characteristic that it does not replace other models, but could be implemented in any model (Arkesteijn et al., 2015, p. 118). In this way, it provides structure and a way to measure and process preferences correctly and transparently.

3.5.1. Quantitative versus qualitative data

It is easy to rely on hard data, which is quantified information in graphs and tables, since this type of data is easily taken for granted. Using the word "statistics" provides numbers with an even higher status of reliability and the use of figures to present them reflects their perceived "scientific" value (Mintzberg, Ahlstrand, & Lampel, 2005, pp. 123-124).

Basing a real estate strategy on the relatively hard data that the PAS procedure generates out of both quantitative (hard) and qualitative (soft) data seems to be sensible. Also because it might enable the real estate manager to eventually measure the state of alignment with the corporate strategy.

The tough thing with hard data, however, is that it often has a narrow scope and lacks certain richness. Another disadvantage of hard data is that it is often aggregated and in the process of aggregation inevitably information is lost (Mintzberg et al., 2005, pp. 120-121). The previous might also hold for the PAS procedure where preferences are quantified in preference curves, which could result in a rather straightforward strategy with few creativity.

Not surprisingly, managers often rely on soft data, comprising of e.g. oral communication, speculation, gut feeling etc. Especially in strategy making, the relevant data almost never becomes "hard". If it does, it is too late due to the dynamic and iterative nature of strategy making. On the other hand, soft data is also subject to e.g. human error and psychological bias. Therefore, in the ideal situation strategy is based on both (Mintzberg et al., 2005, pp. 120, 124).

The soft information approach to strategy making is comparable to the current heuristic judgement of alignment in REM practice. The advantage of the PAS in this case is that during the process, soft data is made transparent and turned into hard data, while also the interaction with other stakeholders is incorporated. In the first steps of the PAS procedure stakeholders translate their preferences (soft data) into preference curves (hard data). This also makes it transparent. The resulting preference data, in turn, is used to rate portfolio alternatives (Arkesteijn et al., 2015, p. 118; Valks et al., 2014, pp. 13-14). These preference ratings are also hard data. The resulting real estate strategy is defined within the design constraints provided by the stakeholders, these constraints can be based on hard data, determining the feasibility of the design alternatives. In this way, the PAS procedure is able to combine both soft and hard information. However, the output of the model consists of hard, quantitative information again. When following Mintzberg's view on strategy, this implies that during the execution, still soft information might have to be added to it in order to adapt the strategy to changing circumstances. This could be done by continuously iterating the process of strategy design in the PAS procedure and implementation of the design.

3.6. Conclusions

In order to be able to arrive at one outcome by means of multiple decision variables, the use of MCDA becomes necessary. Most tools developed so far, however do not use correct preference measurement in the way this is defined by Barzilai. The first tool to do this in decision-making, is the PFM tool (Barzilai, 2005). Consequently, the implementation of this PFM in a design tool called PBD, by Binnekamp (2010), means that this is the first design decision-making tool that makes use of correct preference measurement. This tool is further developed into the PAS procedure.

The first tests with the PAS in practice showed that participants are able to determine their preferences and improve their representation through an iterative portfolio design process. The outcome of the tests is an improved portfolio rating. Still, recommendations are made to implement a search algorithm in order to find higher ratings, as more complex cases are expected to push the possibilities of what the stakeholders are able to achieve through self-design of portfolio alternatives.

The implementation of a search algorithm in the PAS procedure would, theoretically speaking, make the self-design process of portfolio alternatives redundant, as the search algorithm does not require alternatives as input. It could just provide the stakeholders with the alternative with the highest preference rating. However, the self-design process has a few critical advantages. Firstly, it helps stakeholders to develop insights in how the model works and what the influence of their input is. Secondly, they are allowed to adapt their input according to these insights. This helps to increase the model's representation of their preferences. Moreover, this increases the quality of the results. The disadvantage is that this process takes more time.

Before conducting a pilot study with the improved PAS, it is important do determine in what fashion the implementation of the algorithm would theoretically yield the highest stakeholder acceptance. Substituting the self-design of alternatives, or in addition to this. This will be discussed in part II. Nevertheless, the algorithm has its limitations, since it is inherent to the type of problems solved with the PAS that it will only be able to find "an" optimum and it is not known if this is also "the" optimum.

Contrary to the PAS, other models have less well-described procedures for comparing alternatives and selecting the best one, they rely more on qualitative assessment, e.g. in case of the Scenario planning model by Dewulf et al., or on a more financial portfolio performance rating, e.g. in Osgood's Strategy Alignment Model. The PAS combines both quantitative and qualitative elements in one rating by means of preference curves and makes the process very transparent. Moreover, the PAS can be implemented in other models in order to provide a well-structured procedure.

Looking at the PAS procedure from a perspective of "soft" and "hard" information, at a first glance capturing both qualitative and quantitative elements in one rating, turns it into a very useful tool for improving the decision-making process. Also the combination of both types of information during the procedure adds to the richness of the output. However, as this output consists of hard information, continuous iterations between the PAS procedure and implementation of the strategy are deemed necessary.

4. Multi Criteria Decision Analysis

This chapter introduces the principle of Multiple Criteria Decision Analysis (MCDA) and the way it is used in problem structuring and generating solutions. The PAS is placed within this framework in order to discover its applicability MCDA process. Furthermore, the chapter presents a classification of problems that could be solved by the application of MCDA, based on their characteristics. Finally, this classification is applied to the problems that the PAS is aimed at, hereby establishing its appropriateness to solve such problems.

4.1. MCDA process

In order to make a decision, one mostly has to take into account multiple factors that are more or less explicit. Imagine the decision what to prepare for dinner. To take this decision, you might take into account what you like most or what you ate yesterday. You might also think of whom you will have dinner with and any dietary requests. Finally the weather could have a more implicit influence on your decision. This is a decision you can easily take on your own and you do not need a tool to help you. An example of a situation that might require a tool to help decide, is that of a government that has to decrease its budget deficit while doing as few harm as possible. This is a situation where basing a decision on just reasoning, seems to be inappropriate.

In such cases, Multiple Criteria Decision Analysis (MCDA) could be applied to support the decision-maker in solving the problem. According to (Belton & Stewart, 2002, p. 2), MCDA is defined as *"an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter"*. It is meant to provide a transparent way of measuring subjectivity, in order to turn this into explicit elements in the decision-making process. This is most relevant in situations with multiple stakeholders that bring along often conflicting opinions (Belton & Stewart, 2002, pp. 2-3). This means that the user should realise that the outcome of an MCDA process is typically the product of the criteria and value judgement of the users and is not the only true answer. Moreover, there does not exist just one optimum in an environment with multiple criteria, as has been discussed in more detail in chapter 3.

The process of MCDA roughly comprises of three phases (see figure 12). Problem identification and structuring is the first phase and is focussed on the identification of the issue at hand and structuring this issue in terms of e.g. stakeholders, values, uncertainties and constraints. During this phase, all people involved should get a common understanding of the issue. The second phase is that of model building and use. This phase consists of building a mathematical model of the problem and using it to generate alternatives of possible futures. The model also provides tools for a transparent comparison of alternatives, based on the set of criteria defined by the users. Based on the synthesized information, a decision is taken for a future development direction. The third phase consists of developing an action plan to solve the issue, using the knowledge that was developed in the previous phases (Belton & Stewart, 2002, pp. 6-7, 14).

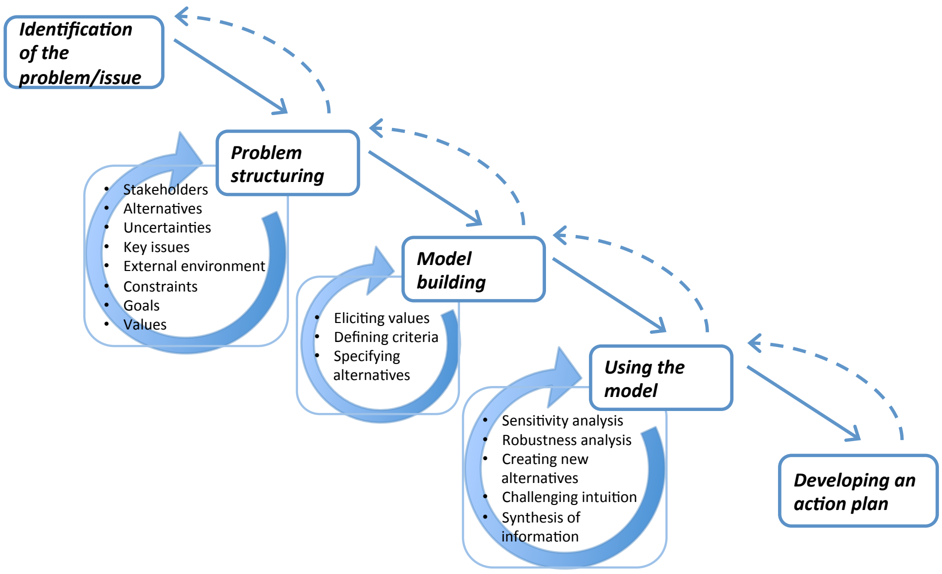


Figure 12 – The MCDA process (own illustration based on Belton & Stewart, 2002, p. 6)

This process is generally supported by a facilitator that guides the problem structuring and manages the model development process, in order to help the stakeholders to make a satisfactory decision. In order to do so, a thorough understanding of the issue is required, which is translated into an appropriate model. This is generally achieved by iteratively running through the different phases (Belton & Stewart, 2002, pp. 7-8, 14).

When the PAS is placed in the MCDA process in figure 12, it can be typically seen as a problem structuring method used in the first phase. However, as presented in the previous chapter, it also inherently enables the building of a mathematical model that closely represents the problem. The development of this model helps to further structure the problem and can be used to generate alternatives. The development and use of a model to generate alternatives, defines the second phase in the MCDA process. Furthermore the algorithm that is part of the improved PAS, generates a solution, which is the third MCDA phase. Because the PAS transcends those phases, it can be seen as an integral MCDA tool.

4.2. Multi Criteria Decision Making problems

"Consideration of different choices or courses of action becomes a Multiple Criteria Decision Making (MCDM) problem when there exist a number of such standards which conflict to a substantial extent" (Belton & Stewart, 2002, p. 1). This means that problems where MCDA could be applied to find an appropriate solution are MCDM problems. There are many of such MCDM problems, among which roughly three main categories can be identified. One is that of selecting from or sorting/ranking a discrete set of known alternatives. The other is that of a rather vague problem that needs to be identified, followed by a creative process of designing alternatives to meet the needs that are identified in the MCDA process. Also mixed processes of the previous two are possible, in which the design process delivers a small set of alternatives to be evaluated (Belton & Stewart, 2002, pp. 13,15, 22).

The multi-objective design problems in the second category, are further characterised by a theoretically infinite set of alternatives that are designed by varying a set of characteristics (Belton & Stewart, 2002, p. 19). This set of alternatives can be found within what Dym and Little (2004, pp. 97-98) call the design space. *"A design space is a mental construct of an intellectual space that envelops or incorporates all of the potential solutions to a design problem. As a broad concept, the utility of the notion of a design space is limited to its availability to convey a feel for the design problem at hand. The phrase* ***large design space*** *conveys an image of a design problem in which (1) the number* *of potential designs is very large, perhaps even infinite, or (2) the number of design variables is large, as is the number of values they can assume"* (Dym & Little, 2004, p. 97). The size of this design space is mainly determined by the constraints that are imposed to it by the stakeholders. The multi-objective design problem type is the most prevalent in practice in general and in this project specifically, as the solutions need to be designed based on the set of criteria provided by the stakeholders.

Belton and Stewart (2002) provide a classification of MCDM problems, based on several characteristics. First there is the distinction between decision problems that are faced repeatedly, for which MCDA could provide a more process-oriented approach, and problems that occur only once and require a unique approach that goes more into detail. A second characteristic is the number of stakeholders that are involved in the process. In case of a single decision-maker with final responsibility or a small group with common goals, the MCDA process could be used to directly identify a solution. Whereas a group of stakeholders with diverging interests, requires much more negotiation on the influence of each stakeholder and joint analysis of the problem, involving all stakeholders. Also the position of the user is important for the MCDA approach taken. When the user(s) is/are allowed to make the final call on the subject matter, the process could just provide a satisfactory outcome, without any additional justification. In this case, the input of the stakeholders provides the justification of the results for the decision-makers. However, it could be argued that in order to justify the solution to e.g. a supervisory board, more in depth justification is required. In situations where the users are asked to advice the final decision-maker, the process should in any case be transparent and the outcome should be justified thoroughly. The number of available alternatives is the third characteristic in the problem classification. As discussed previously, there are decision problems regarding a discrete set of known alternatives and problems with an infinite number of possible alternatives. The former case is quite straightforward, however the latter might require focus on the analysis of only a shortlist of alternatives. A fourth distinction made, is between facilitated approaches, which mostly applies to more complex problems and do-it-yourself processes that could be performed by use of e.g. a computer programme (Belton & Stewart, 2002, pp. 31-33).

4.3. Classifying the PAS problems on MCDM characteristics.

The real estate portfolio problems that are solved by means of the PAS are characterised as occurring repeatedly, and therefore ask for more of a process-oriented approach. This is exactly what the PAS provides. These problems, often involve multiple stakeholders with somewhat diverging objectives, resulting in conflicting criteria. According to Belton and Stewart (2002, p. 32), in such cases the solution may only be found through negotiation on political level, without the help of a model in an MCDA process. Chapter 3 has shown however, that by using the PAS, it is possible to find an optimum solution by means of a model that transparently processes a set of criteria with preference functions into an overall preference rating, using explicit criteria- and stakeholder weights. In this case the PAS, as an MCDA method, substitutes the process of negotiations and results in an outcome that is accepted by the users. Moreover, when stakeholders would see the need to negotiate over the model outcomes, the model is not appropriate for the problem at hand, as it does not reflect the actual decision-making process correctly. Therefore, the statement by Belton and Stewart (2002) might not hold water in case of the PAS.

Concerning the position of the user in MCDM problems to which the PAS is applied, it can be said that both cases discussed in the previous paragraph hold. In the example of the lecture hall case in chapter 3, the final decision-maker was represented in the stakeholder group involved in the process. However it is most likely that the PAS will also be used by real estate professionals in the CREM department of a company, hence they have to present their recommendations to the board of directors.

The PAS mainly focuses on multi-criteria design problems, hence the number of alternatives can be infinite, depending on the size of the design space However, the starting point often constitutes a portfolio with multiple objects that have to be rated based on the given set of stakeholder criteria. In that sense, those problems constitute the mixed problem type that are identified. Contrary to the suggestion of Belton and Stewart (2002, p. 33), that it would be necessary in design cases to focus on the analysis of a shortlist of alternatives, the previous chapter shows that the application of the search algorithm to the PAS, enables the analysis of a possibly infinite number of alternatives within the design space.

Finally, the PAS is currently a typical facilitated approach, the fascilitation has to enable the improvement of the procedure and the model building process around it. In the future it might, however, be possible to present the PAS in a computer programme that enables a do-it-yourself process.

4.4. Conclusions

Multiple Criteria Decision Making (MCDM) occurs in many daily decisions that we have to take. Approaching such problems with a Multiple Criteria Decision Analysis (MCDA) tool however, is only relevant when the problem concerns an issue with reasonable importance to the decision-maker. Such problems are classified based on the occurrence interval of the problem, the number of stakeholders, the criteria they bring along and their influence in the organisation and the number of alternatives inherent in the problem. In the MCDA process that can be used to approach these problems, three phases are identified; problem identification and structuring, model building and use and developing a plan of action. The PAS procedure as an MCDA method, covers all those phases and can therefore be seen as an integral MCDA tool that is suitable to provide support to solving MCDM problems.

Moreover, the real estate portfolio decision-making problems that the PAS is aimed at, are found in the more complex problem type of multi-criteria design problems. The PAS as a procedure is in accordance with what is suggested in literature as a way to approach the returning nature of the real estate strategy decision-making process.

However, research outcomes regarding the PAS that are presented in the previous chapter, partly refute the suggestion by Belton and Stewart (2002) that in cases with many stakeholders with conflicting criteria, a solution will likely to be found on political level. The argument for this is that previous pilots with the PAS have shown that it is able to substitute the negotiation process using a transparent model to arrive at an acceptable solution for the stakeholders. Also this chapter has shown that, contrary to what Belton and Stewart (2002) claims regarding the focus on a shortlist of alternatives in multi-criteria design problems, the application of a search algorithm to the PAS enables the analysis of an infinite number of alternatives.

5. Preference measurement

Chapter 5 is included in this report in order to clarify the basis of the PFM principle, which is a central element of the PAS. The formal formulation of this approach to preference measurement is rather complex and requires quite some mathematical knowledge to understand. Therefore this chapter aims to provide an explanation of this formal reasoning in less formal terms. Because the formal wording in the original publications cannot be rephrased with the same precision, quotes are presented of the important parts. These quotes are followed by an explanation, larded with practical examples.

"The purpose of measurement is to enable the application of mathematics to the objects under measurement" (Barzilai, 2005, p. 174). An example of this is the addition of the mass of two bags of sand.

The starting point of measurement theory dates back to the work of Von Helmholtz from 1887 that discusses the measurement of object properties and suggests the mapping of an empirical set *E* into a mathematical set *M*, as discussed in the next paragraph. This measurement theory applies both to social science and physics (Von Helmholtz as cited in Barzilai, 2010, p. 2). The question whether it is possible to measure psychological properties like preference in social science is answered in 1940, by a committee of the British Association for the Advancement of Science. The outcome was negative, based on the argument that no mathematical operations are defined on the empirical objects. However, there were some inconsistencies in the reports that covered the project (Barzilai, 2010, pp. 2-3).

Nonetheless, Von Neumann & Morgenstern (as cited in Barzilai, 2010, pp. 2-3, 22) worked on their utility theory that had to enable the measurement of preferences. They focussed on identifying the empirical operations (e.g. addition or subtraction) that are allowed on the property of preference, in order to build a mathematical model that enables corresponding operations. Based on this work and the committee report, Stevens (1946) suggests a set of scales, based on the applicability of mathematical operations, to measure preference. These scales, i.e. nominal, ordinal, interval and ratio (Stevens, 1946, p. 678), are used in social science until today.

However, regarding the model of Von Neumann & Morgenstern, Barzilai (2010, p. 3) proves that *"[...] the operations of addition and multiplication are not enabled in their mathematical model [...]"*. As such, also the scales of Stevens (1946) are faulty (Barzilai, 2010, pp. 4,10-11). Moreover, in the course of time, the focus in measurement theory has shifted towards uniqueness of scales instead of solving the operations issue (Barzilai, 2010, pp. 22-23). This chapter presents the proposed solution for correct preference measurement by Barzilai (2010).

5.1.Mathematical modelling

"By an empirical system E we mean a set of empirical objects together with operations (i.e. functions) and possibly the relation of order which characterize the property under measurement. A mathematical model M of the empirical system E is a set with operations that reflect the empirical operations in E as well as the order in E when E is ordered. A scale s is a mapping of the objects in E into the objects in M that reflects the structure of E into M [...]. The purpose of modelling E by M is to enable the application of mathematical operations on the elements of the mathematical system M" (Barzilai, 2010, p. 2). The mapping of *E* in *M* is shown in figure 13.

Now, what does this mean; "mapping the objects of *E* in *M*? The empirical system *E*, is the name for the objects under measurement in real life. These objects have certain properties, e.g. length, energy, preference etc. that are being measured. Measurement means that the property of each object is associated with a numerical value in the model *M* (Barzilai, 2005, p. 174). The objects in *M* allow for the application of certain mathematical operations, which cannot be applied to the empirical elements (Barzilai, 2010, p. 2).

In measurement theory, the scale *s* is a function that reflects a set of objects in *E* into *M*, which means that *s(E) = M*. The function *s* is not just applicable on the entire set *E* but also on an individual object *e* in the set, which gives the scale value *s(e)* (Barzilai, 2005, p. 174).

Barzilai (2010, p. 5) states that: *"The Principle of Reflection is an essential element of modelling that states that operations within the mathematical system are applicable **if and only if** they reflect corresponding operations within the empirical system".* This means that mathematical operations like addition and multiplication are only allowed on the numerical values in *M*, when they are also allowed on the objects in *E*.

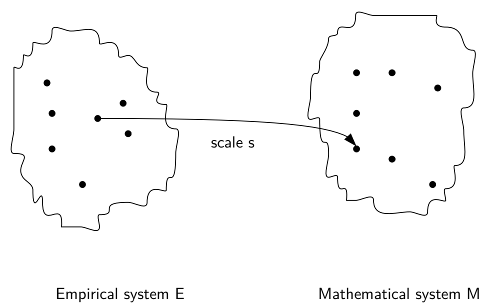


Figure 13 – Mapping of an empirical set E to a mathematical set M (Barendse et al., 2012, p. 25)

Scales

*"It is important to emphasize the distinction between the application of the operations of addition and multiplication to scale values for a fixed scale (for example s(a) = s(b) + s(c)) as opposed to what appear to be the same operations when they are applied to an entire scale whereby an equivalent scale is produced (for example t = p + q * s; where s and t are two scales and p, q are numbers). In the case of scale values for a fixed scale, the operations of addition and multiplication are applied to elements of the mathematical system M and the result is another element of M. In the case of operations on entire scales, addition or multiplication by a number are applied to an element of the set S = (s, t, …) of all possible scales and the result is another element of S rather than M. These are different operations because operations are functions and functions with different domains or ranges are different"* (Barzilai, 2010, p. 4).

The statement above illustrates the problem in measurement theory as presented in paragraph one. In this statement, the distinction is being made between applying mathematical operations to a fixed scale and to an entire scale. The first means that operations are applied to objects in *M* while leaving the scale intact that applies to them. In the example used, $s(a) = s(b) + s(c)$, the scale *s* remains the same. When translated to practice, the example could represent the addition of the mass of two bags of sand, which results in a total with the same mass scale. In case the bags have the same weight, the total equals two times the weight of one bag, $s(a) = 2 * s(b)$. One could say that the mass scale is unique up to addition or a multiplication constant, thus a single operation (Barzilai, 2010, pp. 3-4). The second means that the objects under scale *s* are translated to another scale *t*. A practical example of the formula, $t = p + q * s$, is the translation of temperature in degrees Celsius to degrees Fahrenheit, $F = p + q * C$; where *F* represents the Fahrenheit scale and *C* the Celsius scale. In this case, the scales are unique up to an addition constant and a multiplication constant (Barzilai, 2010, pp. 3-4). The second situation is what Von Neumann & Morgenstern (as cited in Barzilai, 2010, p. 22) focussed on, whereas the real problem is in the first one; the application of operations of addition and multiplication on scale values for a fixed scale (Barzilai, 2010, pp. 10-11).

"Since the purpose of modelling is to enable the application of mathematical operations, we classify scales by the type of mathematical operations that they enable. We use the terms proper scales to denote scales where the operations of addition and multiplication are enabled on scale values, and weak scales to denote scales where these operations are not enabled" (Barzilai, 2010, p. 19). It is therefore important to use proper scales in order to generate meaningful results (Binnekamp, 2010, p. 29).

5.2. Constructing proper models

"In order to enable the "powerful weapon of mathematical analysis" to be applied to any scientific discipline it is necessary, at a minimum, to construct models that enable the operations of addition and multiplication, for without these operations the tools of linear algebra and elementary statistics cannot be applied" (Barzilai, 2010, p. 18).

This means that to be able to apply statistical analysis, i.e. operations of addition and multiplication, to the objects in the models, one should use at least proper scales. Constructing the resulting proper models requires two things. The first is stated by Barzilai (2010, p. 18), as follows:

"If the operations of addition and multiplication are to be enabled in the mathematical system M, these operations must be defined in M. The empirical system E must then be equipped with corresponding operations in order for M to be a model of E".

This means that by using a proper scale, i.e. a scale that enables the operations of addition and multiplication, to map the set of objects in *E* to the model *M*, these operations can be applied to the objects in *M*. This requires the principle of reflection to be applicable (Barzilai, 2010, p. 5). This is the first step towards a proper model.

The second requirement is the following:

"In order for the operations of addition and multiplication to be applicable, the mathematical system M must be:

1. *a field if it is a model of a system with an absolute zero and one,*
2. *a one-dimensional vector space when the empirical system has an absolute zero but not an absolute one, or*
3. *a one-dimensional affine space which is the case for all non-physical properties with neither an absolute zero nor absolute one"* (Barzilai, 2010, p. 23).

An explanation of each case is given below.

1. A field is a set of objects that enables the operations of addition and multiplication (Barzilai, 2005, p. 175; 2010, p. 18).
2. An example of a one-dimensional vector space is shown on the left in figure 14. It shows two vectors that are a former set that lost its multiplicative identity but kept its additive identity (Barzilai, 2010, pp. 18-19). Both have a specified length. They could represent mass or temperature in Kelvin, as both these properties have an absolute 0. In this case they represent mass; the left one in kg. and the right vector in pound (500 gr.), therefore the latter is twice as long as the former.
3. The one-dimensional affine space is *"the algebraic formulation of the familiar straight line of elementary (affine) geometry"* and *"In an affine space, the difference of two points is a vector and no other operations are defined on points. In particular, it is important to note that the ratio of two points as well as the sum of two points are undefined. The operation of addition is defined on point differences, which are vectors,*

[...]. Multiplication of a vector by a scalar is defined and the result is a vector. In the one-dimensional case, and only in this case, the ratio of a vector divided by another non-zero vector is a scalar" (Barzilai, 2010, p. 19).

A one-dimensional affine space is shown in figure 14, on the right. In this space, the vector provides information about the distance between the points, so there is only information about their relative position, not about the operations that are possible on those points (Barzilai, 2005, pp. 175-177; 2010, pp. 18-21). The points in figure 14 could resemble the cities passed on a train trip in the following example. Someone travels at 12.00 from Delft (A) to Tilburg (B) and arrives here at 13.00. This person takes a 30 minute break and leaves Tilburg (C) at 13.30 to arrive at 15.00 in Eindhoven (D). In this example, there is only information available on the relative time distance between the points. A – B, 1 hour; B – C, 0,5 hour; C – D, 1,5 hours. When this traveller would make the same trip, but leaves at 11.00, the same information would be available.

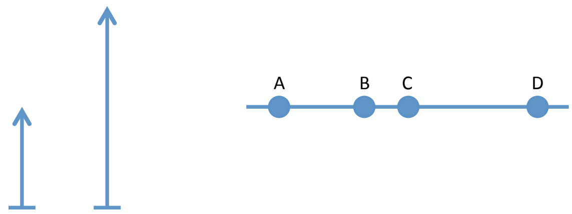


Figure 14 – Representation of a vector space (l); and a one-dimensional affine space (r) (own illustration)

"The expression $\frac{A-B}{C-D}$ *= k, where A, B, C, D are points on an affine straight line and k is a scalar is used in the construction of proper scales"* (Barzilai, 2010, p. 24). The differences between these points, i.e. A – B and C – D, are one-dimensional vectors. In the travelling example, this is the travelling time between two points. This operation of subtraction is aimed at removing the differing 0-points. In the example, the 0-point at A is 12.00 while at C it is 13.30, so they are not comparable. However, by calculating the travelling time between the points, the vector, they become comparable. These two vectors are divided to remove the unit, this results in the scalar k (Barzilai, 2005, pp. 177-179; 2010, pp. 19-22).

5.3. Preference measurement

Preference (also named utility, value etc.) is a non-physical variable that describes a psychological or subjective property of an object (Barzilai, 2010, pp. 1, 25). The empirical system of preferences is characterised by the absence of an absolute 0 and 1, therefore the correct model consists of a straight line of affine geometry, i.e. a one-dimensional affine space. This model *M*, results from a proper scale that enables the operations of addition and multiplication (Barzilai, 2010, pp. 19, 23).

In order to construct such proper preference scales, a minimum of three objects or points is required. This follows from the formula $\frac{A-B}{C-D}$ = k that is used to generate these scales. In this formula, *"the number of points in the left hand side of this expression can be reduced from four to three (e.g. if B=D) but it cannot be reduced to two and this implies that pairwise comparisons cannot be used to construct preference scales where the operations of addition and multiplication are enabled"* (Barzilai, 2010, p. 24).

Also this can be explained by means of the travelling example. As the example is about the travelling time between the three cities, B and C could be combined, while still providing the required information on the travelling time between Delft, Tilburg and Eindhoven. When reducing the number of points to two, information is obviously lost. This pairwise comparison is only possible in a vector space with an absolute zero, e.g. in case of mass or temperature in degrees Kelvin. Recall the left side in figure 14, where the right vector is twice as long as the left one.

Therefore, two points are not enough to construct a proper preference scale (Barzilai, 2010, pp. 22, 24). Moreover, this process also requires a specification of what object is being valued and whose value is being measured. The resulting scale of measurement of the property of preference, is a preference scale (Barzilai, 2010, pp. 14, 25).

5.4. Conclusions on practical application

In practice, preference measurement requires at least three objects that have to be ordered and rated by the stakeholder whose preference is being measured. This results in the following steps to be taken:

1. Ask the stakeholder to name the most preferred object and assign a preference rating of 100
2. Ask the stakeholder to name the least preferred object and assign a preference rating of 0
3. Ask the stakeholder what the preference function in between object 1 and 2 looks like (see figure 15), or assign a preference rating to an intermediate alternative.

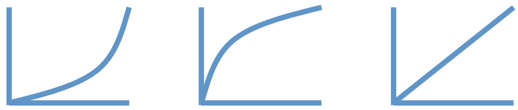


Figure 15 – Possible courses of the preference function between 0 and 100 (x, variable value; y, preference rating) (own illustration)

Note that the values of 0 and 100 are just chosen because they adhere best to the perceptions of stakeholders, a minimum and maximum value of respectively 10 and 85 would have provided the same information. The resultant is an affine space with three points on a line that represent the alternatives. Because a proper scale is used to map the empirical objects E in the mathematical model M, the operations that are allowed on E are also allowed in the model M. However, since one cannot apply operations of addition and multiplication on preferences in E, this is also not possible in M. Therefore, as Binnekamp (2010, pp. 33-35) shows, the process of calculating a weighted sum is problematic, instead a process of preference function modelling (PFM) should be used (Binnekamp, 2010, p. 81). This PFM process is implemented in the tool Tetra that can be used for relatively simple problems. This tool is developed by Barzilai (Binnekamp, 2010, p. 51). However, because providing input in this tool is rather time-consuming, in the mathematical model a weighted average is calculated, which provides an approximation of the actual values.

6. Implications for the research project

This conclusion briefly summarises part I of the report and concludes on the implications of the findings for the rest of this research and design project. It provides insight in the relation between the findings previously presented and the rest of the report. Also it connects these insights directly to the next part.

Part I introduces the problem in CREM practice regarding the alignment of corporate real estate and the business it should support. It also shows the problems with most of the currently available alignment models and therefore the relevance of research into the PAS. The literature study regarding the PAS procedure presents the development towards its current state and the next step to improve it. Current findings are that the procedure helps to improve the portfolio preference rating and that the iterative process of designing portfolio alternatives and adapting preferences, helps to increase user acceptance. The improvement in the PAS comprises of the application of a search algorithm to the PAS model in practice, which is relevant because it is thought to help find alternatives with a higher preference rating than can be found through self-design. Such alternative solutions enable better alignment between the business strategy and real estate strategy and therefore provide a higher added value of the corporate real estate to the core processes.

Chapter 3 and 4 show that one of the core elements of the PAS is that it incorporates both quantitative and qualitative elements in one preference rating for separate objects and an entire portfolio. Also it provides a structured procedure that is designed to facilitate a transparent decision-making process, which makes it to a typical MCDA method. Therefore the implementation process in practice should closely follow the steps in the procedure. In addition to this, the literature on the PAS showed that correct preference measurement should be used to obtain meaningful results. Chapter 5 shows that this requires a correct mapping of the stakeholders' preferences into the model. This mapping is done by rating a set of three objects or variable values with a preference rating, first establishing the most- and least preferred value and at last one value in between to determine the slope of the resulting preference function. Still the calculation of the overall preference rating by the model is only an approximation of the actual value, which can be obtained through the use of Tetra.

In chapter 2 it is shown that this research requires an operations research approach to design an artefact, i.e. the mathematical model. This approach combines both empirical research and formal research in a cyclical model. Part of the empirical research is to establish a set of determinants for successful implementation of a DSS. The formal element comprises of building a model that enables the application of the search algorithm and testing and evaluating this in practice. The model building is a cyclical process in itself, based on the design approach. The empirical element is used to guide and evaluate the formal process and to employ the evaluation results to answer the main question and improve the PAS.

The model is built in an iterative process of interviews and workshops. This process starts with stakeholder interviews that cover the first four steps of the PAS procedure. This input is used to build an initial model that is tested in a workshop. In the interview that follows the workshop, the stakeholders are allowed to adapt the input on the first four steps and evaluate the model and the process. This process is repeated with the second workshop. The evaluation interviews are based on an evaluation structure from literature.

Part II of this report provides the set of determinants for successful implementation of a DSS as discussed above and introduces a basic model of a simple but similar problem in Matlab.

Part II – Towards a solution

7. Successful implementation of Decision Support Systems

This chapter presents the literature study into determinants of successful implementation of decision support systems. Several models are discussed that are brought together in one model that provides a set of process characteristics that help to generate acceptance. When the process facilitates these elements also the trust in the system increases. These elements together provide a checklist that is used in the implementation process of the improved PAS. The most important elements of this checklist are fitted in the conceptual model in the figure below.

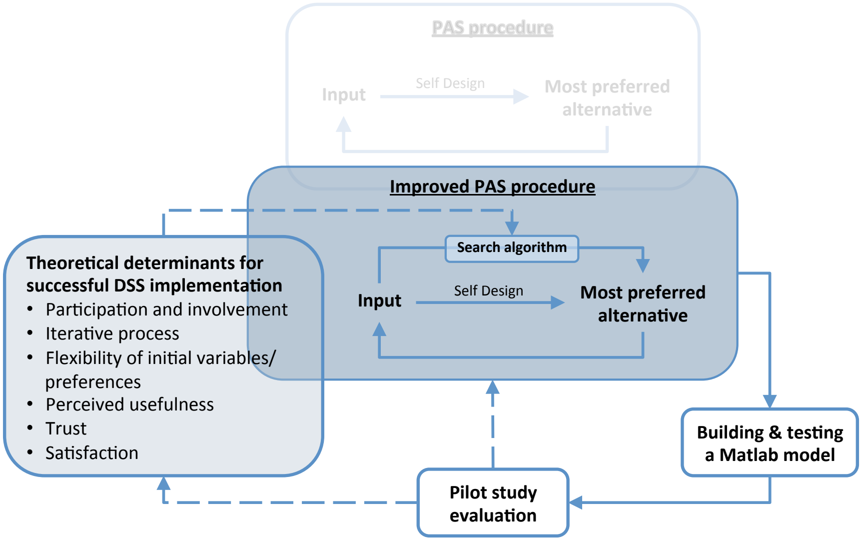


Figure 16 – Conceptual model with elaborate determinants for successful DSS implementation (own illustration)

7.1. Literature study

7.1.1. Creating acceptance for decision support systems

Decision support systems (DSS) are computer-based information systems that support multi criteria decision-making problems by organising information to solve these semi-structured or unstructured problems (Razmak & Aouni, 2015, pp. 101, 113; Riedel et al., 2011, p. 232). The organisation of information is needed as people generally want to process too much information and are unable to make full use of it by themselves (Schrenk, 1969). DSSs are developed as interactive tools to assist in formal steps of problem solving, e.g. generating alternatives and selection of relevant options, integrating the decision makers' preferences and making compromises. They are applied in situations that involve human information processing and making choices, for instance in strategic planning decision-making and strategic option development (Razmak & Aouni, 2015, pp. 102, 111; Riedel et al., 2011, p. 232).

Referring to this definition, the PAS procedure can be seen as such a DSS, as it helps in generating and selecting relevant options in a multi criteria decision-making environment by integrating preferences. Riedel et al. (2011) distinguish four types of DSSs; model-oriented, data-oriented, decision-oriented and general (Riedel et al., 2011, p. 233). The PAS can be classified as a decision-oriented DSS as it focuses on one specific decision-making process. Three main advantages of DSSs stated by Carlson & Turban (as cited in Riedel et al., 2011, p. 234) are; improved efficiency of decision-making, sound decisions and interactive problem solving. Also the application of DSSs helps to remove barriers from the decision-making process (Razmak & Aouni, 2015, p. 112).

Rejection of DSSs
An archetypal process using DSS is sketched in figure 17 in order to identify important aspects of the design and implementation process, to help increase acceptance and to avoid system rejection. Both are required to improve the decision-making process (Venkatesh, Morris, Davis, & Davis, 2003, p. 426).

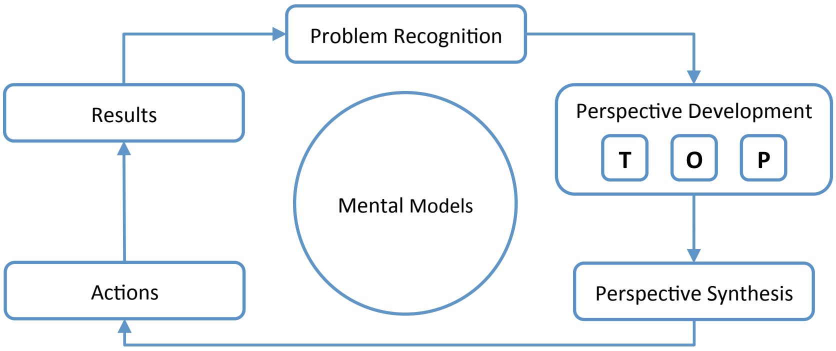


Figure 17 – Archetype model of DSS decision-making (Courtney as cited in Riedel et al., 2011, p. 240)

The T, O and P mean respectively technical, organisational and personal perspectives on the problem at hand. The model shows the influence of mental models on all aspects of the process as they determine what information and perspectives stakeholders take into account regarding the problem at hand. In order to achieve a good representation of these perspectives in the DSS, and to avoid system rejection through divergent mental models, an iterative development process is suggested. In this process, the DSS builder uses testing sessions with the user to improve the model (Riedel et al., 2011, pp. 236, 239-240). Each modelling iteration is made with the feedback resulting from the stakeholder evaluation of the previous model.

In addition to this, the following set of environmental aspects that influences the required structure of a DSS should therefore be taken into account in the DSS design process (Pearson and Shim as cited in Riedel et al., 2011, p. 235):

1. Task structure; is the problem/task ahead structured or unstructured.
2. Supported management level; is the decision taken at strategic, managerial or operational level.
3. Usage pattern; by whom the system is used.
4. Number of supported users.
5. User's computer skills.
6. Interaction with other information systems; does the system need to communicate with internal or external systems or with no other systems.

Failure to take the above into account in the design process, might result in a lack of understanding of the system and its mathematical formulations by the actors, prevalence of negative past experiences and the preference of human advice over the DSS, which may eventually cause rejection of the system (Riedel et al., 2011, p. 238).

Human factors in software design
DSSs provide leverage to the human abilities in the decision-making process, hence they will never really take over the entire task (Riedel et al., 2011, p. 242). Therefore, it is important to take into account the human aspect when designing DSSs. Several research fields provide insights into this matter, some important aspects are discussed below.

The field of Interaction Design (ID) is based on an iterative design process together with the stakeholders in order to create a usable design. Human-Computer Interaction (HCI) aims at making computers more usable by improving their understanding of the user's task. This requires a central position of the user in the design process (Riedel et al., 2011, pp. 242-245). Usability Engineering is related to computer science and user interface design and focuses on the usability of the system. This is defined as *"a context-dependent agreement of the effectiveness, efficiency and satisfaction"* of the design (Riedel et al., 2011, pp. 242-246).

A different approach towards model development is also provided by Beynon, Rasmequan, and Russ (2002). They present empirical modelling as a way to improve the interaction between the software and the user. This way of modelling is open to new observables (i.e. decision variables) and dependencies based on experience in real life and in interaction with the model. By putting the agent in a central place, able to change the model, a better representation of reality can be achieved. Due to the interactive nature, these type of models are called Interactive Situation Models (ISM) (Beynon et al., 2002, pp. 130-132).

A returning element in the above is the focus on active involvement of the user in the design process in order to improve the representation of reality by the model and adjust it to the users' requirements.

Human factors in design and implementation of DSSs
Based on multiple theories, Riedel et al. (2011) present a model that captures the factors important in acceptance and use of DSSs. This model is based on four perspectives that are presented below.

User participation and involvement are recognised in literature as important factors for the user satisfaction with DSSs and provide a basic framework to increase acceptance. Participation is defined here as an observable behaviour, the definition of involvement is a subjective psychological state of the actors, regarding the importance of the system (Riedel et al., 2011, p. 247). Both factors have a positive influence on the user satisfaction and the attitude towards the DSS and therefore contribute significantly to system acceptance (see figure 18). Levels of participation and involvement might differ over the stages of the development and depend on system-, user-, and process characteristics (Riedel et al., 2011, pp. 246-247).

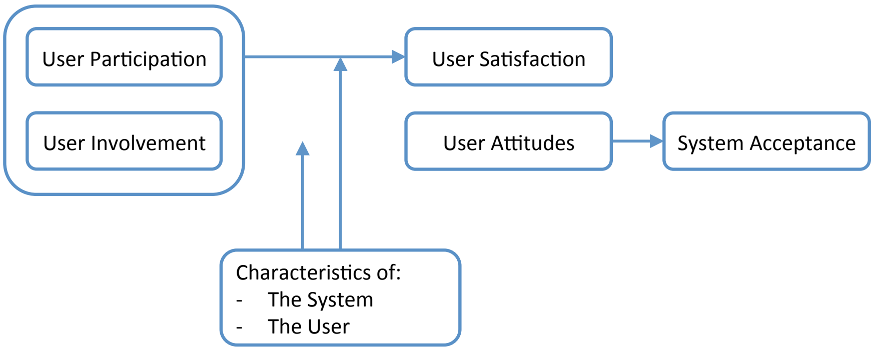


Figure 18 – User participation and involvement in system acceptance (Riedel et al., 2011, p. 249)

The Technology Acceptance Model (TAM) is used to identify further determinants of system acceptance. This model presumes that behaviour is always preceded by behavioural intentions (BI). The TAM comprises mainly of two concepts, perceived usefulness (PU), which is defined as *"the degree to which a person believes that using a particular system could enhance his or her job performance"* (Riedel et al., 2011, p. 249) and perceived ease of use (PEOU), defined as *"the degree to which a person believes that using a particular system is free of effort"* (Riedel et al., 2011, p. 249). Both aspects determine the behavioural intentions, which are equal to system acceptance. However, the influence of perceived usefulness is strongest.

In addition to this, acceptance is found to lead to system use and user satisfaction (Igbarian & Tan as cited in Riedel et al., 2011, p. 250). The latter two concepts also strengthen one another. Together with the influence of external variables they form the model in figure 19.

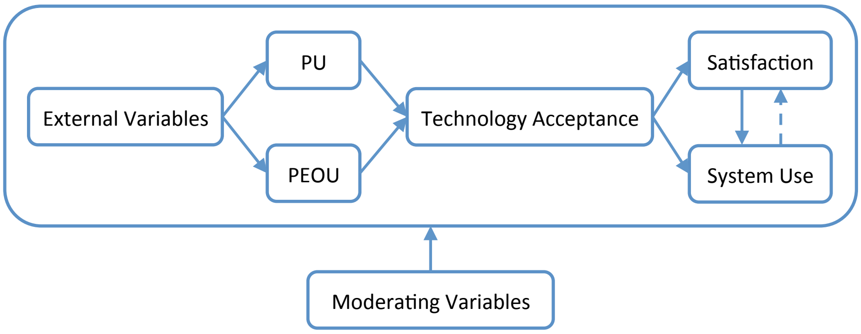


Figure 19 – Technology acceptance model (Riedel et al., 2011, p. 253)

Looking at acceptance of DSSs from the perspective of cybernetics, additional determinants are found. The perception of control, i.e. perceived control, influences the behavioural intentions, the behaviour and the perceived usefulness in the previous model. Perceived control is found to be determined by the level of participation (Riedel et al., 2011, p. 254). Participation helps the actors to build confidence in the model, as it allows them to learn from the effects of changing decision variables on the outcome. Also it allows them to improve the representation of their perceptions of the decision making process in the characteristics of the model. This influence yields an indirect effect on perceived usefulness and perceived ease of use (Davis & Kottemann in Riedel et al., 2011, p. 254). Figure 20 summarises the above.

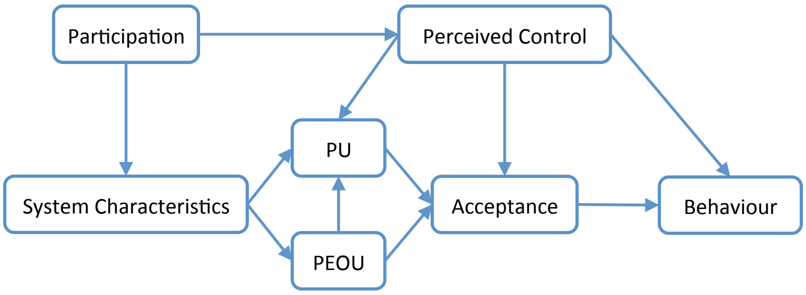


Figure 20 – Cybernetics in the technology acceptance model (Riedel et al., 2011, p. 253)

Finally the apprenticeship model provides lessons for the interaction between the model designer and the user. In the case of DSS development the user is expert in the decision-making process at hand and the designer is expert in supporting this process. This model can be employed to initiate valuable interaction between the two experts that helps to increase the usefulness of the system (Riedel et al., 2011, p. 257).

The elements discussed above are combined in one model by Riedel et al. (2011). This model is presented in figure 21. In the model, participation and involvement is a central element. It helps the stakeholders to improve the representation of their perceptions of the decision making process in the characteristics of the model, which translates to higher levels of system complexity e.g. the number of decision variables, complexity of mathematic formulations etc. Also it positively influences the perceived control. This positive influence means that if the level of participation increases, the level of perceived control follows the increase. A higher level of perceived control raises both perceived usefulness and behavioural intention i.e. acceptance. Perceived usefulness also increases the latter. Acceptance leads to user satisfaction and system use.

Participation and involvement also returns in the central feedback loop in the model. The loop runs from participation to system complexity and via satisfaction back to participation, where a low level of satisfaction should lead to more participation and involvement. The apprenticeship model is incorporated in this loop by guiding the roles that the DSS designer and the user take in understanding the model requirements.

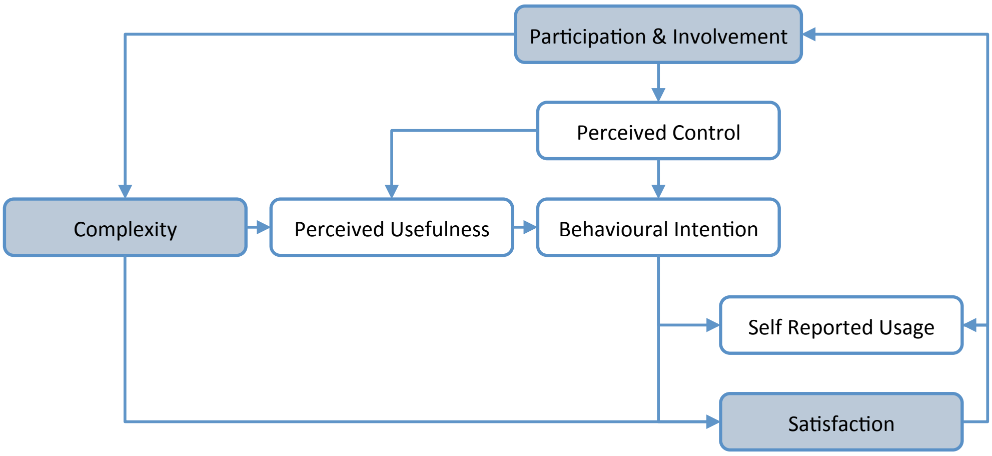


Figure 21 – Conceptual model of determinants in DSS modelling (Riedel et al., 2011, p. 258)

Riedel et al. (2011) performed several case studies in order to find out if the expected dynamic relationship in the feedback loop described above is present in practice (Riedel et al., 2011, p. 259). The case studies show that the relation between user participation and model complexity is indeed present. The former positively influences model complexity and subsequently user satisfaction and model use. However, a too complex system decreases the satisfaction, which results in lower participation in order to decrease complexity. This results in a dynamic development process with varying levels of participation, complexity and satisfaction. The researchers also found that low initial involvement, resulting in low satisfaction, can be compensated in later stages by increased user participation. Finally, the studies found the positive relation of user participation, via perceived control, on the acceptance of a system (Riedel et al., 2011, pp. 266-267).

7.1.2. The role of trust in design and implementation of DSSs

As discussed before, humans will continue to be part of the decision-making process using DSSs. Those users have certain expectations of the tasks a system performs in their place. Because of those expectations, trust is an important concept to take into account in human-computer interaction. The concept of trust is explored by Riedel et al. (2011) in order to develop a model of the role of trust in design and implementation of DSSs.

Trust can be defined as *"the attitude that an agent (the DSS) will help to achieve an individual's goals in a situation characterised by uncertainty and vulnerability"* (Riedel et al., 2011, p. 268). The trust in a system is specifically made operational as the expectation the user has regarding the tasks the system will perform on his/her behalf. In the case of a DSS the complexity of the system makes it impossible to fully understand, hence induces the need of reliance on the system. This requires voluntary interaction of the user with the system (Riedel et al., 2011, p. 270).

According to Lee & Moray (as cited in Riedel et al., 2011, pp. 270-271) trust in automation is influenced by three determinants. First is the performance of the system in terms of the ability and reliability in achieving the user's goals. As the objective measure of performance, reliability is one of the core determinants for trust. Research shows that it is positively related to trust (Wiegmann et al. as cited in Riedel et al., 2011, p. 273). The process, as second, comprises of the suitability of the system's algorithms to achieve the users' goals. Users will put more trust in the system if the backside of the model can be understood and seems to be capable of performing the task. Additionally, when the system justifies its solutions (e.g. by showing the mathematical operations it performed) and the user understands this, it gains trust (Miller & Larson as cited in Riedel et al., 2011, pp. 272-273; Wærn & Ramberg, 1996, p. 23). The third determinant is the purpose of the system. A system that is used for its intended task will be trusted more.

A final influence on a system's trust is imposed by usability, which can be seen as the consistency, controllability and predictability of a system. The last term refers to the aspect of "expectation" related to trust as discussed previously (Riedel et al., 2011, pp. 274-275). The above shows that a system that is not trusted will not be used, because its outcomes would not be accepted.

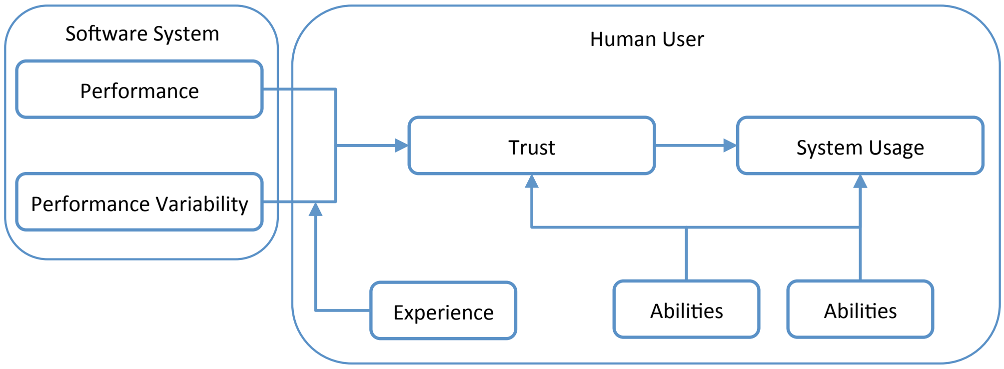


Figure 22 – Conceptual model of trust as determinant for system use (own illustration based on Riedel et al., 2011, p. 277)

The model proposed by Riedel et al. (2011) shows the different aspects that are expected to influence trust. The results of an online survey show that indeed system performance influences trust positively, performance variability has a negative influence. Experience in the field does not influence the effect of performance variability nor do the own abilities of the respondents to solve the problem explain the tendency to ask a human expert to help them instead of the system. However, general attitude towards DSSs, also covering the process and purpose aspects, positively influences trust (Riedel et al., 2011, pp. 282-286).

In the past a similar approach was taken by Venkatesh et al. (2003) towards the integration of different theories into one model to identify the drivers of acceptance of a DSS. They employ roughly the same determinants, though in another configuration and without the use of the insightful feedback loops that the model by Riedel et al. (2011) shows. Moreover it does not show possible influences among determinants of acceptance (Venkatesh et al., 2003, pp. 447-454).

The main difference is in the combination that this model seems to make of determinants of acceptance with the concepts of trust, including the moderators experience, attitude and abilities. Trust is treated separately by Riedel et al. (2011), which helps to identify drivers of acceptance that are important during the design and implementation process. This is important as it could be argued that trust is the result of this process. Venkatesh et al. (2003) also add 'social influence' as a determinant of system acceptance, however the effect of this determinant only occurs in mandatory contexts. As both models seem to be aimed at creating a situation in which the DSS is accepted and used voluntarily this determinant seems to be of no value. Therefore it is reasonable that Riedel et al. (2011) leaves it out.

Overall, the model of Riedel et al. (2011) seems to be better fitted to guide the process of design and implementation of DSSs, whereas Venkatesh et al. (2003) provide a more static approach towards the identification of acceptance drivers.

7.1.3. Evaluation of a DSS pilot, the case of the Urban Decision Room Heijsehaven

The urban decision room (UDR) is developed for the redevelopment of the Heijsehaven area in Rotterdam, The Netherlands. It is meant to support decision-making by finding an optimal common solution space for the stakeholders involved in the area development process. The evaluation results from this tool can be valuable for the development of the PAS and DSSs in general (Van Loon et al., 2008, p. 65).

The interactive part of the system is evaluated positively, especially the way in which it helps to communicate and provide insight in common grounds and areas of disagreement in order to facilitate discussion. However, participants do not think that generating final decisions with the tool is feasible. They mainly envision a potential role for the tool in the early phases of a project. A major drawback of the system is the equal treatment of all stakeholders in the model and the fact that all input data is shared with all stakeholders, regardless of its sensitivity. The participants indicate that this does not well represent the real power relations and that the presentation of possible confidential information should change in order to increase the usefulness of the model. Finally an important question to be answered is whether the real decision makers want to negotiate on the basis of such a system (Van Loon et al., 2008, pp. 65-66).

Van Loon et al. (2008) show that in the implementation process of a tool like the UDR, the social context in which it has to be used should be taken into account (Van Loon et al., 2008, p. 71). They clarified this by means of the triangle of content, process and communication (CPC) (see figure 23). The triangle provides insights in the requirements to the development of new support systems. On the content aspect, the authors indicate that consultation of the user and regular calibration of the variables in the new system requires attention. The process aspect points at the importance of a clear system goal to improve the efficiency of stakeholder interaction. Also the authors point at the importance of being able to change the initial preference values through communication, when new insights in the consequences of these are gained in test runs (Van Loon et al., 2008, pp. 72-73).

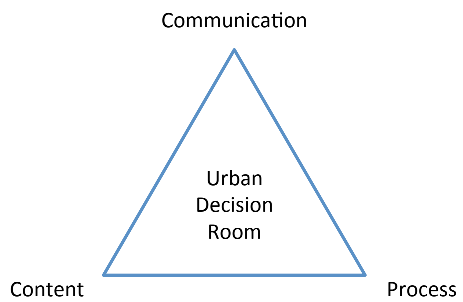


Figure 23 – CPC diagram (Van Loon et al., 2008, p. 72)

7.1.4. Conclusions

According to the definition of a DSS, both the PAS procedure with and without the algorithm can be depicted as a decision-oriented DSS that assists specifically in generating design alternatives and selecting the relevant options. In order to avoid system rejection, the DSS should reflect the human perspectives on the decision-making process. Therefore the development should take place in an iterative process between the DSS builder and the user. This is supported by multiple software design theories.

The concepts of user participation and involvement that follow from the literature, provide a basic framework to increase system acceptance. In combination with concepts derived from cybernetics theory, they help to increase perceived usefulness (PU) and perceived ease of use (PEOU), which stem from the TAM, through the system's characteristics. Eventually the PU and PEOU are the main determinants for system acceptance. Moreover, as participation and involvement increase the perceived control, an additional positive influence is imposed to system acceptance.

The most important conclusion from the conceptual model by Riedel et al. (2011) is that stakeholder participation and involvement is a key element in the process of achieving system acceptance. A high level of participation increases perceived control, which positively influences the level of perceived usefulness of the system in the first place, but also directly influences system acceptance positively. Moreover, participation is a central variable in the dynamic feedback loop that connects it to system complexity and satisfaction. In this loop, the system's complexity, influenced by the stakeholders, both has a direct positive influence on satisfaction as well as indirect, through perceived usefulness. However, too much complexity leads to a decrease in satisfaction. This induces a reduction in participation in order to decrease the complexity. The importance of participation and involvement is also confirmed in the evaluation of the UDR tool.

In the cases where a DSS is required, the system is too complex to fully understand, which causes the need for reliance on the system. In order to rely on the system, the user has to trust the system regarding the tasks it performs on his or her behalf. This trust is positively influenced by the performance of the system, i.e. the extent to which it meets the expectations. Variability in this performance decreases system trust. When the backside of the model can be understood and seems able to perform the task, users tend to have a more positive attitude towards the system. Hereby both trust and system use, are positively influenced. Moreover, as trust is made operational as the expectations of the tasks the system will perform, the following conclusion can be drawn from the trust model; when expectations and performance of the system are equal, and the system performs consistently, users will put trust in the system.

Therefore, the following relationship can be established between the model on acceptance and the model on trust. Trust can be influenced through user involvement in the design and development process, as this could bring in accordance the expectations and the system characteristics. Therefore, to increase trust, participation should be a central element.

A limitation of these findings is that the case studies performed by Riedel et al. (2011) comprised of projects involving advanced planning systems in an industrial setting. This is not the same as designing portfolio alternatives with the PAS. However, because the process of system development and implementation can be described in most cases by the same determinants (Riedel et al., 2011), it seems reasonable to induce these results and apply them in the context of this research into the development and test of the improved PAS.

The table below provides a checklist that can be used during the modelling of a DSS in order to evaluate both the process and the system itself. The left column shows whether the characteristic is related to the process (P) or the system (S), the next column presents the most important characteristics as they are found in the literature study. The following column describes for which of the evaluation criteria by (Joldersma & Roelofs, 2004) the characteristic is an indicator. This match was made by matching the category descriptions to the characteristics concepts from literature. The right column presents the resulting effect that is expected to be sorted in case of a positive evaluation of the characteristics.

Process (p)/ system (s)	Characteristic	Evaluation category (Joldersma & Roelofs, 2004)	Resulting effect (Riedel et al., 2011)
P	Participation & involvement of users (Riedel et al., 2011); user consultation (Van Loon et al., 2008)	Experience	System acceptance
P	Stakeholder interaction (Van Loon et al., 2008)	Experience	System acceptance
P	Iterative system development (Van Loon et al., 2008)	Experience	System acceptance
P	Perceived control (Riedel et al., 2011)	Attractiveness	System acceptance
P	Familiarise with backside of the system (Riedel et al., 2011)	Experience	Trust in the system
P	Clear system goal (Van Loon et al., 2008)	Effectiveness	System acceptance
S	Complexity (Riedel et al., 2011)	Attractiveness	System acceptance
S	Calibrated variables (Van Loon et al., 2008)	Attractiveness	Trust in the system
S	Perceived usefulness (Riedel et al., 2011)	Attractiveness	System acceptance
S	Purpose (Riedel et al., 2011)	Attractiveness	Trust in the system
S	Perceived ease of use (Riedel et al., 2011)	Attractiveness	System acceptance
S	Performance reliability (Riedel et al., 2011)	Effectiveness	Trust in the system
S	Justification of outcome (Riedel et al., 2011)	Attractiveness/ Effectiveness	Trust in the system

Table 4 – Checklist for evaluating DSSs and their development process

7.2. Interview results

This paragraph discusses the results of an interview with Monique Arkesteijn, who played a central role in previous pilots with the PAS. The interview was aimed at discovering similarities between the findings from the literature study into the determinants of successful implementation of DSSs and the elements that were already implemented in previous PAS pilots.

General
Monique is the project leader of the PAS research project. This means that she is responsible for the requirements to e.g. model interfaces, workshops and interviews. In the different pilots, she worked with multiple system engineers that performed the mathematical modelling.

Lack of trust
During the pilots, there were three issues with a lack of acceptance of the outcomes or with a lack of trust in the system.

In one case, one of the stakeholders was rather sceptical towards the procedure as a whole, because he could not imagine how to solve the issue in such a way. However, after the first workshop his perception had totally changed and he was very enthusiastic about it. So this shows that working with the model in a workshop helped to prove its potential. Another issue was that one of the stakeholders indicated in the evaluation interview, that he was very satisfied with the results of the pilot, which increased his trust in the system. However, in case he would not be satisfied, he would express his doubts about the system or he might try to act strategically to obtain a more satisfying result. The third issue involved the final decision-maker in one of the pilots, who indicated that they might not always appreciate the transparency that a system like the PAS provides.

The first issue solved itself by the way in which the PAS works, for the second actually holds the same. Where it should be noted that such issues can be avoided by making sure the model closely reflects the stakeholders' preferences. However, the stakeholder weights play quite a big role here, so they should be very clear and accepted amongst the stakeholders. Unfortunately, the third issue cannot be solved otherwise than to discard the use of the PAS in cases where transparency is not appreciated.

Comparison of checklist elements
The interview revealed that most of the elements found in literature, are applied in the previous pilots with the PAS. The details are discussed below.

- **Participation & involvement** of stakeholders is included explicitly through the iterations made with the interviews and workshops.
- **Stakeholder interaction** is also high, through the workshops that are part of the process.
- **Iterative system development** is included in the PAS by means of the workshops that are used to allow the stakeholders to gain insight in the model and to improve it. The model can be improved in two ways:
    - One is because the stakeholders change the preference curves, based on a workshop.
    - The other is a more fundamental change in the model that is induced by the addition of new criteria or radical change of current criteria. In such occasions, the backside of the model has to be changed more drastically because also the interventions change.

  In previous pilots with similar tools like the UDR, there was only one workshop. However, because of the need to closely reflect the actual decision-making process, iteration is required. Therefore the minimum number of workshops in the PAS pilots is increased to two with a minimum of three interviews. However, even more workshops might be required in a case where the results will actually be implemented.
- **Perceived control** can be seen in two ways in the PAS pilots.
    - For the model input in terms of criteria and preference functions, the perceived control was 100%, because the stakeholders could determine and alter this information as they liked
    - The perceived control over the interventions that could be made in the portfolio, might have been lower. These interventions had not been defined by the stakeholders themselves, but by the researchers and the real estate department. However, the stakeholders did not indicate in any way that they were not satisfied with it.
- **Familiarise with the backside of the system** was not done by showing the stakeholders the model code, but was done, on the one hand, by presenting them the interventions together with all the effects they would sort in the object characteristics when applied (e.g. change in m^2, costs etc.). The stakeholders also received a logbook with the changes previously made to the objects in the model, as

well as the results of previous workshops and the transcripts of evaluation interviews. On the other hand, during the workshops, the stakeholders sat around a computer with a systems engineer to design alternatives in the model. However due to the complexity of the interface, the stakeholders were not able to operate the model themselves, instead the systems engineer did this. Also, the researchers decided not to provide them with the model, hence they were not able to further familiarise themselves with the model, outside of the workshops.

- The **system goal** was made clear from the beginning of the project and was repeated every meeting.
- The **complexity of the model** is interpreted as the extent to which the model reflects the actual decision-making process. In the first pilot, the model accurately reflected the actual process. However in the second pilot, the model was much more complex, but reflected the actual process less well. However, according to the stakeholders the process was much more like the ideal process to make the decisions at hand. So it actually provided an improvement of the process.
- The **calibration of variables** was achieved through the workshops. In the first interview, the stakeholders were only able to provide an estimation of their preference curve for each variable. After the first workshop they could calibrate their variables, because they had seen what the effects of their preference curves were. Also during the workshops they could see the variables of other stakeholders and were able to compare those with their own, which enabled them to incorporate alternative visions in their variables as well.
- The **perceived usefulness** of the model was quite high overall. Some of the stakeholders indicated that they were very happy about the tool, because it makes it easier to have a more to the point discussion about their preferences. Also these stakeholders indicated that, with the PAS, the entire process of problem definition and solution finding takes less time than the original process. However, there was also one stakeholder that indicated that the process took much more time, but he compared the entire process to the fact that in the past he only had to provide input in a single interview.
- The **purpose** of the models in the pilots was specific to each case, which requires a specific model. The models were built by means of the PAS procedure, which is a generic procedure. However this procedure results in a model that fits its intended purpose.
- The **perceived ease of use** of the models was not explicitly evaluated in the previous pilots. However, observations showed that the first workshop was found more complicated than the second. Also this depended on the case.
- **Reliability** of the system performance was not so much an issue as there were no optimisation runs made in the previous pilots. An issue related to this was the way in which certain variable values are calculated. If this is simplified for a variable that is found very important, it distorts the outcomes. Therefore such formulations could be called unreliable and the simplification should be removed where possible.
- **Justification of outcomes** is mainly taken care of in the model environment, where the stakeholders could keep track of the portfolio alternative ratings on each of their criteria. They could also see on which criteria they still could make easy progress, by showing the variables of all stakeholders with their values and preference rating in the design screen. In general, however, the designed interventions should provide sufficient justification of the resulting preference score of the portfolio alternative.

Reflection on previous pilots

Monique indicates that the element of "*familiarise with the backside of the system*" was only included through the presentation of the effects of the interventions on the object characteristics. Moreover, the stakeholders did not directly operate the model themselves, but this was done through the systems engineer. However, she does not know whether this was really sufficient. In new pilots, the assumptions in the interventions should be made clear in the modelling environment. Ideally, also the model interface should enable the stakeholders to really operate the model themselves and even work with it at home. Another improvement to be made in the model interface should be to enable the comparison of object preference scores and characteristics among one another.

Based on the previous pilots, Monique depicts the *"iterative system development"* as one of the most important elements. However, as this is closely related to *"participation & involvement"* and *"stakeholder interaction"*, she sees them as one important element. Moreover, when implemented properly, these elements result in *"calibrated variables"*. A second important element is the *"perceived ease of use (PEOU)"*, because if this is low, people will not use the system. Also, she indicates that *"performance reliability"* is very important.

Conclusion
A general conclusion is that the PAS, as it was used in the previous pilots, performs quite well in terms of creating trust in the system and acceptance of the outcomes. Also it is capable of changing the mind of sceptics. This was mostly achieved by making sure that the model closely reflects the stakeholders' preferences, something that is inherently incorporated in the PAS. Nevertheless, a requirement is that all stakeholders involved appreciate a transparent decision-making process.

The interview showed that all elements from the checklist are already included to a certain extent in previous pilots with the PAS. However, three things should be noted. One of the important aspects, "*familiarise with the backside of the system*", could be improved by presenting the assumptions in the modelling environment and by making improvements to the interface to enable the stakeholders to operate the model themselves. This might be achieved through the building of a simplified model or an info-graphic, to show the process that happens on the backside. The *"perceived ease of use (PEOU)"*, another important aspect, was not evaluated explicitly in the previous pilots. Because it is deemed important, it should be evaluated more explicitly, this is a point of improvement in the evaluation interviews. Finally, in the previous pilots, the interventions that are applied by the stakeholders provide justification of the result. However in the improved PAS, where the search algorithm will yield a final result, the justification by means of a subdivision in the individual criteria ratings seems to be appropriate.

7.3. Conclusions

This conclusion briefly summarises the main findings from this literature study chapter on the successful implementation of DSSs. This is combined with the results from a comparative interview with Monique Arkesteijn regarding the implementation of the theoretical findings in previous pilots with the PAS.

The chapter presents a model comprising of multiple determinants for successful implementation of a DSS. This model points in the direction of participation and involvement of users as a central element to develop a DSS that represents the decision-making process best. This increases the model complexity, i.e. the representation of the actual decision-making process, which increases the perceived usefulness and creates acceptance and satisfaction. The model by Riedel et al. (2011) is supported by findings regarding the users' trust in a system, because this can be increased by bringing the stakeholder expectations in accordance with the system performance, through stakeholder participation and involvement.

These findings are in accordance with the evaluation of the UDR tool and the main findings in the literature study regarding the development of the PAS procedure (see chapter 3). This study finds that the current iterative process of self-design, used in the

PAS, helps the users to become familiar with the model and improve its representation of their preferences. This increases the acceptance of the outcomes and trust in the system.

The elements depicted as determinants of successful DSS implementation, are summarised in a table that could be used as a checklist to evaluate the process and system before, during, or after DSS development (see paragraph 7.1.4) An interview with Monique Arkesteijn, who is the project leader of the PAS research project, showed that all those elements were more or less taken into account during previous pilots studies with the PAS.

8. Matlab modelling exercise

This chapter presents the conclusions and recommendations from the first steps in building a model of the PAS in Matlab. This mathematical calculation tool enables a model based on interrelated functions, which makes it easy to add objects and alternatives. It is used because the search algorithm is written in Matlab. This modelling exercise is undertaken to practice the writing of such models in Matlab in order to achieve a basic programming proficiency to be used in the pilot study in this project. Both in this exercise and in the pilot study, Rein de Graaf assists in the complex modelling parts as a modelling expert. The chapter starts with a brief problem description and the model requirements. A more elaborate case description, the structure of the model and the results are presented in appendix A. The conclusion presents the take away points from this modelling exercise.

8.1. Problem description

The problem description was based on a case from a previous pilot study with the PAS at Delft University of Technology (Arkesteijn et al., 2015; Valks et al., 2014), but it was strongly simplified for the sake of this experiment. The supply of lecture halls of the university does currently not meet the demand in terms of capacity and functionality.

The capacity of the lecture halls is not able to accommodate the demands and requirements of the teachers and the scheduling department. The discrepancy in size and the traveling time between lecture halls hampers the effectiveness of both students and teachers. Moreover, most lecture halls are rather dated in terms of their features, which hampers the learning process of the students. In order to facilitate the current education style, a plan should be made to improve the characteristics of the portfolio of lecture halls to the current standards.

The problem description is summarised in the table below, which shows a hypothetical set of objects (lecture halls) with a set of characteristics that was made up for this experiment. This is presented in a so-called Operations Research table that was adapted to this case. The criteria that are used to provide the imaginary portfolio with an overall preference rating are also partly made up. Because the table is meant to explain the principle, the data is not optimised in any way.

	Preference rating		*Number of objects:*		*Number of characteristics:*		
Current state:	61		5		3		
Future state:	70						
Portfolio alternatives:	5						
Object number:	#1	#2	#3	#4	#5	Total	*Characteristics:*
Example:	102	278	334	98	289	1.101	Capacity (# seats)
	1	0	0	1	0	2	Flexible (1/0)
	13.770	-	-	13.230	-	27.000	Costs (EUR)
	Variable value (calculated from alternative)						*Preference rating*
Criterion 01	Total capacity			1101			96
Criterion 02	Percentage flexible			40%			45
Criterion 03	Average capacity			220			80
Criterion 04	Total Costs			27000			60

Table 5 – Problem statement in OR table

8.2. Model requirements

The model requirements established in this experiment were the following; the model should be able to determine the preference rating per criterion for a set of potential future portfolio alternatives. It is able to present these preference ratings per demand criterion in order to show the decision maker how changes in the demand (i.e. the preference function) lead to a different preference rating of the supply and how a change in supply could accommodate the demand. It should also provide a weighted overall preference rating for each of the possible future supply states (i.e. the portfolio alternatives). These ratings should be provided in such a way that the user is able to visually compare them with each other and with the current supply rating.

8.3. Conclusions & recommendations

The exercise showed that it is possible to build a Matlab model of the type of problems that are approached with the PAS. The output of the model is the weighted average of the preference ratings of the defined decision variables. This is presented in such a way that the user can easily compare the preference ratings of the alternatives to that of the current portfolio. Also it was possible to make the model provide a justification of the outcomes when required, by providing the individual preference ratings for each variable. A test with the model proves that in a process of self-design an alternative can be found with a higher preference score than the current portfolio.

The case that was used in this exercise was, however, not very complex. It only existed of a small set of decision variables and no design constraints were imposed to the solution, nor were decision makers' weights included. The low complexity explains the large influence of the variable weights on the overall preference rating. Therefore it was quite easy to design alternatives that yield an improved preference rating. Although the expectation is that a real life case requires a larger set of variables, which requires taking account of more object characteristics, the concept of this modelling approach is proved.

Improvements could be made especially in the way in which the output is provided and the portfolio alternatives are designed. Currently this happened through loading excel spreadsheets with numbers. This was far from user friendly and also hampers the development of insight in the model by the stakeholders. A suggestion is to find a way to implement a script that provides an interactive input screen where the users can design portfolio alternatives by changing the object characteristics. Such interface should visualise the model output and hereby the portfolio design to some extent and should provide direct feedback in terms of overall preference rating. In Matlab it is possible to implement such scripts, they are called Graphical User Interface (GUI).

Furthermore, in order to use the model together with the search algorithm, a list of requirements is needed to connect these two elements. These requirements should be incorporated in the model structure.

9. Lessons for implementation

This chapter combines the conclusions from the previous chapters in this part of the report in order to integrate the implications of the findings in these chapters and to make explicit the lessons learned for the implementation process. Furthermore it provides an answer to the first sub-question.

The main findings from literature in chapter 7 constitute of a set of characteristics that are determinants for the successful implementation of a Decision Support System (DSS). A subset of these characteristics reflect key elements in the development process of such a tool, another subset is concerned with the system itself. The resulting checklist can be applied in two situations; the evaluation of the process and system after the implementation of the system, in order to identify possible improvements. The second application is to prepare a process of implementation of a DSS, by facilitating these elements.

In this research and design project both applications are used. Prior to the implementation, the checklist is used in the preparation of the process, in order to achieve system trust and acceptance during implementation. Both during and after the implementation, a set of evaluation interviews is held, based on the checklist. The interview with Monique Arkesteijn showed already that in the previous PAS pilots the most important elements to achieve system trust and acceptance, the stakeholder involvement and iterative development process, helped to increase the representation of the real decision-making process. Also the other elements were more-or-less included.

This brings us to the theoretical answer to the first sub-question; *what is theoretically the best way to implement the search algorithm in the PAS?* The most important element is that the users of the DSS should be involved in the development and implementation process, preferably from the start on. This participation creates system acceptance and brings into accordance the expectations of the system and the system characteristics. Together they help to improve trust and system use. As an important part of the involvement is embedded in the iterative self-design process in the PAS, the algorithm should be implemented in addition to this in order to achieve the best representation of the stakeholders' preferences. Therefore it should be applied to the model in step 6 of the PAS procedure. This conclusion confirms the second hypothesis in paragraph 2.4.

In practical terms this means that from the beginning of the process, the stakeholders should be informed about the goal of the process and the resulting model. This was done by means of several PowerPoint presentations with a visual description of the PAS, the process and each step taken, e.g. establishing preference functions. Also each model building interview and each session started with stating the goal of the model clearly. Moreover, just like in the previous pilots, the iterative model development process was used, with workshops where the stakeholders became acquainted with the model and evaluation interviews to improve the model and process.

The Matlab modelling exercise provided some additional practical lessons. In the first place, the output of the model should be presented more in relation to a visual representation of the portfolio that is being designed. Secondly, the interface for designing alternative portfolios should provide a more interactive input screen. This screen should enable the stakeholder to easily adapt the object characteristics and/or locations included and provide direct visual feedback of the impact on the portfolio and overall preference rating.

Part III – Model building & tests

10. Current decision-making process

In order to implement the PAS in practice, a company was sought that was willing to facilitate this research project. Oracle was found prepared to put time and effort into this pilot study. This chapter briefly introduces the company first and the case in the end. However, the core of this chapter is used to present the current real estate decision-making process used at Oracle, in order to be able to draw conclusions on possible improvements for their process, based on the pilot study with the PAS. All content in this chapter is based on an interview on corporate real estate (CRE) alignment held by Monique Arkesteijn and Lisa Kuijpers with Randy Smith, vice president Global Real Estate and Facilities at Oracle, and project meetings with Carol Leipner-Srebnick and Katie Davenport. The latter two are the mentors at Oracle and are in the position of respectively director Real Estate Advanced Planning and Global Location Strategy Programme manager within the Advanced Planning team.

10.1. Oracle

Oracle is a globally operating ICT company that provides its services in more than 145 countries. They provide hardware, software and data storage services to a range of industries, from education and banking to high tech engineering companies and the public sector. A lot of their work is in data storage for customers and the development and maintenance of software and applications. Also they do quite a lot of advisory work for their clients. Altogether, the company has more than 130.000 employees, spread over four global regions with total revenues of US$38.2 billion over 2015.

All those employees and data servers need accommodation and the portfolio should stay aligned with the business. This is taken care of by the Global Real Estate and Facilities department that is sub-divided in four so-called global shared service groups that provide support to the global regions. The one mostly oriented towards real estate strategy making and alignment to the business is the Advanced Planning (AP) Team that conducts so-called Global Location Studies in search of low-cost locations, i.e. cities or metropolitan areas that a Line of Business (LOB) could pick for e.g. centralisation or expansion. The real estate departments of the four global regions take care of the execution of the strategy, accompanying transactions and possible interventions.

Another service group that is responsible for strategy making is the Global Data Centre Planning Group. This group manages all Oracle's data storage facilities and optimises their use and specifications. Also based on the data they acquire, they try to align the demand and supply of these facilities with the IT activities of the company. The Global Real Estate Operations Group focuses on the portfolio administration, corporate communication and website. The last shared service group is responsible for the internal audit of Oracle and is called the Process Controls Office.

10.2. Current process

In general Oracle's real estate organisation maintains close ties with the business, with the result that LOBs contact the organisation in case they want to make considerable changes in their portfolio. This improves the control over the execution of a high-level real estate strategy. The alignment between the real estate and the business is maintained by monitoring a lot of object characteristics, the resulting data is made insightful in a dashboard environment and is reported monthly. In addition to these reports, the organisation keeps track of the effects of planned interventions on the portfolio in a so-called Plan of Records that shows the development of the portfolio over time. This tool is used to evaluate the decisions and provide insight in when they will influence the portfolio data. Suggestions for improving the alignment are made if necessary.

The AP team conducts roughly two types of studies; the low cost location studies per global region and LOB specific studies upon request of a specific LOB. LOBs ask the AP team to view the results of a low cost study in their region and pick a location after having had the possibility to adapt the weights that were initially assigned to the criteria. In this way, the AP team keeps track of the alignment of the LOBs with the study outcomes. Sometimes, the presentation of a low cost study results in an additional study for the specific LOB, often because they search for a different location with other criteria.

In addition to the studies, the real estate department works with a mission statement that is shared among the regional real estate departments to be used in their daily activities. Furthermore certain targets are connected to the data that is monitored, which can be used to decide upon interventions to improve the alignment.

Low cost location studies

The low cost location studies are conducted by the AP team in collaboration with seven internal partners, for instance the departments for HR, IT, Tax and legal. Over the past decade, together they developed a weighted scorecard with a set of location assessment criteria. The scorecard covers criteria like political stability, labour market circumstances and tax conditions. Also the costs of hiring employees are collected for each location.

The location data for each criterion is partly found in external sources and partly from internal business information. This data is translated into a 1-5 rating with 5 being the best. This is initially done by the AP team and then reviewed with the respective partners. Once the locations are rated, the sites with the ratings obtained in the scorecard are plotted against the costs in order to find the location with the lowest costs relative to the rating.

The executive of the LOB makes the final decision for a location and decides upon the exact object to move into, based on the process with the AP team and the regional real estate team.

LOB specific studies

The LOB specific studies are conducted upon request. These studies differ from the low cost studies on a number of aspects. Mostly, these studies are not meant to find the cheapest location, but a location with specific characteristics. This means that the set of criteria and their weightings differs from the low cost studies and is more tailored towards the requirements of the specific LOB. They start often with a general aim for a location, as was the case in the study that is used in this research and design project. This case is used below, to illustrate how such a study could work.

Based on the general aim expressed by the specific LOB, the AP team identified a large set of potential locations in the region where the LOB is based. This selection was narrowed down to a set of locations in countries where Oracle already had an existing sales presence. This was perceived as a positive attribute of a location because it improves possibilities for promotions and enables sharing services. Also the project team from the LOB provided input in narrowing down the number of potential locations. This process resulted in a selection of 26 potential locations and 6 current locations assessed in the scorecard.

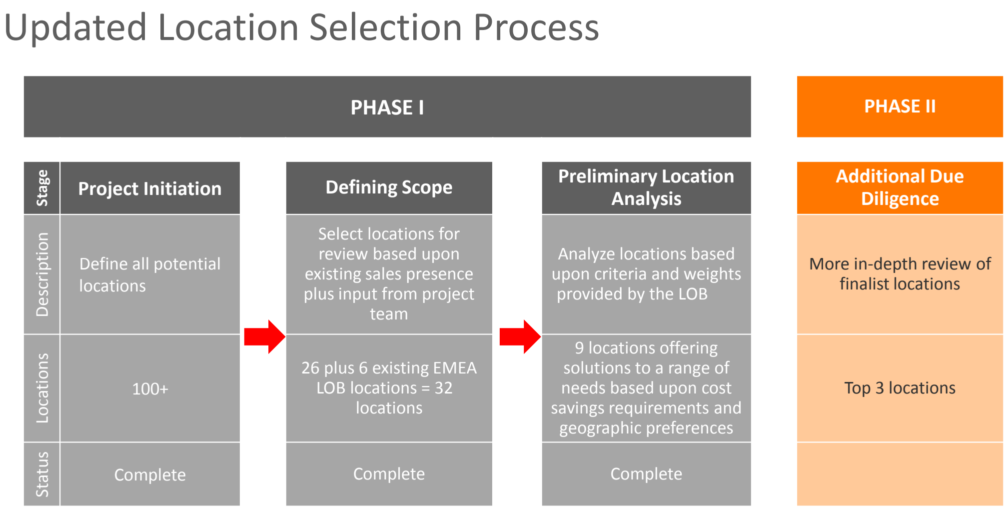


Figure 24 – The process followed in the study[3]

Based on the request made by the LOB, the AP team established a set of criteria making use of external sources. In this case the AP team defined 39 criteria including some cost criteria, all criteria were confirmed by the representative of the LOB who also assigned the weights to the criteria. The AP team then proceeded with searching for the required data for each criterion and assigned the arrays covered by the 1-5 scale, just like in the low cost studies. The arrays were checked globally by the LOB, however they mostly relied on the assessment of the AP team. After the rating was established, the locations were rated based on the data and the weighted average rating was calculated. The representative of the AP team indicated however, that it was rather complex for the stakeholders to determine the appropriate weights for the criteria.

After the outcome of the scorecard was known, a selection of the nine best-rated locations (current locations excluded) was assessed in more detail on an additional set of qualitative aspects. This resulted in a set of strengths and weakness per location that was used to make the recommendation for a final selection of three location alternatives. Based on this selection, the final decision for a new location was made by the representative from the LOB.

[3] Davenport, K. (2015). Presentation: location assessment LOB 1 final phase. Boston, MA: Oracle Real Estate and Facilities, Advanced Planning.

10.3. The case

The case used in this research and design project consists of an LOB specific location study, conducted by the AP team. The original study started upon the request of LOB 1 to propose up to three locations for a new hub in the global region covering Europe, Middle-East and Africa (EMEA). LOB 1 is expecting to grow considerably in the coming years, which means that the current portfolio is not able to accommodate the increasing number of employees. The new hub should be operational in 2018.

The general aim of the new hub is to attract millennials, a generation of people that is born around the time of the millennium, i.e. the year 2000, and is grow up with computers, smartphones and the internet. The main criterion for the location is the attractiveness for native English speakers, in addition to this, costs should be taken into account as a less influential criterion.

Based on the request by LOB 1, the AP team previously established a set of criteria, making use of a report[3] that presents a set of indicators that are found to attract millennials to cities (see figure 25). These criteria are confirmed by the representative of LOB 1 and cover multiple perspectives from within the business line. So effectively only one stakeholder is involved that brought in criteria. In addition to the representative, whom was closely involved in the original study, there are two stakeholders from the AP team involved. The process of establishing the criteria and selecting locations was presented in the previous paragraph.

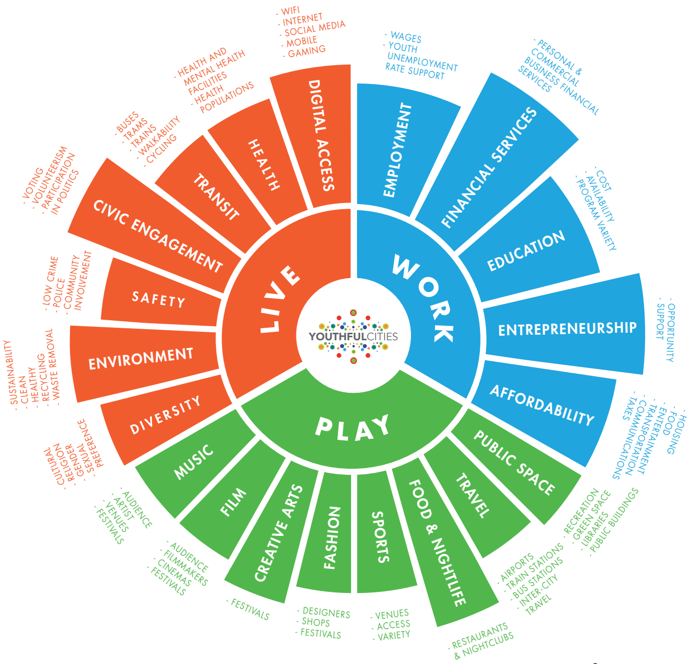


Figure 25 – Indicators for attracting millennials[4]

[4] Youthful-Cities. (2015). Youthful cities global index 2015: ranking the world's 55 most youthful cities. Toronto: Youthful Cities.

The case consists of 26 alternative locations and 6 current locations that are included as benchmarks. The original scorecard comprised of 39 criteria that are sorted in 5 categories that are connected to a weighing. The scorecard takes the average of the criteria ratings in each category to calculate the category rating. The weighted average of those five category ratings provides the overall rating for each location. However, to make the case better to handle and because multiple criteria cover the same aspects, a selection of 22 criteria is made for this pilot study. This selection is made in such a way that for all five categories a representative set of criteria remains (see table 6).

Categories of interest
Costs
Ease of sourcing native speakers & millennials
Labour environment
Fit to LOB 1 EMEA vision and value proposition
Government support

Table 6 – Categories covered by the criteria

The data that is used in this case comes from different sources, both internal and external to Oracle. It comprises of roughly three types. The first type is the hard quantitative data e.g. annual costs, the second data category is that of indices e.g. CPI and the third type is data presented in ratings.

The data in the latter category is gathered by asking for preferences on a 1-7 scale. From the perspective of the preference measurement paradigm presented in chapter 5, the data in this category is based on a scale with a false basis and is therefore meaningless. In order to correct this issue, the entire study would have to be reproduced in a correct way, however that is beyond the time budget and scope of this graduation project. Therefore, in the project this data is interpreted as a physical location value and rated by means of stakeholder's preference curves. This is not a perfect solution, but it is deemed to be the best possible way to cope with the issue.

Regardless of the outcomes of the scorecard and the in-depth qualitative analysis, the team from LOB 1 choose for a different location that was not even in the top-10 best-rated locations in the scorecard. Therefore, this second opinion on the study aims for a better representation of the LOB's preferences to reach an outcome that is closer to the location chosen. Furthermore, because of the lack of a real design element in the original study, the design element implemented in this case is the design of the optimum portfolio for LOB 1 in EMEA. This should happen based on selecting a portfolio of locations from the current and alternative locations included in the study.

10.4. Conclusions

When looking at the current process, Oracle already has a system that keeps the AP team close to the regional real estate teams and the internal users, the LOB's. In combination with their location data information system, they are able to manage the real estate portfolio quite directly based on where the business moves as a whole.

The scorecard process is quite an advanced system to make well-funded decisions in a transparent process. The way it is structured makes it possible to communicate the outcomes easily to the LOB's. The fact that specialists in each specific field determine the criteria for the low cost location studies, makes it possible to control the value and continuous quality of the outcomes for each global region. This process also maintains the connection between the requirements from the business and the characteristics of the real estate locations. Also the way in which the influence of the LOB's is arranged, keeps the AP team in control of the alignment.

When looking at the data rating system from the perspective of the preference measurement paradigm in chapter 5, this is not a correct way to do it. What is used here is a ratio scale that is based on a false model.

The case that is used in this pilot study is already defined in terms of a set of criteria and the data is already available. This means that step one of the PAS procedure already has been completed. Since there is only one representative for the LOB involved, whom confirmed their inclusive set of criteria, stakeholder weights are not relevant. The solution for the problematic data from the original study is that it will be interpreted as physical location values, because replicating this data correctly is beyond the scope and time budget of this study.

Finally, because the pilot study should provide a second opinion on the original study, there are some requirements to the output of the model. Next to the overall portfolio rating, the model should also present the individual overall location preference ratings.

11. Writing the model in Matlab

The modelling process and the model structure are based on the structure of the data that is to be used, the availability of data and the purpose and requirements of the model. The modelling expert, Rein de Graaf helped to assess the suitability of the model basis. In this chapter, after the presentation of the model requirements, the modelling process and resulting model structure are discussed. The aim of the chapter is to provide insight in the model and following this, discuss whether or not it meets the requirements established to fulfil the task in order to be able to answer the second sub-question in the end of this part. This is shown in the elaborated conceptual model in the figure below.

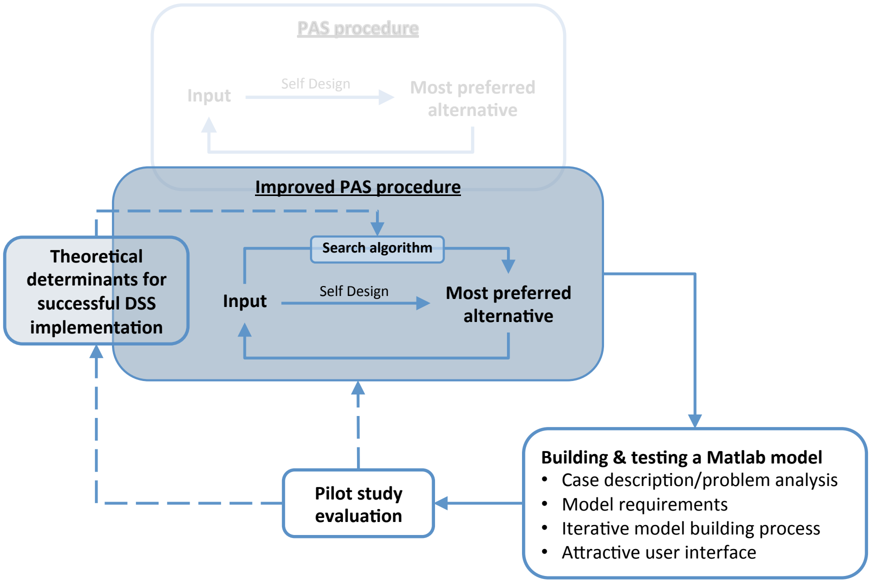


Figure 26 – Conceptual model with elaborated model building (own illustration)

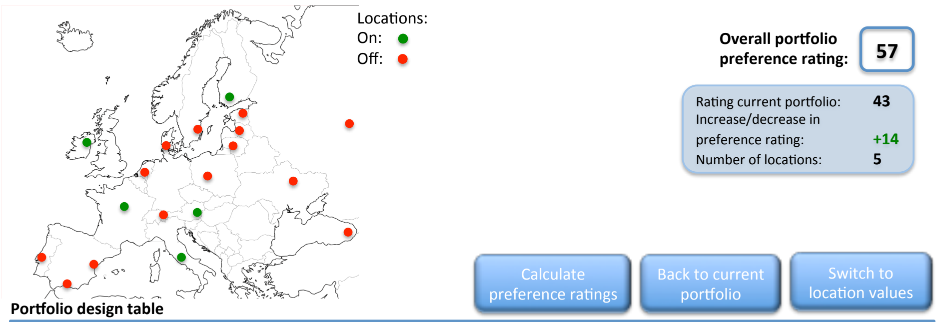
11.1. Model requirements

The model requirements are based on the case description in chapter 10. Following this description, the model should at least be able to calculate the preference rating per criterion for each of the locations and combine this into a set of overall weighted preference ratings per location. The calculation should be made based on a set of preference curves and criteria- and stakeholder weights combined with the location data. This minimum requirement enables the construction of the same ranking as has been done in the original study, by which these outcomes can be compared. Furthermore, it is able to present the location ratings on each criterion in such a way that the stakeholders can use this to determine whether changes in preference curves or the weighing of criteria are required. It might even well be that changes in the criteria set are necessary. In addition to this, the model should be able to calculate an overall weighted preference rating for each portfolio alternative designed by the stakeholders. In this calculation, the preference ratings per criterion should be based on the average physical value of the locations selected. These criterion ratings are used to calculate the weighted preference rating.

However, both calculations of the overall weighted preference rating are problematic according to the preference measurement paradigm presented in chapter 5, because also when measured correctly, operations of addition and multiplication are not allowed on preferences. Therefore the exact rating of the optimum portfolio solution was obtained from the search algorithm that uses a correct, but unknown procedure to arrive at the correct preference rating. As noted in chapter 5, this basic procedure is available in Tetra, which is used in the relatively simple problem of obtaining the correct ranking of locations and to obtain the correct overall rating for the optimum portfolio found through self-design by the stakeholders.

However, because the application of Tetra takes time, the model presents the overall weighted preference rating per location and the preference rating per portfolio alternative. This rating provides a close estimate of the actual value and is used by the stakeholders to evaluate to what extent the model reflects their preferences. Also it should be able to work with a set of design constraints to determine whether certain portfolio alternatives are possible or not.

The model should make use of an interactive design interface where the stakeholders can design portfolio alternatives. The best way in Matlab to do this is to make use of a Graphical User Interface (GUI) plugin. Such a design interface should provide, in addition to the requirements before, a simple way to design portfolio alternatives, by selecting and deselecting locations. Moreover it should be able to get back easily to the current portfolio, to start all over. The GUI has to present a visual representation of the portfolio, preferably on a map that shows the locations selected and not selected in the design. Also it should feature the overall weighted preference rating of the portfolio design that is made, the preference rating for the current portfolio and the difference between these ratings. To provide the users with sufficient information, the GUI should provide insight in the physical values and ratings per location per criterion. The GUI should look somewhat like presented in the figure below.



Portfolio design table

Criteria:		Criterion 01	Criterion 02	Criterion 03	Criterion 04	Criterion 05	[...]	[...]	[...]	[...]	[...]	Criterion 22	
Criterion weight:		35%	15%	23%	12%	5%	-	-	-	-	-	-	*Overall weighted portfolio rating:*
Stakeholder weight:		25%		75%									
Portfolio rating per criterion (based on average loc. values):		64	39	83	51	69	-	-	-	-	-	-	57
Location code:	Portfolio design:	Location ratings:											*Overall weighted location rating:*
A	1	57	43	98	50	76	-	-	-	-	-	-	52
B	0	-	-	-	-	-	-	-	-	-	-	-	-
C	0	-	-	-	-	-	-	-	-	-	-	-	-
D	1	94	28	13	56	45	-	-	-	-	-	-	66
[...]													

Figure 27 – Initial GUI design (own illustration)

The model requirements are summarised in the tables below, which might partly be used as an element in the GUI. The tables are based on hypothetical locations and criteria. The first table shows the requirement of calculating the preference ratings per location, the second table shows the calculation of the overall preference rating for a portfolio alternative.

	Preference rating			Number of locations:					
Current portfolio:	39			32					
Future portfolio:	55								
Criteria:		Criterion 01	Criterion 02	Criterion 03	Criterion 04	Criterion 05	[...]	Criterion 22	
Criterion weight:		35%	15%	23%	12%	5%			
Stakeholder weight:		25%			75%				
Location code:		**Location ratings:**							***Overall weighted location rating:***
A		57	43	98	50	76	-	-	**59**
B		36	12	40	87	36	-	-	**36**
C		54	87	46	39	72	-	-	**51**
D		94	28	13	56	45	-	-	**49**
[...]							-	-	

Table 7 – Problem statement, individual location ratings, in OR table

	Preference rating		Number of locations:			Interventions:			
Current portfolio:	39		32			**Code:**		1	Use in design
Future portfolio:	55							0	Not use in design
Criteria:	**Example portfolio design:**	Criterion 01	Criterion 02	Criterion 03	Criterion 04	Criterion 05	[...]	Criterion 22	
Criterion weight:		35%	15%	23%	12%	5%			***Overall weighted portfolio rating:***
Stakeholder weight:		25%			75%				
Portfolio rating per criterion (av. value):		64	39	83	32	79			**55**
Location code:	**Average value:**	71.065	0,42	16,9	40,5	35			
A	1	76.300	0,60	12,0	33	6	-	-	
B	0	-	-	-	-	-	-	-	
C	0	-	-	-	-	-	-	-	
D	1	65.830	0,24	21,8	48	64	-	-	
[...]							-	-	

Table 8 – Problem statement, overall portfolio rating, in OR table

11.2. Modelling process

The modelling process started with set of interviews to compile the client statement. These interviews were used to go through the first four steps of the PAS procedure, as indicated in chapter 2. However, as the criteria already had been established in the original study, the first interviews focus on establishing preference curves and criteria weights. Also design constraints were discussed in the interviews. In this paragraph the content and the process of these interviews is briefly described. After this, the paragraph describes the process of building the Matlab model.

11.2.1. Compiling the client statement

All interviews started with a brief explanation of the model goal and the research goal. This was followed by a visual introduction of the process of establishing the preference curves and how they are used by the model. This is shown in figure 28.

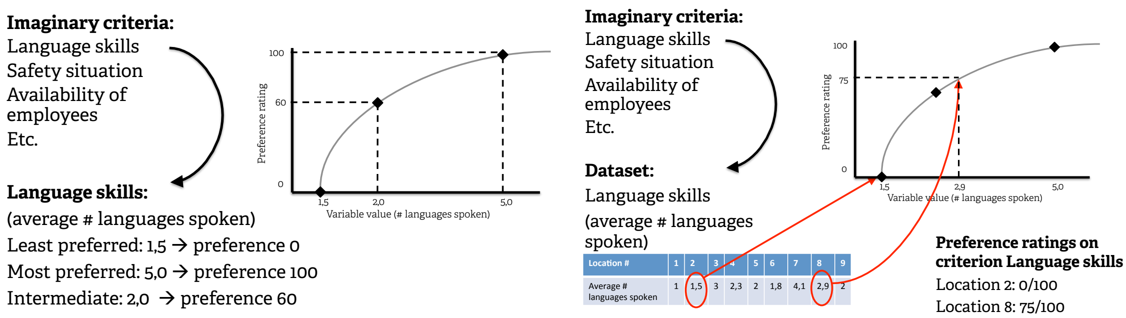


Figure 28 – Establishing preference curves and their use (own illustration)

Establishing the curves for all 22 criteria took three interviews, with a total of 2,5-3 hours. As the representative of the LOB had a strict time budget, a selection of criteria was made that were deemed most important to the business. Most of these criteria were based on hard data, which was most easily to interpret by the business line representative. Katie Davenport established the other curves. As the interviews were held via a conference call connection, the systems engineer shared his screen with the interviewee. Two documents were used, one excel file with all the data clearly presented, the other with predefined graphs where the curves were generated based on the input by the stakeholder. The latter file provided direct visual feedback to the interviewee with regards to the shape of the curve. This is shown in the figure below.

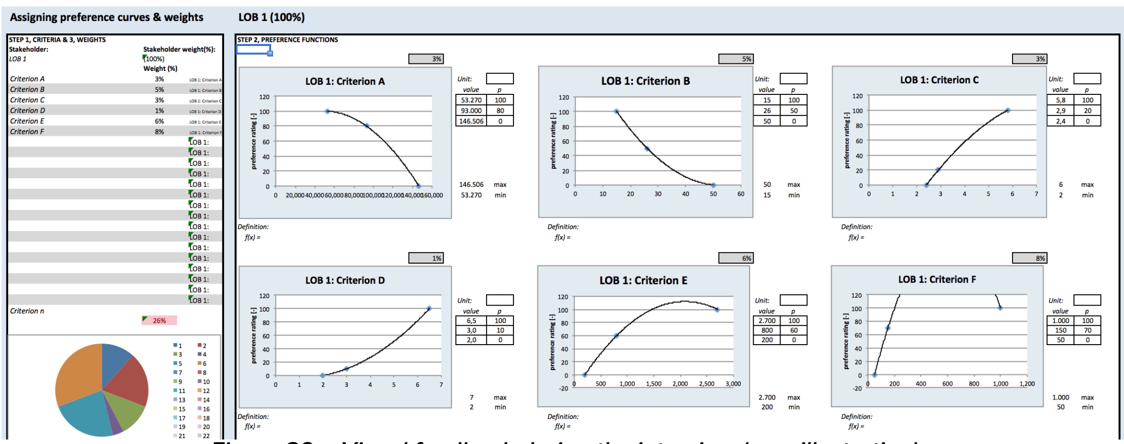


Figure 29 – Visual feedback during the interview (own illustration)

After these interviews, the curves were sent to the LOB 1 representative together with the data file in order to be adapted and/or confirmed. Also because of the time constraint in the interview, the criteria weights still had to be established. The document was received back in a week with the design constraints.

The data that was available differed slightly per criterion. For some criteria, the data was available for a set of cities and/or countries all around the globe, for other criteria there was just the data for the 32 locations. This mostly concerned in-house data, e.g. current FTE presence in a country that was gathered specifically for this process and therefore only for the locations to be assessed. The result of this is that for some criteria the preference curve only ranges roughly from the lowest to the highest location value in the locations involved in the study and for others the range is based on a broader view.

11.2.2. Building the Matlab model

The modelling process started by discovering the structure of the data available. As shown in chapter 10 and the beginning of this paragraph, the stakeholder already defined the criteria and the location data was already available per criterion. In order to be able to import this data into the model in the simplest way, the model structure was suited to use this data. Also, the model code that processes the data had to match the data structure.

The discovery of the datasets showed that for some locations, the data on a certain criterion was missing. When leaving these particular values at 0, the resulting preference rating for that location would be distorted. In order to fill these gaps, an appropriate value was determined, based on data for other locations in the same country. If this was not available, logic reasoning was used to arrive at a number. This was made explicit in the data file, so the stakeholders could approve it.

Parallel to the model building interviews, an initial model was built to determine the appropriate model structure. The first attempt closely followed the original data structure and was able to reproduce the overall preference ratings per location, one of the requirements stated previously. Some help from the modelling expert was used in this process.

Before continuing with more detailed explanations of the model, a brief clarification of terminology is required. The model makes use of functions. These functions are sets of mathematical operations based on varying input. These functions are stored in files that are called scripts. In addition to functions, there are “normal” scripts, stored in the same file extension that, contrarily to functions, only make use of fixed variable files that are stored in the model. Those variable files are sets of data stored in matrices in the model, e.g. with location data, preference data or criteria weights.

The first iteration with Rein de Graaf resulted in the confirmation of the basic model structure and a set of improvements. Based on the entire set of locations, the model calculates the overall weighted preference ratings for all locations. These are used to rank the locations and to compare this to the outcome of the original study. However, as these ratings cannot be used to calculate the overall portfolio rating, an additional calculation should be included. This calculation is based on one basic variable that is used to define the portfolio alternatives and provides the input for the other functions. Furthermore, the calculation uses the average physical value over the locations in the portfolio design to calculate the preference rating on each criterion. These ratings are then used to calculate the overall weighted preference rating for the portfolio alternative.

In this meeting the components and structure of an initial GUI design were also discussed. This GUI presents the elements discussed above and enables the design of portfolio alternatives by switching the locations on and off. Also it was concluded that it should also present the portfolio rating for each criterion that is used to calculate the weighted overall preference rating. The element in the initial design that may not be possible is the map with locations that shows whether they are switched on or off. Therefore it should be modelled last.

In the meantime the first set of interviews was finished, so all preference curves were established and an indicative set of criteria weights was established. The one design constraint that was established by the stakeholder was the fact that only seven locations are allowed in the portfolio.

In the modelling process, three foci were discerned; one was that the functions that calculate the criterion specific preference rating per portfolio design, use the portfolio design as an input. In this way these functions could be connected to the search algorithm. Secondly, an overall weighted preference rating should be calculated, in order to be presented in the GUI. Third was the calculation of the overall weighted preference ratings per location, which should be presented together with the location names in a ranking.

Before building a model with all variables and locations included, the functions were optimised with the help of the modelling expert, in order to calculate the results most efficiently. This meant that one function was written to calculate the physical values, criteria preferences and the overall weighted preference for the individual locations. Also one function calculates the overall weighted preference rating for the portfolio designs.

During a model discussion it was concluded that including all the location data in the design interface would result in a lack of clarity due to the large information load. Therefore the GUI will only be used to design portfolio alternatives and present the overall preference rating. Moreover, because the physical values and preference ratings per criterion for each location remain the same during each workshop, these are provided to the stakeholders in a separate document that can be printed and used during the design of portfolio alternatives. Also the location ranking will be provided separately.

Finally, some additional features were added to the GUI, e.g. the possibility to save and recall a portfolio alternative. Also the design constraint was implemented in the function that calculates the overall preference rating. This function warns the user when the constraint is violated. Moreover, after the first workshop, three additional design constraints were added to the model and the GUI.

11.3. Model structure

The structure of the final model is mainly based on the model requirements presented in paragraph 11.1. In the model, roughly two parts can be distinguished. One calculates the overall portfolio preference rating based on the average physical values in a particular portfolio alternative. The other part generates all location ratings per criterion and calculates the overall preference rating per location. This paragraph only briefly describes how the model works, a more technical explanation is included in appendix B.

As introduced briefly in the beginning of this chapter, in general the model is organised by means of functions that call for other functions in order to make calculations. Due to this integrated approach, at the end of the calculation there is only one function required to return the final outcome, based on one input variable with a portfolio design. This variable consists of a list of all locations with 1's and 0's, indicating respectively that that particular location is or is not included in the portfolio design. In addition to this, different operations are written in separate scripts or functions as much as possible. This is done to structure the model and create overview in the modelling environment. In this way, adding, removing or adapting criteria is less prone to errors because one can see when the criterion is added or removed from the functions list. The importance of this structure is also that in this way, the model can be connected to the search algorithm.

Overall portfolio preference rating

This part of the model is meant to return the overall weighted preference rating for the portfolio alternatives made. The procedure for two criteria is shown in figure 30. This output is then presented in the GUI to provide the users with feedback on their design. This process uses four steps, based on the designed portfolio alternative as input. First there is a function for each criterion that calculates the average physical value from the variable with location data on this criterion. Second there is a function for each criterion to calculate the preference rating. This function calls for the first, to provide this physical value as input. Together with the variable with preference data for this criterion, the physical value is used to calculate the preference rating on this criterion in the function *Preference*. Third, these preferences are bundled and fourth, combined with the criteria- and stakeholder weights into the overall weighted preference rating for that particular portfolio design. Actually the input X is fed through all the functions from the right side of the figure, in this function it is also tested if it meets the design constraints by the function *IsFeasible*.

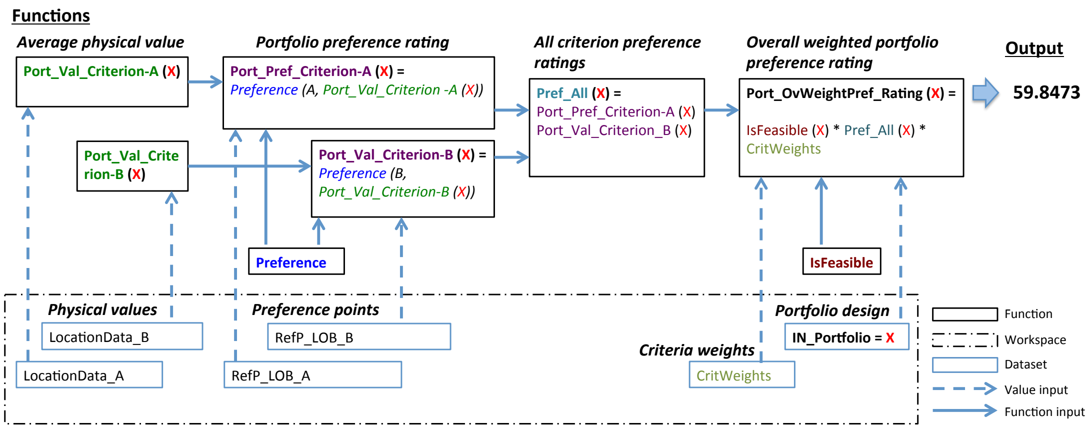


Figure 30 – Model structure overall portfolio preference rating (own illustration)

As mentioned before, the structure described above is especially suited to the requirements of the search algorithm. As the algorithm is built to provide input into the model in terms of portfolio alternatives, this is what the functions use to make their calculations (i.e. the red X in the figure). The algorithm tests the input for the design boundaries. The output that is evaluated by the algorithm consists of the individual criteria preference ratings for each portfolio design. This output is used by the algorithm to find the overall weighted preference rating. Based on this rating, the algorithm searches for portfolio alternatives with a higher overall preference rating. Therefore the algorithm does not use the function that calculates the overall weighted preference rating. In addition to this, the algorithm makes use of a different variable with the criteria weights and stakeholder weights combined.

Individual location preference rating

This part of the model returns all individual physical values and preference ratings per criterion per location (see figure 31). Based on these values, it calculates the overall weighted preference rating per location. This part consists of one large function that returns for a given location, per criterion the physical values and calculates the preference rating, using the variables with preference data and physical data. Also this function calculates the overall weighted preference rating for a given location. These ratings, however, cannot be used to calculate the overall portfolio rating. A separate function makes sure that all locations in the study are put into the previous function in order to generate three matrices with respectively all physical values, all preference ratings and all overall weighted preference ratings for the locations. These matrices are exported to text files by a separate function in order to load them into an excel file that is to be used by the stakeholders in the workshops. A final function ranks the overall location ratings and location names in descending order. This output will be compared to the outcome of the initial study.

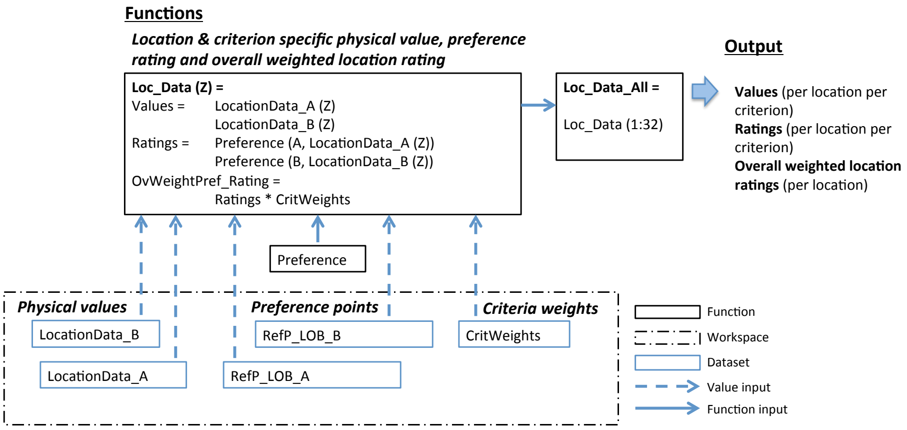


Figure 31 – Model structure individual location preference rating (own illustration)

Graphical User Interface (GUI)

The final GUI is shown in figure 32 and provides the possibility to design portfolio alternatives quite intuitively by filling out a set of checkboxes. This is done in the design table on the left side, which also provides the location preference rating. The selected locations appear in the table in the middle, presenting the current design. Above this table, the number of locations selected is shown. Once selecting the button "Calc. Preference", the overall weighted preference rating for the design appears in the top right corner. In the table on the right side with the criteria and criteria weights, the average physical values and preference ratings per criterion appear for the portfolio design. Below this table, the difference between the preference rating for the current portfolio and the alternative design appears. The numbers are presented with two decimals, which suggests a certain level of precision. The systems engineer and model expert realise that this could give the wrong signal. Unfortunately their Matlab proficiency was not sufficient to programme this differently.

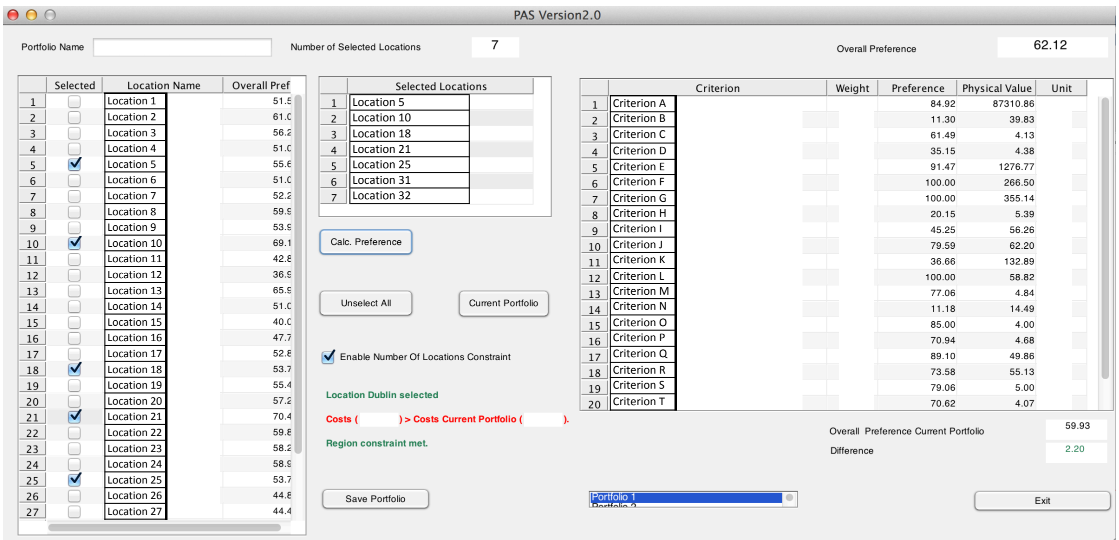


Figure 32 – Final GUI impression with confidential information coded (own illustration)

A first special feature is the possibility to name and save a portfolio alternative. This is done by typing the title in the text box above the design table and selecting the button "Save Portfolio". The alternative then shows up in the list next to the previous button and can be called back into the design screen, for a simple check or adaptation. Also there is the possibility to bring the current portfolio into the design screen, by selecting the button "Current Portfolio", which could be used as a starting point for designing a portfolio alternative. The design constraint for number of locations can be switched on by selecting the checkbox before "Enable Number Of Locations Constraint", once checked, the interface provides a visual warning in the top of the window and does not calculate the overall preference rating if the constraint is violated. In the column of the checkbox, the GUI also provides feedback on whether or not the alternative is within the other design constraints by colouring them in green or red. Finally the user can also unselect all locations by clicking the "Unselect All" button.

11.4. Conclusions

The model is able to calculate the overall weighted preference ratings for all locations individually, and provides the outcome in a ranking with descending preference rating. This can be used to compare to the original study. In this way the minimum requirement is met.

Furthermore, the model meets the requirement of presenting all physical location data and preference ratings per criterion. It also calculates the overall weighted preference rating per portfolio alternative and uses the design constraints to abort the latter operation in case the portfolio design does not meet the requirement.

The final GUI that was modelled covers most of the requirements formulated previously. Only including the visual representation of the portfolio alternative in a map was not possible due to the time constraint of this research and design project and the modelling proficiency of the systems engineer and expert. A GUI was modelled that enables the stakeholders to intuitively design portfolio alternatives by means of selecting a set of locations. The GUI tests this alternative for the design constraints, and provides the user with an overall preference rating. It also provides insight in the average physical values and accompanying criteria ratings for the portfolio. To provide feedback on the portfolio design in relation to the current portfolio, the GUI provides the preference rating for the current portfolio and the difference in rating with the alternative. Also it is able to return to the initial portfolio in one click.

Moreover, some additional features have been implemented to improve the design process. The possibility to name and save design alternatives makes it possible to get back to previous ideas and build upon them by recalling them in the design screen. Other features are the possibility to disable the design constraint on the number of locations and to unselect all locations at once. Finally also the visual feedback that is provided in the middle of the design interface, on whether or not the designed alternative is within the design boundaries, is expected to improve the design process.

In the end, the GUI does not provide a visual representation of the locations on a map, something that could have made the design process more insightful for the stakeholders. Also the GUI does not present the physical values and criterion ratings for the individual locations. These values are provided separately as they remain the same over one workshop. This is even expected to improve the design process as the GUI provides a clear overview now.

12. Testing & improving the model in practice

This chapter presents briefly the process of the pilot study with the PAS in the Oracle location study. It presents some observations during the workshops with the users from the Advanced Planning (AP) team and the comparison of the additional rankings used in the pilot study to isolate the effects of several steps taken in the ranking of locations. Also the chapter presents the improvements in the model that were made in between the two workshops, and the application of a brute force function as a substitute for the search algorithm.

12.1. Pilot study observations

Each workshop started with an introductory presentation by the systems engineer, who was responsible for the model and workshop structure, to refresh the goal of the research project and the workshops and to present the expected outcomes of the workshop. In this presentation also the two elements in the workshops were introduced; designing an optimum location portfolio for LOB 1 and comparing the rankings from the original study and the PAS model. The introduction to the first workshop also included an elaborate explanation of the model backside in a visual representation. Each presentation ended with an explanation of the assumptions made in the modelling of the stakeholders' input and an explanation of the design interface. Also the systems engineer indicated that from that point off, the control over the model was in the hands of the users.

In the workshops, the users received two design assignments; one with the current portfolio plus one location and one to design a portfolio regardless of the current portfolio. During the first workshop, one of the users correctly observed from the design interface how the overall preference rating for a portfolio alternative followed from the preference ratings based on the average physical values per criterion. Also it was observed that in order to design the optimum portfolio it would be logical to start with the locations with the highest individual preference rating, although these ratings were not directly used to arrive at the overall preference rating. Another element that stood out in this design process was that one of the users came up with the note that in reality some locations would never be left by the LOB because they needed to cover certain regions. Therefore she thought that these locations should always be included, which resulted at the end of the workshop in an additional constraint, requiring a certain regional coverage. Also the observation was made that designing the portfolio with the highest preference ratings, meant that a lot of expensive locations were included. In real life this could not be the case because it would make the portfolio too costly. The users discussed amongst one another that costly locations are not forbidden, but should be compensated with cheaper locations. This resulted in a constraint that determines that the average costs for a portfolio alternative are not allowed to exceed the costs of the current portfolio. The formulated two constraints resulted in three new design constraints because one of them actually incorporated two separate constraints.

In the comparison of rankings in the first workshop, the users were interested to see what the individual effects of using preference curves and new weights are on the ranking. They recognised that the new weights might represent progressive insight in the matter from the LOB's point of view.

In the second workshop, designing portfolio alternatives that did not violate either of the constraints had become somewhat more complex as the users indicated. However, they also noted that it made them more aware of the implications of certain decisions, e.g. regions with only one location. Also the users observed that in the future they might need somewhat more refinement in the location data by means of including the headcount per location in order to optimise the portfolio for costs versus regional coverage, i.e. covering a region with an expensive location, however with low headcount to decrease total costs.

12.2. Comparing rankings

Another element in workshop two was the comparison of different rankings that were generated by the systems engineer in order to isolate the effects of changes in the set of criteria used; the type of calculation of the location ratings and the use of preference curves in rating the location values and the criteria weights used. The table with these rankings is presented on the next page. It shows the rank for each location per step and the change in rank compared to the previous ranking. However, from the perspective of correct preference measurement as explained in chapter 5, the underlying values of these rankings i.e. the weighted average preference ratings, are only an approximation of the actual values and are strictly taken undefined. Therefore in the analysis of the differences, the operations applied to the changes in rank are minimised.

The first two rankings, respectively Original study and SC_Orig-procedure_OrigW, show the effect of changing the set of criteria on the ranking of locations in the original scorecard calculation. The changes in ranking are due to the change in their overall location rating. One can see that generally only reasonably small shifts occur in the ranking, which means that the change in the set of criteria only has a small effect. Something that attracts the attention is that location 2 and 5 remain in the same position and location 18 shows quite a substantial shift downwards. Overall, more locations shift up than down. Finally, the location that was initially chosen by the LOB, location 13, increases 4 places in rank.

The ranking SC_Weight-av_OrigW calculates the overall rating per location in the scorecard based on weighted average instead of the original calculation procedure. It is constructed because in this way, the results are better comparable to the PAS output as this also uses the weighted average to come to the location ratings. The difference with the ranking SC_Orig-procedure_OrigW is insignificant, as only two locations switched one place in rank.

Comparison three, between SC_Weight-av_OrigW and SC_Weight-av_NewW, shows the effect on the ranking caused by the difference between the original weights and the new weights assigned to the criteria by LOB 1. It shows quite large individual shifts for some locations. Location 4 and 8 go up respectively 12 and 10 places, whereas location 16 and 18 go down respectively 9 and 10 places. It is striking that location 18 again goes down a significant number of places. Again location 13 goes up a few places to the last place in the top-10. In this comparison, the number of locations that goes up equals the locations that decrease in rank. In the discussion, the users from the AP team indicated that they expect this ranking to be equal to the result of the adaptations made by LOB 1, after they delivered their final results.

The comparison between the ranking SC_Weight-av_NewW and the PAS procedure outcome is the one that is most accurate in showing the added value of using the PAS. More specifically, it shows the result of the use of preference curves, since both procedures use a weighted average calculation. So in this research and design project it is the most interesting comparison, contrary to the users interests, who found the comparison with the original ranking more interesting. In this comparison there are some locations that attract the attention. Location 18 again goes quite a large number of places up, just like location 9. Also location 29 decreases substantially in rank. The total number of changes is smaller than in the previous comparison. Again location 13, finally chosen by the LOB, again goes up a few places to end in place 4. This rank is +6 compared to the ranking based on which the LOB is expected to have made this choice.

1: Effect of different selection of criteria (Original study → SC_Orig-procedure_OrigW)

2: Effect of weighted average compared to original calculation (SC_Orig-procedure_OrigW → SC_Weight-average_OrigW)

3: Effect of LOB 1's adaptations (weights) (SC_Weight-average_OrigW → SC_Weight-average_NewW)

4: Effect of the use of preference curves in rating locations (SC_Weight-average_NewW → PAS procedure outcome)

	Original study	SC_Orig-procedure_OrigW		SC_Weight-average_OrigW		SC_Weight-average_NewW		PAS procedure outcome	
Number of criteria:	39	22	**Locations up:**	22	**Locations up:**	22	**Locations up:**	22	**Locations up:**
Calculation:	Procedure scorecard	Procedure scorecard	16	Weighted average	1	Weighted average	15	PAS	11
Weights (original/new):	Original	Original	**Locations down:**	Original	**Locations down:**	New	**Locations down:**	New	**Locations down:**
Position chosen location:	17	13 (+4)	14	13 (0)	1	10 (+3)	15	4 (+6)	16

Locations	**Rank**	**Rank:**	**Change**	**Rank:**	**Change**	**Rank:**	**Change**	**Rank:**	**Locations:**
Location 1	28	27	1	27	0	25	2	19	6
Location 2	7	7	0	7	0	11	-4	5	6
Location 3	16	14	2	14	0	14	0	11	3
Location 4	30	28	2	28	0	16	12	22	-6
Location 5*	23	23	0	23	0	19	4	12	7
Location 6	26	25	1	25	0	28	-3	20	8
Location 7	25	24	1	24	0	15	9	18	-3
Location 8	20	16	4	16	0	6	10	6	0
Location 9	24	21	3	21	0	26	-5	14	12
Location 10*	2	1	1	1	0	2	-1	2	0
Location 11	32	31	1	31	0	30	1	28	2
Location 12	31	32	-1	32	0	31	1	31	0
Location 13	**17**	**13**	**4**	**13**	**0**	**10**	**3**	**4**	**6**
Location 14	22	18	4	18	0	20	-2	21	-1
Location 15	19	26	-7	26	0	24	2	29	-5
Location 16	9	12	-3	12	0	21	-9	24	-3
Location 17	8	11	-3	11	0	13	-2	17	-4
Location 18*	13	22	-9	22	0	32	-10	16	16
Location 19	21	20	1	20	0	18	2	13	5
Location 20	11	8	3	8	0	4	4	10	-6
Location 21	1	2	-1	2	0	1	1	1	0
Location 22	3	4	-1	3	1	5	-2	7	-2
Location 23	5	6	-1	6	0	8	-2	9	-1
Location 24	10	9	1	9	0	9	0	8	1
Location 25*	4	5	-1	5	0	7	-2	15	-8
Location 26	15	17	-2	17	0	22	-5	25	-3
Location 27	18	19	-1	19	0	23	-4	27	-4
Location 28	27	29	-2	29	0	27	2	30	-3
Location 29	12	10	2	10	0	12	-2	23	-11
Location 30	29	30	-1	30	0	29	1	32	-3
Location 31*	14	15	-1	15	0	17	-2	26	-9
Location 32*	6	3	3	4	-1	3	1	3	0

*Table 9 – Comparison of rankings (* = location in current portfolio)*

Both users from the AP team noticed that there were no shocking changes, except for location 18 that showed some large changes in between the original ranking and the PAS ranking. Both users found the comparison quite insightful and it made them feel confident in the model. They also recognised that the changes in ranking caused by the new weights of the LOB were quite large. However, it did not surprise them as they expected that the LOB dived quite deep into the scorecard and adapted the ranking on a detailed level, maybe even to increase the rank of location 13 on purpose. In conclusion, from the perspective of modelling real life, the ranking from the PAS model is a better representation of reality than the ranking SC_Weight-av_NewW.

12.3. Model adaptations

An additional goal in the second workshop was to find out if the design constraints implemented after the first workshop, improved the representation of the stakeholders' preferences in the model. During the evaluation of the model at the end of the first workshop, the users defined the following design constraints in order to achieve a better representation of the actual decision-making process by the LOB.

1. Location #10 should always be included.
2. In order to cover the different types of languages used in the EMEA region, i.e. Roman, Germanic, Slavonic and Arabic, each of the following regions should be covered by at least one location: Northern-Europe (N-EU); Southern-Europe (S-EU); Eastern-Europe (E-EU); Middle-East (M-E); Russia (R); UK & Ireland (UK&I)
3. The average annual costs p.p.p.y. of the new portfolio ≤ the average annual costs p.p.p.y. of the current portfolio

At the end of the second workshop, both users said that they were glad to see the refinement in the model, induced by the additional design constraints. Moreover, they indicated that they accept the final outcome as the optimum found in the self-design process. Also the users indicated that the ranking reflects their preferences very well.

12.4. Application of a brute force function

Unfortunately, at the second workshop, the output of the algorithm was not available yet. However, it became clear that the case was of such complexity that it was possible to generate all feasible alternatives with a brute force function. The complete case comprised of a total of 3.365.856 possible portfolio alternatives, however due to the design constraints imposed to the solution space, only 4.480 feasible portfolio alternatives remained. This was a number that could be generated by use of a mathematical function that finds the feasible alternatives and calculates their overall preference rating. This brute force function, as it is called, was used instead of the algorithm, as it could reasonably be assumed that the algorithm would be able to find the same result, however this is not certain. Still to the users the brute force function has the same characteristics of the black box of the algorithm. Therefore it is a good substitute.

The use of a brute force approach has some particular advantages. First and foremost, a ranking of all the feasible alternatives in the model means that the portfolio alternative that appears at the first position is the global optimum. This is certainly the best solution, contrary to the search algorithm that would only provide a local optimum. Secondly, based on this ranking, the stakeholders could be provided with insight in the top-5 portfolio alternatives. Based on this result they had the possibility to indicate whether or not they would accept the number one portfolio or if they preferred another alternative. The function was modelled after the last workshops and the results, including a preference ratings checked in Tetra, were presented to the stakeholders and evaluated a few weeks after the last workshop. The first reactions of the users were positive, they indicated that they expected such an optimum solution. However, they also note that this theoretical portfolio does not simply replace the current portfolio.

13. Model outcomes

In this chapter the results of the pilot study are presented, in terms of the model and its outcomes. The results are coded because they incorporate confidential information. These results are compared to the outcomes of the algorithm and to the results of the original study that was conducted by the Advanced Planning (AP) team. This chapter is structured according to the six steps of the PAS procedure and presents the results of the model at the end of the pilot study. The results of the evaluation interviews on the PAS are presented in chapter 14.

13.1. Step 1: specify the criteria the user is interested in

As presented in paragraph 10.3, the criteria in the study are based on five categories that are of interest to LOB 1 and are established by their representative. In the criteria set, only a small part comprises of cost related criteria. This is the result of the main aim of this location study, to find a location that attracts millennials. Therefore, the category that covers aspects of the ease of hiring native English speakers and millennials is much larger. The categories labour environment and government support cover elements of doing business in the countries the locations are in. The final category provides criteria related to the LOB's specific vision.

13.2. Step 2: determining preferences

The stakeholders determined their common preferences based on the data that was available for a selection of cities/countries around the world or just for the 32 locations taken included in the case. The representative of LOB 1 established a third of the preference curves, the rest was established by the representatives from the AP team.

The preference curves are established just like in the description of the PAS procedure in chapter 3. The users determined a least preferred reference alternative $[x_0, y_0]$, followed by the most preferred reference alternative $[x_1, y_1]$. Finally the shape of the curve was determined by means of an intermediate reference $[x_2, y_2]$.

Decision maker	Criterion	$[x_0, y_0]$	$[x_1, y_1]$	$[x_2, y_2]$
LOB 1	Criterion A	[146506, 0]	[53270, 100]	[93000, 80]
	Criterion B	[50, 0]	[15, 100]	[26, 50]
	Criterion C	[2.4, 0]	[5.8, 100]	[2.9, 20]
	Criterion D	[2, 0]	[6.5, 100]	[3, 10]
	Criterion E	[200, 0]	[2700, 100]	[800, 60]
	Criterion F	[50, 0]	[1000, 100]	[150, 70]
	Criterion G	[50, 0]	[800, 100]	[100, 50]
	Criterion H	[4, 0]	[7, 100]	[5, 10]
	Criterion I	[114, 0]	[25, 100]	[90, 10]
	Criterion J	[30, 0]	[95, 100]	[70, 90]
	Criterion K	[300, 0]	[40, 100]	[200, 10]
	Criterion L	[25, 0]	[90, 100]	[45, 80]
	Criterion M	[3, 0]	[6,2, 100]	[5.4, 90]
	Criterion N	[21.6, 0]	[0, 100]	[8, 40]
	Criterion O	[1, 0]	[5, 100]	[4, 85]
	Criterion P	[3, 0]	[6, 100]	[5, 80]
	Criterion Q	[35, 0]	[57, 100]	[40, 40]
	Criterion R	[30, 0]	[76, 100]	[65, 90]
	Criterion S	[2.5, 0]	[6.6, 100]	[4.2, 60]
	Criterion T	[2, 0]	[6.5, 100]	[4.5, 80]
	Criterion U	[61, 0]	[1, 100]	[30, 20]
	Criterion V	[62, 0]	[1, 100]	[44, 15]

Table 10 – Criteria and their respective preferences

An example of a preference curve is that of criterion B (see figure 33). The least preferred reference alternative was set at the highest acceptable physical value, the most preferred reference was set at a low physical value. For the intermediate reference alternative, the stakeholder took the physical value of their benchmark location #10 in order to direct the rating for locations with a higher and lower physical value. The goal was not to rate too much in favour of locations with a lower physical value.

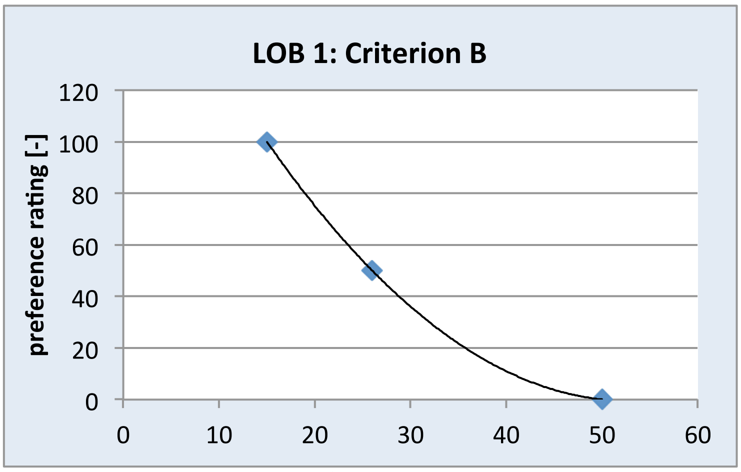


Figure 33 – Lagrange interpolation relating preference rating to the physical value of criterion B for the location portfolio of LOB 1 (own illustration)

13.3. Step 3: assigning weights

The representative of LOB 1 assigned weights to the criteria, so they are based on the actual stakeholder's preferences. Also these weights might incorporate progressive insight in their effects, because the implementation of the results of the initial study already started. There is no stakeholder weight included in this study, as there is only one stakeholder representative that provided criteria.

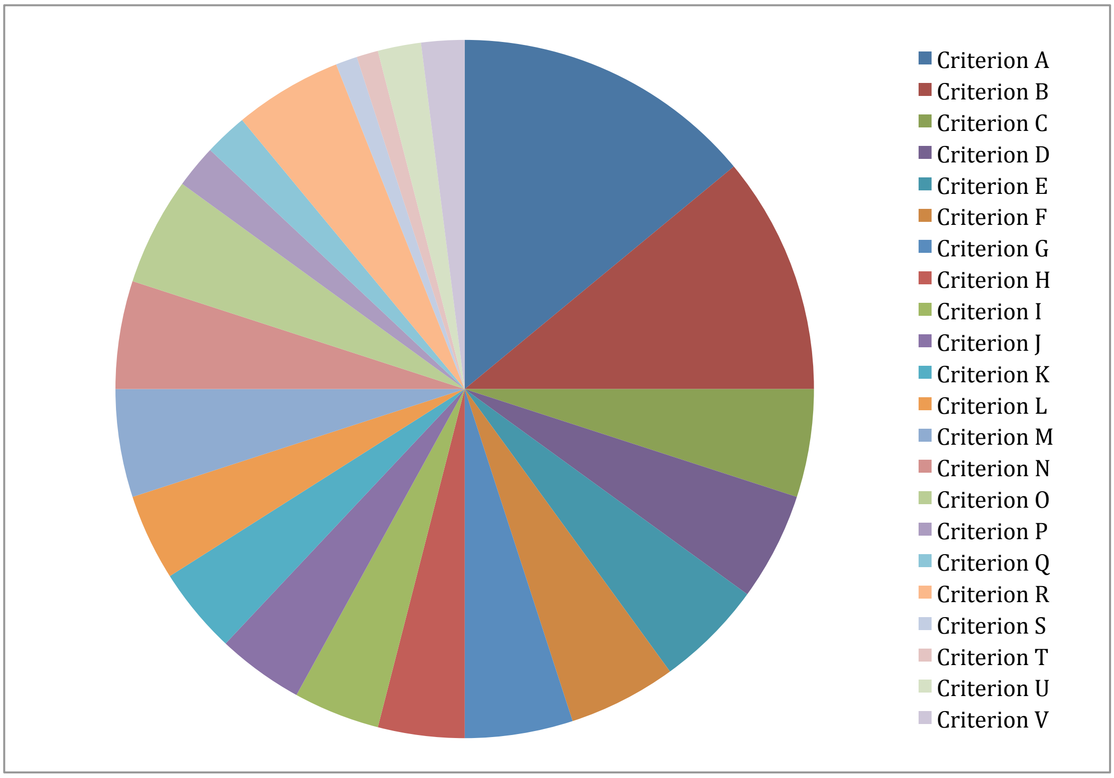


Figure 34 – Criterion weights determined by the decision maker (own illustration)

13.4. Step 4: determining design constraints

During the pilot study, the users formulated a total of four design constraints (see table 11). The first established constraint determines the number of locations in the portfolio alternatives. It is based on the number of locations in the current portfolio of LOB 1 and the desire to find one additional location.

The other three constraints determine the possibilities for the selection of this alternative location, as they determine that some locations cannot be left and that at least one location should be selected in each of the regions defined by the stakeholders. These regions are determined, based on the requirement of language coverage by the LOB, i.e. Roman, Germanic, Arabic and Slavonic languages. The cost constraint determines that the costs for more expensive locations should be compensated by cheaper locations.

Decision maker	Design constraint
LOB 1	The new portfolio should consist of 7 locations
	The location #10 should always be included
	At least one location should be selected in each of the following regions: Northern-Europe (N-EU); Southern-Europe (S-EU); Eastern-Europe (E-EU); Middle-East (M-E); Russia (R); UK & Ireland (UK&I)
	The average annual costs p.p.p.y. of the new portfolio ≤ the average annual costs p.p.p.y. of the current portfolio

Table 11 – Design constraints incorporated in the model

13.5. Step 5: generate alternatives

The output of the model and the pilot study comprises of two elements. The ranking of locations based on their individual preference rating and the portfolio alternatives resulting from the self-design process by the stakeholders. The elements will be discussed in this specific order.

13.5.1. Comparing location rankings

A location ranking was the main output of the original study by the AP team, therefore it is a main element in establishing acceptance of the model and gaining trust in the model. Therefore the users compared the PAS ranking to the ranking from the original study. However, because the location ratings from the PAS are based on a weighted average, they are only an approximation, so the resulting ranking was checked. The basic version of the algorithm in Tetra was used to obtain the correct preference rating of the individual locations in order to construct a correct ranking.

Table 12 shows that the Tetra output almost exactly mirrors the location ranking that resulted from the PAS model, despite the fact that all of the location ratings are different. The only difference in the order is the switch of the locations 4 and 14, however this can be attributed to the tiny difference in preference rating that occurs in both rankings. The fact that there are only numerical differences in the preference ratings and not in the ranking supports the statement that the weighted average calculation is a close approximation of the preference rating that is obtained in a correct way through Tetra.

Output PAS model			**Output Tetra**	
Rank:	**Locations:**	***Overall weighted location rating:***	**Locations:**	***Overall preference rating:***
1	Location 21	70,43	Location 21	72,45
2	Location 10*	69,19	Location 10*	70,89
3	Location 32*	66,41	Location 32*	69,53
4	Location 13	65,99	Location 13	68,18
5	Location 2	61,00	Location 2	62,48
6	Location 8	59,98	Location 8	62,12
7	Location 22	59,84	Location 22	61,19
8	Location 24	58,93	Location 24	60,51
9	Location 23	58,26	Location 23	59,76
10	Location 20	57,28	Location 20	58,97
11	Location 3	56,21	Location 3	57,24
12	Location 5*	55,67	Location 5*	56,91
13	Location 19	55,48	Location 19	56,50
14	Location 9	53,97	Location 9	54,85
15	Location 25*	53,75	Location 25*	54,61
16	Location 18*	53,72	Location 18*	54,58
17	Location 17	52,89	Location 17	53,59
18	Location 7	52,25	Location 7	52,73
19	Location 1	51,56	Location 1	51,82
20	Location 6	51,05	Location 6	51,31
21	**Location 14**	**51,04**	**Location 4**	**51,22**
22	**Location 4**	**51,00**	**Location 14**	**51,20**
23	Location 29	48,49	Location 29	48,18
24	Location 16	47,78	Location 16	47,28
25	Location 26	44,88	Location 26	43,47
26	Location 31*	44,55	Location 31*	43,22
27	Location 27	44,42	Location 27	43,15
28	Location 11	42,82	Location 11	41,05
29	Location 15	40,09	Location 15	37,98
30	Location 28	39,15	Location 28	36,33
31	Location 12	36,95	Location 12	34,34
32	Location 30	35,16	Location 30	31,61

*Table 12 – Location ranking from the PAS model compared to the ranking from Tetra (* = location in current portfolio)*

The users compared the ranking from the PAS model to the ranking from the original study (see the table below). However because quite some adaptations were made in the process between the original ranking and the output of the PAS model, a set of additional rankings was generated and analysed as discussed in the previous chapter. The comparison that the users made between the original ranking and the PAS output in table 13, showed that roughly 2/3rd of the top-15 locations in the original study returns in the top-15 of the PAS outcome. Moreover, location #13, which was selected by LOB 1 after the initial study, moves from place 17 to place 4 in the PAS ranking, which makes it the second most preferred location that is not included in the current portfolio. This is an initial indicator that the PAS model quite closely reflects the stakeholders' preferences in a more accurate way than the original scorecard procedure.

Output original study		**Output PAS model**		
Rank:	**Locations:**	**Rank:**	**Locations:**	***Overall weighted location rating:***
1	Location 21	**1**	Location 21	70,43
2	Location 10*	**2**	Location 10*	69,19
3	Location 22	**3**	Location 32*	66,41
4	Location 25*	**4**	**Location 13**	65,99
5	Location 23	**5**	Location 2	61,00
6	Location 32*	**6**	Location 8	59,98
7	Location 2	**7**	Location 22	59,84
8	Location 17	**8**	Location 24	58,93
9	Location 16	**9**	Location 23	58,26
10	Location 24	**10**	Location 20	57,28
11	Location 20	**11**	Location 3	56,21
12	Location 29	**12**	Location 5*	55,67
13	Location 18*	**13**	Location 19	55,48
14	Location 31*	**14**	Location 9	53,97
15	Location 26	**15**	Location 25*	53,75
16	Location 3	**16**	Location 18*	53,72
17	**Location 13**	**17**	Location 17	52,89
18	Location 27	**18**	Location 7	52,25
19	Location 15	**19**	Location 1	51,56
20	Location 8	**20**	Location 6	51,05
21	Location 19	**21**	Location 14	51,04
22	Location 14	**22**	Location 4	51,00
23	Location 5*	**23**	Location 29	48,49
24	Location 9	**24**	Location 16	47,78
25	Location 7	**25**	Location 26	44,88
26	Location 6	**26**	Location 31*	44,55
27	Location 28	**27**	Location 27	44,42
28	Location 1	**28**	Location 11	42,82
29	Location 30	**29**	Location 15	40,09
30	Location 4	**30**	Location 28	39,15
31	Location 12	**31**	Location 12	36,95
32	Location 11	**32**	Location 30	35,16

*Table 13 – Location ranking from the PAS model compared to the ranking from the original study (* = location in current portfolio)*

When looking at the changes in rank for each individual location as presented in table 14, one can see that there are quite some locations that go a lot of steps up or down in the ranking. However, there are also a few locations that stay in the same position. Among the latter group are the first and second most preferred locations. Moreover, 21 of the 32 locations stay within a minor shift of 3 places up or down. In this comparison, the number of locations that goes down is lower than the locations that go up.

Locations:	Output original study (rank)	Output PAS model (rank)	Change in rank
Location 1	**28**	**19**	9
Location 2	**7**	**5**	2
Location 3	**16**	**11**	5
Location 4	**30**	**22**	8
Location 5*	**23**	**12**	11
Location 6	**26**	**20**	6
Location 7	**25**	**18**	7
Location 8	**20**	**6**	14
Location 9	**24**	**14**	10
Location 10*	**2**	**2**	0
Location 11	**32**	**28**	4
Location 12	**31**	**31**	0
Location 13	**17**	**4**	13
Location 14	**22**	**21**	1
Location 15	**19**	**29**	-10
Location 16	**9**	**24**	-15
Location 17	**8**	**17**	-9
Location 18*	**13**	**16**	-3
Location 19	**21**	**13**	8
Location 20	**11**	**10**	1
Location 21	**1**	**1**	0
Location 22	**3**	**7**	-4
Location 23	**5**	**9**	-4
Location 24	**10**	**8**	2
Location 25*	**4**	**15**	-11
Location 26	**15**	**25**	-10
Location 27	**18**	**27**	-9
Location 28	**27**	**30**	-3
Location 29	**12**	**23**	-11
Location 30	**29**	**32**	-3
Location 31*	**14**	**26**	-12
Location 32*	**6**	**3**	3

*Table 14 – Locations and their rank in the PAS model compared to the rank in the original study (* = location in current portfolio)*

13.5.2. Generating alternatives

The goal of designing portfolio alternatives is to maximise the overall portfolio preference rating, while staying within the established design constraints. This case incorporates only one possible intervention, which is to switch locations on and off to design a portfolio alternative. Hence, during each workshop the users had to find per region the location that resulted in the highest overall preference rating for an alternative. In case the costs constraint was violated, the users had to substitute a location for a cheaper alternative. In this way they could easily meet all the design constraints, while optimising the overall preference rating.

During the second workshop, three feasible alternatives were designed, shown in table 15. The correct overall preference ratings have been obtained from Tetra. The table shows what the users found an alternative with a higher preference rating than the portfolio with their current choice, Current & Location 13.

Name:	*Current portfolio*	Current & Location 13	Optimum_alt_03	Optimum_alt_04
Locations:	*Location 5*	Location 5	Location 8	Location 8
	Location 10	Location 10	Location 10	Location 10
	Location 18	Location 13	Location 13	Location 13
	Location 25	Location 18	Location 18	Location 17
	Location 31	Location 25	Location 25	Location 25
	Location 32	Location 31	Location 31	Location 31
		Location 32	Location 32	Location 32
Preference rating:	*59,93 (Tetra: 61,43)*	**61,36 (Tetra: 63,05)**	**62.14 (Tetra: 63,98)**	**62.48 (Tetra: 64,46)**
Difference	-	**3%**	**4%**	**5%**

Table 15 – Portfolio alternatives designed by the stakeholders, compared to the current portfolio

In this workshop, one of the users noticed that by replacing location 18 in portfolio alternative Optimum_alt_03 by location 17 with a slightly lower location preference rating, the overall preference rating increases (Optimum_alt_04). The systems engineer explained this to the users. This explanation is supported by the data shown in table 16, which represents this particular case. The line with the coloured cells shows that alternative 04, has a higher preference rating than alternative 03 on three criteria (in green), however it also has a lower rating on three criteria (in red). So on the former three criteria, location 17 has a positive influence on the physical value, which increases the preference rating. The opposite holds for the latter three criteria. However the relative weight of the criteria determines whether the net result on the preference rating is positive or negative. The fact that the weighted average of the differences is a positive value (+0,34), explains the higher preference rating for portfolio alternative Optimum_alt_04. One user noted that this made her appreciate the PAS approach more.

Criteria:	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Criterion F	Criterion G	Criterion H	Criterion I	Criterion J	Criterion K	Criterion L	Criterion M	Criterion N	Criterion O	Criterion P	Criterion Q	Criterion R	Criterion S	Criterion T	Criterion U	Criterion V
Criterion weight:	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alternatives	**Location preference ratings**																					
Optimum_03	85,95	9,95	60,73	31,82	90,29	100,0	100,0	22,36	40,83	80,80	45,93	100,0	78,79	11,09	85,00	70,76	88,23	72,91	78,60	71,37	26,37	33,86
Optimum_04	85,66	9,95	60,73	31,82	98,82	100,0	100,0	22,36	39,16	83,09	42,62	100,0	78,79	11,09	85,00	70,76	91,50	72,91	78,60	71,37	26,37	33,86
Rating Opt_04 > Opt_03	-0,29	0,00	0,00	0,00	8,53	0,00	0,00	0,00	-1,67	2,29	-3,32	0,00	0,00	0,00	0,00	0,00	3,27	0,00	0,00	0,00	0,00	0,00
Weight_av_ difference:	-0,04	0,00	0,00	0,00	0,43	0,00	0,00	0,00	-0,07	0,09	-0,13	0,00	0,00	0,00	0,00	0,00	0,07	0,00	0,00	0,00	0,00	0,00
Sum of weighted_ av_difference:	**0,34**																					

Table 16 – Comparison optimum alternative 03 (with location 18) and 04 (with location 17)

13.6. Step 6: selecting the best alternative

The portfolio alternative with the maximum preference rating designed by the stakeholders, which meets all the design constraints, is the alternative Optimum_alt_04 (See table 15). This alternative includes four of the six locations from the current portfolio. Three of those, location 10, 31, 32 are included to stay within the design constraints that require to include location 10 and Russia and the Middle-East, because in the latter two regions no other locations are available in the model. Also the final choice of LOB 1, location 13, is included. This portfolio alternative provides an improvement of 5% in the preference rating over the current portfolio, based on the correct Tetra ratings.

The optimum portfolio alternative designed by the stakeholder yields the preference ratings per criterion, as presented in table 17. The right column shows that the rating increased or remained stable on all criteria, except for criterion I. The stakeholders indicated after the second workshop that they accept this portfolio alternative as the final outcome of the self-design process and confirmed that the model closely reflects their preferences.

Decision maker	Criterion	Preference rating d_0	Preference rating d_1	Difference (%)
LOB 1	Criterion A	85,63	85,66	0,04
	Criterion B	9,50	9,95	4,74
	Criterion C	57,04	60,73	6,47
	Criterion D	29,62	31,81	7,39
	Criterion E	77,08	98,82	28,20
	Criterion F	100,00	100,00	0,00
	Criterion G	100,00	100,00	0,00
	Criterion H	19,58	22,36	14,20
	Criterion I	44,98	39,16	-12,94
	Criterion J	76,22	83,08	9,00
	Criterion K	37,62	42,62	13,29
	Criterion L	100,00	100,00	0,00
	Criterion M	75,87	78,79	3,85
	Criterion N	8,31	11,09	33,45
	Criterion O	85,00	85,00	0,00
	Criterion P	67,86	70,76	4,27
	Criterion Q	85,26	91,50	7,32
	Criterion R	69,19	72,91	5,38
	Criterion S	77,14	78,60	1,89
	Criterion T	69,50	71,36	2,68
	Criterion U	23,30	26,37	13,18
	Criterion V	32,84	33,86	3,11

Table 17 – Preference rating per criterion; current (d_0) and future (d_1) state of the portfolio Optimum_alt_04

After the pilot study, a brute force function was used to generate all feasible alternatives. By ranking those on their accompanying preference rating, the users could compare the top-5 portfolio alternatives (see table 18). The advantage of this was that the number one is the global optimum instead of a local optimum that would have been generated by the algorithm. However, the table shows that the check of the preference ratings in Tetra resulted in a shift in the ranking. The number three in the original top-5 went to place five, based on the Tetra rankings. Nonetheless, it also shows that there is an insignificant difference of 0,01 between number 1 and number 2.

Name:	***Number 1***	***Number 2***	***Number 3***	***Number 4***	***Number 5***
Locations:	Location 10	Location 10	Location 10	Location 10	Location 10
	Location 13	Location 13	Location 13	Location 13	Location 13
	Location 17	Location 17	Location 16	Location 18	Location 15
	Location 21	Location 21	Location 21	Location 21	Location 21
	Location 27	Location 26	Location 27	Location 27	Location 27
	Location 31	Location 31	Location 31	Location 31	Location 31
	Location 32	Location 32	Location 32	Location 32	Location 32
Preference rating:	**64,01 (Tetra: 65,88)**	**63,92 (Tetra: 65,87)**	**63,83 (Tetra: 65,64)**	**63,81 (Tetra: 65,59)**	**63,84 (Tetra: 65,54)**

Table 18 – Top-5 portfolio alternatives from brute force function, based on Tetra preference rating

The number one alternative has a higher preference rating than found by the stakeholders. This confirms the hypothesis that the algorithm, here substituted by the brute force function, is able to find a portfolio alternative with a better preference rating than the stakeholders are able to find. Moreover, the ranking with all portfolio alternatives (numbers rounded at two decimals), showed that there are 78 portfolio alternatives with a better rating than the optimum found by the users through self-design.

As shown in table 19, the optimum alternative includes the minimum number of three of the six locations from the current portfolio. All are included to stay within the design constraints that require including location 10 and Russia and the Middle-East, because in the latter two regions no other locations are available in the model. As such, it differs from the optimum found by self-design, which also included the current location 25. In addition to this, the location with the highest individual preference rating, location 21 and the actual choice of LOB 1, location 13, are included. The fact that location 21 is included is the most important difference with all alternatives designed by the users. At the same time it is the most logical step in the design of the optimum portfolio, since this is the only way to increase the portfolio preference rating as much as possible. The global optimum portfolio alternative provides an improvement of 7% in the preference rating over the current portfolio, based on the correct Tetra ratings.

Name:	***Current portfolio***	**Current & Location 13**	**Optimum_alt_04**	***Global optimum alternative***
Locations:	*Location 5*	Location 5	Location 8	Location 10
	Location 10	Location 10	Location 10	Location 13
	Location 18	Location 13	Location 13	Location 17
	Location 25	Location 18	Location 17	Location 21
	Location 31	Location 25	Location 25	Location 27
	Location 32	Location 31	Location 31	Location 31
		Location 32	Location 32	Location 32
Preference rating:	*59,93 (Tetra: 61,43)*	**61,36 (Tetra: 63,05)**	**62.48 (Tetra: 64,46)**	**64,01 (Tetra: 65,88)**
Difference	-	**3%**	**5%**	**7%**

Table 19 – Comparison of optimum portfolio alternatives to the current portfolio and the actual choice by LOB 1

The optimum portfolio alternative yields the preference ratings per criterion, as generated by the PAS model, presented in table 20. The right column shows that there are increases, decreases and ratings that remain stable. Generally the changes are larger than for the alternative found in the self-design process, which can be explained by the larger difference in overall preference rating. On the criteria I, K, O, P and U the preference rating decreases a few percent compared to the current portfolio, however this is compensated by some large increases for e.g. criterion B, E and N. In an evaluation of this alternative, the stakeholders indicated that they expected such an outcome and accept this as the final outcome of the pilot study, although one of them prefers Number 2 slightly more, since Oracle already has a small office in location 26. Also some additional criteria could be included regarding moving out of current locations. Nonetheless, together with their statement on the close reflection of their preference by the location ranking, the answer to the second sub-question: *Does the outcome of the algorithm reflect the stakeholders' preferences?*, is positive, although it better represents the stakeholders' preferences in the location rankings than in the optimum portfolio.

Decision maker	Criterion	Preference rating d_0	Preference rating d_1	Difference (%)
LOB 1	Criterion A	85,63	87,09	1,71
	Criterion B	9,50	18,15	91,05
	Criterion C	57,04	59,62	4,52
	Criterion D	29,62	34,5	16,48
	Criterion E	77,08	100	29,74
	Criterion F	100,00	100	0,00
	Criterion G	100,00	100	0,00
	Criterion H	19,58	22,62	15,53
	Criterion I	44,98	40,53	-9,89
	Criterion J	76,22	79,25	3,98
	Criterion K	37,62	35,97	-4,39
	Criterion L	100,00	100	0,00
	Criterion M	75,87	79,43	4,69
	Criterion N	8,31	23,84	186,88
	Criterion O	85,00	82,31	-3,16
	Criterion P	67,86	64,83	-4,47
	Criterion Q	85,26	89,52	5,00
	Criterion R	69,19	76,42	10,45
	Criterion S	77,14	81,6	5,78
	Criterion T	69,50	74,05	6,55
	Criterion U	23,30	21,26	-8,76
	Criterion V	32,84	40,58	23,57

Table 20 – Preference rating per criterion; current (d_0) and future (d_1) state of the portfolio Global optimum alternative

Part IV – Pilot study evaluation

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14. Evaluating the pilot study

In this chapter the results of the pilot study evaluation are presented, according to the conceptual model in the figure below. Recall that the entire PAS comprises of the procedure, the process with the sequence of interviews and workshops that results in a final model and its outcome. The data for this chapter is obtained in individual evaluation interviews that were held with each of the stakeholders after each phase in the process. In total, interviews were held at three points during the process; after the model building interviews and after the first and second workshop. The interview protocol used in these interviews is based on the checklist that is part of the conclusions of chapter 7. The full protocol is presented and explained in appendix C. This evaluation chapter is structured after the elements in the checklist and together with chapter 15 it provides the answer to the third sub-question.

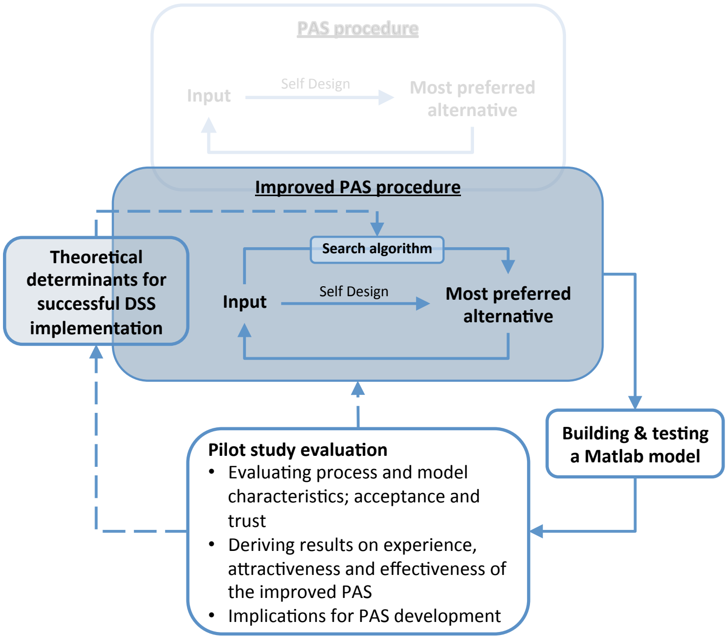

Figure 35 – Conceptual model with elaborated pilot study evaluation (own illustration)

14.1. Evaluating the PAS process and model

In general, the users evaluated the PAS as very positively. They even indicated that the model is a great improvement over their current process and they are looking forward to be able to implement the tool in their actual decision-making process.

Because this chapter will provide an evaluation of all the elements in the checklist individually, it is presented in the table below.

Process (p)/ system (s)	Characteristic	Evaluation category (Joldersma & Roelofs, 2004)	Resulting effect (Riedel et al., 2011)
P	Participation & involvement of users (Riedel et al., 2011); user consultation (Van Loon et al., 2008)	Experience	System acceptance
P	Stakeholder interaction (Van Loon et al., 2008)	Experience	System acceptance
P	Iterative system development (Van Loon et al., 2008)	Experience	System acceptance
P	Perceived control (Riedel et al., 2011)	Attractiveness	System acceptance
P	Familiarise with backside of the system (Riedel et al., 2011)	Experience	Trust in the system
P	Clear system goal (Van Loon et al., 2008)	Effectiveness	System acceptance
S	Complexity (Riedel et al., 2011)	Attractiveness	System acceptance
S	Calibrated variables (Van Loon et al., 2008)	Attractiveness	Trust in the system
S	Perceived usefulness (Riedel et al., 2011)	Attractiveness	System acceptance
S	Purpose (Riedel et al., 2011)	Attractiveness	Trust in the system
S	Perceived ease of use (Riedel et al., 2011)	Attractiveness	System acceptance
S	Performance reliability (Riedel et al., 2011)	Effectiveness	Trust in the system
S	Justification of outcome (Riedel et al., 2011)	Attractiveness/ Effectiveness	Trust in the system

Table 21 – Checklist for evaluating DSSs and their development process

The users indicated that they felt very much **involved** in the development of the model by thinking about the right selection of criteria and establishing preference curves. This made them accept the model and its outcome. They also think that the use of preference curves helped to develop their preferences and it better reflects the actual preferences. One of the AP team representatives indicated that

"she feels inclined to put more thought in fewer criteria, which means a choice for quality over quantity."

Both representatives of the AP team indicated however, that due to the complexity of the PAS principles, i.e. thinking in terms of criteria, preference curves and weights, the real challenge is to get the right people from the LOB's involved that are able to understand the principles and have the time to provide the right information. A manual, explaining the principles of each step of the PAS, might be helpful to improve the understanding.

Stakeholders experienced the **interaction** and combined effort in the process of establishing preference curves and criteria weights as extremely helpful. This also helped to develop their preferences.

The users think that the current process contains sufficient **iterations**. Moreover, they found the iterative model development process and the workshops extremely helpful to understand the principles of the PAS and the model, which increased their acceptance. As the representative of LOB 1 indicated, *“this [the PAS principles and model building process red.] gives a sense of analysis robustness to the user who is customising the variables that will contribute to the final results.”*

The effect of the current process is that the users have a positive **perception of their control** over the model, as they see the effects of their input. This partly resulted from their perception of involvement and the fact that a model has been developed with the right level of complexity.

The users have gained sufficient understanding of the **backside of the model**, during the workshops and through the explanation of the systems engineer, to trust the model and its outcomes. It made them understand how the model uses the physical location data to arrive at the preference rating. However, one of the users would be interested to develop more knowledge of the actual operations in Matlab.

In every model building interview and workshop, the **goal of the model** was recapitulated, in order to refresh this. According to the stakeholders’ answers, the goal was clear at all times.

All users indicated that the final **model complexity** reflects the actual decision-making process very well. Especially the improvements made in the model after the first workshop, by adding additional design constraints, helped to establish the right complexity level. This increases the users’ model acceptance. The representative of LOB 1 recognised that

“the good thing is that the model is flexible and just setting to 0% [weight red.] some of the variables, the complexity can be reduced if needed”

Both representatives of the AP team indicated that the **calibration of variables** at the end of the pilot study was sufficient. They both positively evaluated the flexibility in the procedure, which enabled adaptation of their input. One of them indicated that it was good to see the refinement of the model in the second workshop. Both aspects increased trust in the model.

The stakeholders’ **perception of the usefulness** of the model is very positive as well. In general, all of them see it as a very useful tool that they would like to use in the actual location decision-making process. They were specifically positive about the use of the preference curves to interpret the data, which results in a more refined interpretation and better representation of actual preferences than was possible in their original process. Also the users indicate that the optimisation with the brute force function adds up to their positive perception of the usefulness. However, one of the representatives wondered whether there are graphical representations of the outcomes possible that enable presenting the output to executives more easily. The positively perceived usefulness is directly connected to acceptance of the model, according to one of them.

The users indicated multiple times that they trust the model. The fact that the model in the pilot study was custom made for the **purpose** it was used for, might have had a positive influence.

In terms of **ease of use** of the model, the representatives of the AP team are divided to some extent. Both provided very positive feedback on the ease of use of the design interface, the feedback it provided on the locations selected and the constraints. Also designing and evaluating portfolio alternatives was easy enough. Together this increased their system acceptance. However, one representative indicated that in practice the ease of use would also depend on the amount and complexity of the back-end modelling that is required.

According to the users from the AP team, the model **performs as expected** or even better. The expectations were mostly confirmed during the workshops with the model. Also the model outcomes are in line with the expectations that are based on the understanding of the model. Especially the fact that there is a large overlap in the top-15 of the location ranking from the PAS, with that from the original study increases the trust in the model.

The **justification of the outcome** in the design interface is evaluated as sufficient by the stakeholders. One of the AP team representatives indicated that it would also help to increase the trust in the model from this perspective, when she would have an improved understanding of the model's back-end.

14.1.1. Experience, attractiveness and effectiveness

As described in chapter 2 on research methods, the PAS is evaluated on the criteria: user experience with the method, attractiveness of the method and the combined perception of the users and systems engineer regarding the effectiveness of the method.

As each of the characteristics of the checklist is connected to one of these criteria, it can be deducted from the positive evaluations regarding these elements that the users had a positive experience with the PAS in this pilot study. Also they clearly find the resulting model attractive, as they indicate that it is very useful and easy to use. The users indicate that it better represents the preferences than the current process, it is flexible and works efficient in terms of rating physical location data and also designing and comparing alternatives is easy. Also the optimisation with the brute force function is evaluated positively. Moreover, they said that they would like to use it in their daily practice.

The effectiveness of the tool as perceived by the stakeholders is good. As indicated by the LOB 1 representative,

"it is an excellent data driven tool to support the decision-making process."

The observations of the systems engineer regarding the effectiveness of the tool are summarised below. During the first interviews the stakeholders neatly picked first the bottom and top reference alternative and only then established the intermediate value. It was striking however that both interviewees most of the time automatically used the variable value of the EMEA headquarters as this intermediate reference, in order to determine the respective relation with the locations with a higher or lower value. They mostly did this in such a way that it received a preference rating of >50. Because the users really relate to the values they use in establishing the preference curves, the tool is quite effective.

Another observation is that during the pilot study, people from the LOB were not able to dedicate a lot of time to it. This could have been due to the fact that this was a research project without direct gain for the LOB representative. However, also in the original study, the AP team had to work under a certain time pressure. This could mean that the tool is only effective when used purely by the real estate department, to generate outcomes and present these to an LOB in question. On the other hand, however, only the first time use of the PAS with an LOB takes some more time, because users have to get used to the approach. Once this has happened in each global region and a broad set of criteria, preference curves, weights and design constraints has been established, for each new case only the first four steps of the PAS procedure have to be completed. Of course also location datasets have to be loaded, which should be updated once in a while. This would make it into a fairly effective tool for all users involved, in the systems engineer's perspective.

14.1.2. Acceptance and trust

From the checklist in the beginning of this chapter, it follows that each of the evaluated characteristics results in either acceptance of the system or trust in the system and its outcome. The results presented previously show that the stakeholders repeatedly confirmed their acceptance of the model and trust in the model.

A specific element that induces the user's acceptance of the model is the fact that they felt involved in the iterative development process of the model and gained understanding of the principles of the PAS and the model. Also the fact that the model is perceived as very useful in practice and very well reflects the actual decision-making process and the user's preferences, adds up to the acceptance level. This is summarised as follows by the representative of LOB 1:

"The model is flexible and gives the user levers for customising it in line with the requirements and the reality of the data points [i.e. criteria]."

According to the evaluation results, an important role in trusting the model is played by the knowledge of the principles of the PAS procedure and the backside of the model operations. Also the performance that exceeds the expectations plays a role here, especially the overlap in ranking from the PAS with the original study is deemed important.

In the final evaluation interviews, both representatives of the AP team were asked whether or not they accepted the optimum portfolio alternative they designed as final outcome of the self-design process and if they would use the current model in their daily practice.

Both of the AP team were very confident in their positive answer. Also they indicated that it would require only minor iterations on the data to actually implement the model's outcomes. Also one of them indicates that she would trust the optimum portfolio alternative found by the optimisation algorithm, because she understands the model. Still a question is, however, whether or not it would be possible for her to replicate the current model code for a similar project. The evaluation of the outcomes of the brute force function, instead of the algorithm, was quite positive. Both users accepted the number 1 alternative as the best outcome of the pilot study. However, one of them indicated that she feels a little more comfortable with the number 2, since Oracle has already a small office in location 26, which is incorporated in that alternative instead of location 27. However this does not affect the assessment of the brute force function since there is only an insignificant difference in preference between both alternatives. The other user indicated that she accepts it as the best theoretical outcome. She notes, however, that in reality this might not be the best solution since there is a current portfolio and there are no criteria included that rate making changes in this current state. Still both users indicate that their level of trust in the system is not affected and that the optimisation results strengthen their perceived usefulness of the improved PAS.

14.2. Conclusions

In Part II of the report, the question is posed whether or not the algorithm should be implemented in addition to the process of self-design. The literature study in chapter 7, shows the importance of participation and involvement and other elements to create acceptance and trust in the system. Therefore the conclusion is drawn that the algorithm should be implemented in addition to the process of self-design, i.e. in step 6 of the procedure.

The table below shows the development of the criteria and design constraints over the course of the pilot study. It shows that in the first interview the stakeholders established a set of criteria and one constraint that led to the resulting preference rating in workshop 1. After workshop 1, the users included three extra constraints. This shows that the users gained insight in their input through the self-design process in the first workshop and were able to adapt it accordingly. This resulted in a better representation of their preferences in the model. However, from the table it also becomes clear that no iterations were made in the criteria. This can be explained by the fact that this pilot study is conducted with an existing case for which the criteria were already deemed suitable. Finally the table shows that the brute force function was indeed able to find a portfolio alternative with a higher preference rating than the stakeholders could find in the second workshop. This confirms the first hypothesis established in paragraph 2.4.

Interview 1	Workshop 1	Interview 2	Workshop 2	Interview 3	Brute Force
Criterion A					
Criterion B					
Criterion C					
Criterion D					
Criterion E					
Criterion F					
Criterion G					
Criterion H					
Criterion I					
Criterion J					
Criterion K					
Criterion L	**Result: 71,30 (+9,87)**				
Criterion M			**Result: 64,46 (+3,03)**		**Result: 65,88 (+4,45)**
Criterion N					
Criterion O					
Criterion P					
Criterion Q					
Criterion R					
Criterion S					
Criterion T					
Criterion U					
Criterion V					
Constraint 1					
		Constraint			
		Constraint			
		Constraint			

Table 22 – Development of the criteria and boundary conditions

The evaluation of the improved PAS, confirms the above findings and shows that the participative process of self-design really pays-off in terms of model acceptance and trust in the model and its outcome. One of the stakeholders even indicated already before the search algorithm outcomes were available that she would trust them, because she understands how the model works. Eventually, the outcome of the brute force function was indeed accepted by the stakeholders as final result of the pilot study.

In the end of chapter 7, a few improvements in the pilot study are suggested based on the interview with Monique Arkesteijn, whom performed previous pilot studies. Improvements concern the way in which the users are made familiar with the backside of the system, the evaluation of the perceived ease of use and justification of the model outcomes by providing the preference rating per criterion. In the evaluation, the users were predominantly positive about these aspects, although for some the explanation of the model back-end could have been more in-depth.

This chapter provides answers to the first part of the third sub-question: *What is the judgement of the improved PAS by the stakeholders in practice, and what implications does this have?*

In general the users evaluated the improved PAS very positively. They were especially positive about their involvement in the iterative model development process, which made them understand the PAS and model principles. The use of preference curves, the selection of criteria and the adaptations made in the design constraints, made the model reflect their preferences and the actual decision-making process very well. Also the model usefulness was rated highly by the stakeholders. The representatives of the AP team were specifically enthusiastic about the visual feedback and ease of use of the design interface. Moreover, the model performed as expected from the process. Finally, both users also accept the outcomes of the brute force function as the final outcome of the pilot study. They regard it as a useful addition to the self-design process, which adds up to their positive perception of usefulness.

These results imply a positive user experience with the PAS. Also they find the model very attractive, and would like to use it in their daily decision-making process. Moreover, the model is deemed effective in the decision-making process by the AP team according to both the users and the systems engineer. These results again confirm again the second hypothesis in paragraph 2.4, that the algorithm could be best implemented in addition to the self-design process, since this was evaluated very positively.

In addition to this, the above evaluation results confirmed the expected relation between the participation and involvement, complexity, satisfaction and acceptance from the model by Riedel et al. (2011) in chapter 7. The users explicitly indicated that their involvement and the iterative model development were related to the model complexity that was established. This leads to a model that is very useful in their daily practice and is also easy to use. All these elements are directly connected to their acceptance of the model.

Also the conclusions from literature on how to establish trust in the model seem to be confirmed in the pilot study. As trust is made operational as the expectations of the tasks the system will perform and expectations and performance of the system are equal, users will put trust in the system. From the evaluation interviews it followed that the users have developed their expectations of the model performance during the model development process, while at the same time contributing to the input of the model. This brought the final model performance into accordance with their expectations, which resulted in trust in the model. Moreover, they indicated that the understanding of the model backside and the model output increased their trust.

However, there are also elements that can be improved. For instance one of the users asks for a more in-depth explanation of the backside of the model. Understanding of the complexity of the model code could influence her perception of the ease of use in broader terms and the trust in the usability of the model. The amount and complexity of back-end modelling required could also affect the attractiveness of the tool. Another aspect is that the complexity of the principles and the model could make it challenging to find the right people in the LOB's to collaborate with. An improvement in this light is to provide a manual with directions for each of the steps in the PAS. Also one of the users touches upon possible improvements of the graphical presentation of the output in order to present and underpin the results towards executives that are the final party to agree with the results although they are not involved in the process.

15. Implications for further development of the PAS

The conclusions from the evaluation presented in the previous chapter have their impact on the further development of the PAS. This chapter presents these implications. Hereby, the chapter provides an answer to the second part of the third sub-question: *What is the judgement of the improved PAS by the stakeholders in practice, and what implications does this have?*

In general the PAS was evaluated very positively and the process generated the necessary acceptance and trust that were required for use of the model and its outcomes. Therefore the evaluation did not have any structural implications for further development of the PAS. However there were some aspects that should be noted, although they were evaluated positively.

Most important is the conclusion on the user evaluation of the improved PAS, i.e. with the brute force function in addition to the self-design process. The evaluation is mostly positive and confirms that the self-design process results in understanding of the model and a better representation of user preferences. Also the outcome of the brute force function was received positively and accepted as the final result from the pilot study. This implies that in future studies, the PAS should be used with a search algorithm, or in less complex cases a brute force function, in addition to the self-design process.

An element that adds to a better model and results, which was perceived very positively, is the explanation of the PAS principles, e.g. explaining the process of establishing preference curves and the model backside. This increases understanding and helps the users to formulate improvements of their input to better reflect their preferences. It could be worthwhile to more explicitly discover these elements in further development of the PAS towards a standalone application. Also the development of an attractive, intuitive and informative design interface is important from this perspective.

In addition to the positive evaluations, the users also suggested some minor improvements. First is that the users were already looking beyond the actual results from the model and made the step towards presenting them to their executives. Therefore they touched upon the possibilities for visual representation of the outcome in order to present and underpin this easily. This is an element for further development of the PAS.

Another element is that the principles of the PAS might seem quite complex at first sight when you are not used to work that way, like the people from the LOB's, with whom the users have to collaborate. Therefore it could be worthwhile to develop a manual with directions for each step in the procedure, to make sure the stakeholders that will be involved from the LOB's know what is expected from them at what point in the process.

Part V – Discussion & conclusions

Downtown LA_Sep 2010 by: Bert Kucinski [CC BY 2.0]

16. The results in perspective

This chapter puts the results from the previous chapters in perspective by reflecting on the case and relevant process elements in order to put the results in perspective of the current research into the PAS. Where possible, the influence of unforeseen circumstances on the answers to the sub-questions is explained and the PAS process is put in the perspective of the original scorecard process. Also the chapter reflects on the general meaning of the results and whether they can be induced to the theory of implementation of DSS's.

16.1. Comparison with previous PAS pilots

The table below provides the basic data for a comparison of the case used in this research and design project with previous pilot studies with the PAS.

Characteristics:	Food facilities, Delft University of Technology (Pilot #1)	Lecture halls, Delft University of Technology (Pilot #2)	EMEA location portfolio Oracle (Pilot #3)
New or existing case	New	New	Existing
# Stakeholders	4	6	1 (one person representing an inclusive set of criteria)
# Criteria	17	28	22
# Design constraints	6	5	4
# Interventions	5	11	1
# Objects	14	18	32
Preference rating current portfolio	43	58	61,43 (correct Tetra rating)
Preference rating optimum alternative	96	69	65,88 (correct Tetra rating)
Algorithm applied	No	No	Yes (substituted by a brute force function)
Modelling programme	Excel	Excel	Matlab

Table 23 – Comparison of PAS pilots; Pilot #1 (Arkesteijn, Binnekamp, & De Jonge, 2016, pp. 7-13), Pilot #2 (Arkesteijn et al., 2015, pp. 109-117)

The table above shows that the previous two cases have an increasing level of complexity. The main characteristics that determine the complexity are the number of locations and interventions, since these are basic determinants for the number of solutions as shown in chapter 3, although the design constraints also play a role. However, also the increase in the number of stakeholders and criteria points to an increasing level of complexity.

In comparison with the previous cases, the case used in this research and design project was less complex. The main basis for this statement is the fact that only one intervention is possible, i.e. switching a location on or not, which makes designing portfolio alternatives quite simple. Also the interventions did not comprise of changes in the physical characteristics of the individual locations like in the previous cases. Another fact that influences the relatively low complexity is that there was only one representative for the criteria used in this pilot. Despite the fact that the criteria that are expected to be representative for multiple stakeholders within the LOB, it seems that less perspective differences had to be bridged during the pilot study, compared to previous cases. This does not mean that there are no conflicting criteria involved because there are. For instance, looking at the location data, criterion A and R are generally conflicting for the cities included in the study. Moreover, an existing case was used, which means that the criteria were already developed previously. The previous elements appeared unexpectedly during the process, and had to be coped with. Also the original location study that would be reproduced in this project did not have a design element, this has been implemented for the sake of testing the PAS.

Because of the relatively low complexity, the Oracle case did not fully meet the requirement of testing the improved PAS in a more complex case then previously. This was meant to see the boundaries of self-design and the added value of the algorithm by finding a higher rated alternative. Nevertheless, the outcome of the pilot study showed that even with the case used in this research and design project, there was a clear boundary to the preference rating found in the self-design process. The brute force function proved its added value by finding an alternative wit a higher preference rating.

Table 23 also shows that in previous PAS pilots, the model was built in excel. This programme is better accessible for companies because they use it every day. However, in an excel model, the data is stored in multiple locations, which means that changes have to be made multiple times, which makes it prone to errors. In this pilot study, Matlab is used for the first time to model the case.

At first sight Matlab has a few disadvantages as it not directly available for companies because of the expensive licence and the time it cost the systems engineer to get used to it. Also initially there was quite some uncertainty about the possibilities for developing an attractive user interface.

The pilot has shown that the Matlab model provides great overview in the model and it provides a structure that is relatively easy to understand and explain to the users. Also adapting the model according to the stakeholders' preferences is quite efficient once the model structure is established, since data is stored in only one location and functions are linked. This makes it less prone to errors as changes have only to be made once. Eventually it was even possible to build an attractive interface that resulted in very enthusiastic users because it provided a good overview and visual feedback on the portfolio alternatives designed. Most important is that the Matlab model can be connected to the search algorithm, to find an optimum alternative. Moreover, the evaluation results of the pilot study are a proof of concept for this type of models in Matlab.

However, there are also drawbacks of using Matlab. So far it was not possible to provide the users with visual feedback on where on the preference curves the portfolio alternative that is being designed, is rated. Also in this case there was only one intervention, however, in case of a more complex model it might be hard to implement all interventions in a single GUI screen.

Nonetheless, another positive element of the current case is that due to the level of complexity, users could understand what was going on in the model, although there was a second element that influenced this. The original process of location studies used by the stakeholders in practice is already quite advanced, therefore a part of the users was already used to several elements in the PAS, e.g. formulating and using criteria, weighing criteria and calculating a rating per location. This might have spurred the understanding of the PAS and the model. Nonetheless, the case provides the lesson that in order to make users understand, accept and trust a model, it is helpful to start with providing insight in a less complex model first, before expanding it to the full scale.

The interview with Monique Arkesteijn in chapter 7 showed that all elements of the checklist compiled in that same chapter are more or less included in previous pilots. So in that sense this pilot does not have many novelties. However, there were some improvements regarding explanation of the model and evaluation of perceived ease of use, which have been implemented in this pilot study. Both were evaluated positively. Also the other checklist elements were evaluated explicitly, which confirms that the PAS helped to in generating acceptance and trust..

Since the case did not have the complexity that was aimed for, it is interesting to see to what extent this influenced the answers to the research questions. With regards to the first sub-question, it can be concluded that there was no influence, since this question did not involve the case. Looking at the answer at the second question, the complexity of the case might have made it easier to obtain a positive answer because it takes less time and iterations to construct a model that closely reflects the stakeholders' preferences. In that sense, the answer itself was not affected. It could be reasoned that there is a more clear effect on the answer to the last sub-question. A part of the positive evaluation could be attributed to the fact that the original process used by Oracle was already quite advanced, which made it easier to understand the PAS. Also the fact that an existing case was used could have increased the understanding and therefore the positive evaluation. Also the initial knowledge level of the users meant that there was more time to go in depth in the time available, e.g. on the explanation of the model backside. This might have been an additional element in the positive evaluation. However, the way of modelling, the design element and the design interface were entirely new elements for the users in the pilot study. Also the use of the brute force function, which has the same characteristics of a "black box" represented by the actual algorithm, to generate the optimum alternative, was new to the stakeholders. Therefore, in conclusion, the effects of the relatively low complexity of the case on the answers to the third sub-question are expected not to have been significant.

An unforeseen element in the pilot study was the fact that the algorithm output was not available during the workshops. It would have been valuable to compare its outcome several times with the result of the self-design process and to evaluate the users' experience after each workshop. However, the outcome of the brute force function was discussed and evaluated with the users after the pilot. This evaluation confirmed the user statement, that they trust the outcomes of the algorithm or brute force function because they know how the model works. However, one of the users noted that some criteria related to moving from current locations in the portfolio are not included. Since the users' evaluation of the model regarding to the ranking of locations was very positive, apparently there are additional criteria required to also make the model outcomes in terms of portfolio alternatives closely reflect the stakeholders' preferences. Nonetheless, also this aspect did not influence the answers to the research questions.

From this pilot study, also a conclusion regarding the use of a brute force function relative to the actual search algorithm can be drawn. As explained in chapter 12, the added value of the brute force function is that it provides the global optimum portfolio alternative instead of a local optimum. Despite that it is expected that the algorithm would have found the same optimum alternative, it cannot be assumed that this is the global optimum. Therefore, in relatively simple cases where it is possible to generate all feasible alternatives, it is preferable to use a brute force function instead of the search algorithm.

16.2. The highest possible preference rating

The ranking of locations from the PAS model on page 82, shows that location 21 obtained the highest preference rating, i.e. 70,43. Despite the fact that this rating is just an approximation of the actual preference rating and these ratings are not directly used to calculate the overall preference rating of a portfolio alternative, an important conclusion that can be drawn from this data, is that no portfolio alternative will have a preference rating above this value. Therefore the portfolio could never be fully aligned with the business, even if no design constraints would be imposed. This raises the question why this is the highest preference rating and how it is possible that this cannot be increased.

The main cause for this maximum rating is a combination of the criteria established and the accompanying preference curves. Looking at the individual preference ratings per location per criterion, location 21 has a preference rating higher than 70,43 on 16 of the 22 locations. Obviously, this is nullified by the 6 criteria on which the location receives a lower preference rating. A brief analysis of these 6 criteria shows that between half and all of the other locations receive a rating below their weighted average on these criteria. So no higher preference rating is possible due to these conflicting criteria. However, an additional aspect of this issue is the fact that it is not possible to intervene in the physical characteristics of the objects in the study. Since these are locations and not real estate objects, their characteristics are fixed and cannot be changed to obtain a higher preference rating.

Another interesting question is whether or not the model could be used to design the optimum location, i.e. the location with a preference rating of ca. 100. Theoretically, his exercise could be conducted by looking at the physical values connected to the top reference of each preference curve. Combining al those values in one hypothetical results in a preference rating that could equal 100. However, as shown above, some of the criteria are conflicting in reality in the locations in this case and the exact relationships between their values are unknown. Therefore this theoretical exercise would yield a merely utopian location that might only be useful in practice to know where to look for.

16.3. PAS in perspective of the scorecard process

Based on the outcomes of the pilot study, combined with the evaluation results and observations of the systems engineer, this paragraph presents a comparison between the original scorecard process and the PAS. Furthermore it shows the improvements the PAS provides for the Oracle Advanced Planning (AP) team compared to the scorecard process.

At first sight, there are quite some similarities between the PAS and the scorecard system. Both approaches rate locations based on a set of criteria and weights that are developed by the stakeholders in an iterative process. These ratings are used to rank the locations and to choose the one with the highest rating or rank.

However, the procedure in the PAS is more structured and the involvement of the stakeholders is guaranteed in the steps of the procedure. In practice this is implemented in a structured set of interviews and workshops. This process is repeated iteratively as long as the stakeholders deem necessary to make improvements in the model to make it better represent their preferences.

Also the stakeholders' preferences are incorporated in the PAS model in a more fundamental way than in the scorecard, although this already does quite well. In the latter, the stakeholders are involved in the development of the criteria and establish weights, but the AP team determines the relation between the physical location data and the 1-5 rating used to rate the locations. In the PAS, the stakeholders themselves establish this connection, by means of preference curves. Together with their role in establishing the criteria weights, their preferences are better represented in the model. Despite having anchored the stakeholders' preferences quite deeply into the PAS model, it is still easy to adapt them. Moreover, in the PAS the stakeholder preferences are measured correctly according to the paradigm discussed in chapter 5, whereas in the scorecard process incorrect 1-5 scales are used.

In terms of effectiveness of the tool, i.e. in rating and comparing locations, the PAS is much more efficient. It is very easy to rate and rank additional locations after the first time use by a particular LOB, because only new location data has to be added to rate a new location. In addition to this, the PAS process enables the design of portfolios and connected to this, the possibility to incorporate design constraints. Moreover, the PAS model, both with and without algorithm, is a goal-oriented system that provides users with the possibility to optimise their portfolio, a feature that is not incorporated in the original scorecard process.

Another element is the attractiveness of the PAS for the users. They indicated that compared to the scorecard process, the PAS provides a better representation of the stakeholders' preferences and is very useful and easy to use. Especially, when a good manual for the business users would be available, it would become more attractive for them as well.

Finally, it might be surprising that Oracle did not come up with the elements that are incorporated in the PAS. Part of an explanation could be that they were unaware of the existence of other models for alignment and their different characteristics and features. Therefore it could be that they just improved their own process over time, based on the in house knowledge available. Another aspect, the correct measurement of preferences, is a fairly unexplored subject, so it is explicable that they did not know about it. Moreover, their scorecard system is already quite advanced over the systems that other companies use, e.g. a NPV calculation tool with a separate table with preference information. This might have reduced their need to look around further.

16.4. Induction of PAS evaluation results to DSS literature

The evaluation of the pilot study confirms the theoretical findings that it is best to implement the algorithm in addition to the process of self-design, because the users were very positive about this element of the process. Moreover, one of them indicated already before the outcome of the algorithm was available, that she would trust it, because she understands how the model works. When the outcome was presented in the end, both users from the AP team confirmed their acceptance of the portfolio alternative. This is the best confirmation of the findings that could be wished for.

Moreover, the evaluation results confirm the relationships found in literature between user involvement and acceptance and the final model performance and trust. The stakeholders also confirm the relationship between these two models as suggested in chapter 7. This relationship states that user involvement and participation, which leads to system acceptance, can bring into accordance the users' expectations of the model and the actual model performance, because the input provided by the users influences the performance. Trust is developed at the point where performance meets expectations. This was clearly the fact in this pilot study. Therefore the conclusions could be added to the literature on successful DSS development and implementation. However, also here holds that the low complexity of the case might have made it easier to understand the model and therefore increased trust. Nonetheless, the fact that a large multinational company like Oracle confirms this relationship and the importance of these aspects, can be interpreted as a confirmation of their reliability.

17. Final conclusions

In this chapter the final conclusions from this research and design project are presented. This is done following the structure of the report and thereby providing the answers to the sub-questions. In the end of the chapter, the main question will be answered, based on the results. The structure of the report resulted from this main research question and is summarised in the conceptual model below.

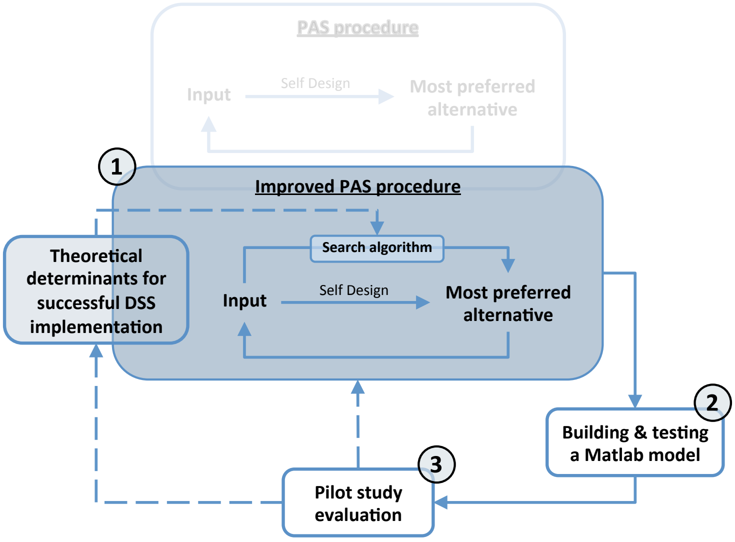

Figure 36 – Conceptual model (own illustration)

Before presenting the conclusions from the subsequent parts of the report, first the research questions are refreshed. The main research question that is covered in this research and design project is: *How could an improved PAS be developed in such a way that the outcome of the algorithm closely reflects the stakeholders' preferences and what insights do a test and evaluation in practice provide?*

This question rose from a literature study meant to provide an overview of the development process of the PAS. This touched upon the lack of knowledge regarding the implementation and use of a support system like the optimisation algorithm and provided a recommendation for further research in a pilot study with the improved PAS.

The main question comprises of three parts that gave rise to the formulation of the following three sub-questions:

1. *What is theoretically the best way to implement the search algorithm in the PAS?*
2. *Does the outcome of the algorithm reflect the stakeholders' preferences?*
3. *What is the judgement of the improved PAS by the stakeholders in practice, and what implications does this have?*

17.1. Part I – Problem analysis

The relevance of the development of the PAS is found in the long-standing issue in CREM practice concerning the alignment between the business and real estate strategy and the problems with the current models available. The PAS, as a solution for these issues, stands out by combining quantitative data with qualitative assessment to arrive at a real estate portfolio strategy that is assessed by one single preference rating, based on correct preference measurement. Moreover, the PAS can be seen as an integral MCDA tool that is able to help develop a transparent model to design acceptable real estate portfolio solutions for a large group of stakeholders by analysing an almost infinite number of alternatives with the algorithm. Moreover, it is a tool that could also be implemented in current alignment models.

The self-design element in the PAS reflects the aspect of designer thinking, which is specifically taught at the Faculty of Architecture at Delft University of Technology. This helps to discover possible alternatives and can help to bridge the gap between the business perspective and real estate perspective.

Earlier tests with the PAS have been successful and have shown that the iterative process of designing portfolio alternatives helps the users to develop insights in the effects of their input on the results. The possibility to adapt the input helps to improve the reflection of their preferences in the model. This increases the quality of the results.

After previous pilots, the recommendation has been made to implement a search algorithm in the procedure that is expected to find an optimum alternative with a higher preference rating than stakeholders are able to obtain in the self-design process. Such alternative would result in better alignment of corporate and real estate strategy and therefore in a higher added value of the real estate portfolio to the company. However, the optimisation algorithm is not able to find the optimum solution with certainty, the limitation is that it is not clear if it finds the global optimum, or a local optimum.

17.2. Part II – Towards a solution

The literature study into the implementation of Decision Support Systems (DSS) resulted in a checklist with 13 characteristics that determine the success of a DSS development and implementation process. Each characteristic results in either system acceptance or trust in the system, which are both elements required for success. A comparative interview on the coverage of checklist elements in previous PAS pilots showed that most elements are already included in PAS. Also it provided some suggestions for improvement that are taken into account in this pilot study.

In this project, the checklist was used to prepare the pilot study process in order to achieve high levels of acceptance and trust, it was also used as a basis for the pilot evaluation in order to improve the PAS procedure and model development process in the future.

These findings resulted in the following answer to the first sub-question: *What is theoretically the best way to implement the search algorithm in the PAS?*

One of the most important elements in the process is the involvement of stakeholders in the model development process from the start, because user participation creates system acceptance and brings into accordance the expectations of the model and the actual system characteristics. This improves trust in the system and system use. Therefore the algorithm should be implemented in addition to the process of self-design and iterative model development, in step 6 of the PAS procedure. This answer confirms the second hypothesis in paragraph 2.4.

The practical implications of this answer are that the users should have a clear understanding of the goal of the model and process and that they have a basic understanding of the principles of the PAS during each step, e.g. understanding how the preference curves are used in the model and generate them visually while they are established. Also the model should be developed iteratively, using the self-design process to let the users gain insight in the effects of their preferences and gain an understanding of the model in order to achieve the best possible representation of their preferences in the model.

17.3. Part III – Model building & tests

Part III starts with a description of the current alignment process within the Oracle Advanced Planning (AP) team. The scorecard process they use is already quite advanced and results in a transparent decision-making process. Working with the scorecards keeps the AP team in control over the alignment while the actual stakeholders, the LOB's, can influence the outcomes by partly determining the criteria and establishing weights. However, the 1-5 scale system to rate the locations is incorrect.

In this pilot study, the original location study for LOB 1 was reproduced with a selection of the original criteria while covering all categories equally. In this study, one stakeholder representative was involved that confirmed the selection of criteria that represented all the involved perspectives in the LOB. This person also established the preference curves. This means that no stakeholder weights are involved. The pilot study reproduced the location ranking and included the design of a hypothetical optimum location portfolio for LOB 1.

Both the Matlab model and the GUI meet most of the requirements formulated upfront. Only the visual representation of the portfolio alternatives in a map was not possible. However, it was possible to implement some additional features like saving and recalling alternatives and visual feedback on the design constraints. The model output consists of two elements; a ranking of locations based on their individual preference rating and an optimum portfolio design alternative found by the stakeholders in the self-design process.

The final ranking shows that a large part of the top-15 of the original ranking returns in the ranking from the PAS, this is confirmed in Tetra. Also the final choice of LOB 1, location 13, went up from place 17 in original ranking to 4 in PAS ranking, which makes it to the second most preferred alternative location. This is an initial indication that the model quite closely reflects the users' preferences, which is confirmed by the users in the evaluation.

The optimum portfolio alternative found by stakeholders through self-design, provides an improvement of 5% in alignment over the current portfolio of LOB 1, based on preference ratings confirmed in Tetra. Eventually it was possible to generate all feasible portfolio alternatives by means of a brute force function. This has the advantage that it provides the global optimum portfolio alternative, which has a higher preference rating than the alternative found by the stakeholders. This confirms the first hypothesis in paragraph 2.4 and improves the alignment rating of the portfolio with 7%. The users accepted this alternative as the final outcome of the pilot study.

The results of the pilot study are a basis for the answer to the second sub-question: *Does the outcome of the algorithm reflect the stakeholders' preferences?*

Yes. Both representatives from the AP team indicated after the pilot study that they feel confident with the location ranking from the PAS and that they accept the alternative with the highest preference rating from the brute force function as the final outcome of the pilot study. This confirms that model closely reflects their preferences, however according to their evaluation of the optimum result, the location ranking better represents their preferences than the optimum portfolio alternative. A better reflection of their preferences in the latter would require some additional criteria.

17.4. Part IV – Pilot study evaluation

This part of the report presents the evaluation results of the pilot study. During the pilot study, the stakeholders have been interviewed three times, using an interview protocol based on the checklist from chapter 7. Also the outcome of the brute force function has been evaluated later on.

The evaluation results, as presented in chapter 14, are used to answer the third sub-question: *What is the judgement of the improved PAS by the stakeholders in practice, and what implications does this have?*

The stakeholders are especially positive about their involvement in the model development process and the iterative nature of it. They indicate that this helped them to understand the model and PAS principles. Also the use of preference curves is rated very positively, because the users see that this gives a better representation of the actual preferences. Together with the adaptation of their input, this results in a very useful model that closely reflects the actual decision-making process. Finally they are enthusiastic about the intuitive way in which they could design portfolio alternatives in the design interface.

The result of the process is that the users accept and trust the model and its outcomes, which is confirmed in the evaluation. Moreover, the users experienced the model positively and find it an attractive and effective method to find alternative solutions. The users indicated that they accept the outcome of the brute force function as being the optimum portfolio alternative. However the reflection of their preferences could be increased for the portfolio alternative by adding some criteria, nevertheless the brute force function still increases their perceived usefulness. This confirms the effect of the designer thinking on bridging of the gap between business and real estate perspective. Moreover, it also confirms the answer to the first sub-question.

Also there are suggestions for improvements. The users indicate that it could be a challenge to get the right people involved from their LOB's and to receive the required information. Something that could enhance this process is to make use of a manual to explain each step of the PAS in order to make people understand what is expected from them. A final improvement suggested is to find a way to represent the model outcomes in a visually attractive way in order to make it easy to present and underpin the results to executives.

An important implication of the evaluation results is that, given that the evaluation of the output from the algorithm is positive, because of the positive user perception of the current process, in future studies with the PAS, the algorithm should be implemented in addition to the self-design process. Also there should be a focus on explaining PAS principles during the process, which could be done by means of a manual. Further development of the PAS in the form of a standalone application should take this into account, as well as the visual presentation of the model output.

17.5. Answering the main research question

The main research question that is covered in this research and design project is: *How could an improved PAS be developed in such a way that the outcome of the algorithm closely reflects the stakeholders' preferences and what insights do a test and evaluation in practice provide?*

In this research and design project, an improved PAS has been developed based on the checklist developed from theory with determinants for successful DSS implementation. The PAS model was built in an iterative process where the stakeholders were closely involved from the start. This process followed the entire PAS procedure and for each of the steps, the principles, goals and expected results were explained to the users as insightful as possible. Together with the workshops, in which the users operated the model, the users gained a good understanding of the effects of their input and the model itself. This helped them to make valuable improvements in the model, which increased the reflection of their preferences. The users confirmed this explicitly at the end of the second workshop.

The results of the pilot study showed an improvement in the representation of the users' location preferences in the final ranking of locations and in the self-design process, the users found an optimum alternative with an improvement in the alignment of 5% compared to the current portfolio. The stakeholders accept this result as the best possible result from the self-design process. Moreover, the equivalent of the algorithm, the brute force function, was able to find an optimum portfolio alternative with an even higher preference rating with an increase of 7% in the preference rating that was accepted by the users as the final outcome of the pilot study.

The pilot study was evaluated very positively. The stakeholders felt very much involved in the process and indicated that they feel comfortable with the model and its output. Moreover, they indicated that they would like to use the model in their actual decision-making process because it better represents actual preferences, it works quite efficient and it is easy to design and compare alternatives. Furthermore, the evaluation showed that the process resulted in acceptance of the model and brought into accordance the users' expectations with the model characteristics, which resulted in trust in the model. One of the users even noted that she would trust the outcome of the algorithm to be the best portfolio solution, because she understands how the model works.

The users evaluated the optimum alternative positively, although the second outcome, with an insignificant lower preference rating, might feel somewhat more comfortable. Also one of the users indicated that some additional criteria would increase the reflection of the actual decision-making process in the optimum portfolio alternative. Still the users indicate it improves their perception of usefulness.

The final outcome is the absolute optimum portfolio alternative in this case and shows an increase of 7% in the alignment between the real estate and the business of LOB1. This means that the model is capable of increasing the added value of real estate to the organisation by improving the decision-making process. Even more so because the users indicated that they accept this outcome and would use the model in their actual decision-making process.

The significance of the findings in this pilot study is in the fact that Oracle is a very large, globally operating company and although their current process was already quite advanced, they still see the improvement of the PAS procedure and indicate that they would really like to use the tool in their daily work and to implement its outcomes.

18. Recommendations for further research

Based on the conclusions in the previous chapter, the following recommendations are made for future research.

The pilot study in this research and design project is evaluated very positively. Therefore an important recommendation for future research is to so use the improved PAS with the search algorithm implemented in addition to the self-design process. The modelling should take place in Matlab as the resulting model can be connected to the algorithm.

However, because this case included one stakeholder representative whom brought in criteria and one intervention, another recommendation for further research is to test the improved PAS in a complex case including multiple stakeholders involved in the pilot with multiple interventions. Such a case is expected to provide additional insight in the boundaries of the self-design process in terms of the improvement of the preference rating that can be achieved and the capabilities of the search algorithm in this respect. This should help to increase the added value of real estate to the business as much as possible.

Nevertheless, it is recommended to use a less complex model, e.g. a basic model with 3-5 criteria and objects with a few interventions, to explain to the users how it works. The current pilot study has shown that this helps to make the stakeholders understand the model, which increases their acceptance of the model and trust in the model and its outcomes. Another recommendation for further research in this direction is to develop a manual that describes the PAS principles per step and indicates what information and thoughts are expected from the stakeholders involved from the business.

In this research and design project, the algorithm was substituted by a brute force function, which incorporates the important advantage that it finds the global optimum alternative. It could be valuable to find out in further research what the boundaries are for using such a function in terms of the number of feasible alternatives combined with the calculation time. In relation to this, it might be worthwhile test the performance and reliability of the algorithm, using brute force functions. Comparing the outcomes of both methods in cases with increasing complexity, could provide insight in the performance of the algorithm.

The enthusiasm of the users for the PAS in this pilot study shows that the tool has a lot of potential. Therefore it might be worthwhile in the future to research the possibilities to develop a standalone application in which users can develop their own model, following the PAS procedure. However, previous pilots, including this one, have shown that each case is different and requires different functionality. Because of this, a recommendation is to first test the PAS in a few more cases within large multinationals to see what possible requirements businesses could have for such an application. Once such an application has been developed, the PAS can be spread faster and more efficiently, hereby creating a bigger impact on the alignment problem in CREM and increasing the added value of real estate for businesses on a larger scale.

Regardless of the research into a standalone application, it could be valuable for future pilots and a possible application, to research in what way the algorithm could be implemented in a PAS model. This would improve the pilot study process and provides more opportunities to test and evaluate the user experience with the outcomes of the search algorithm. Moreover, it would make the model that is developed and a possible application more user friendly.

A final recommendation for future research is to focus on the way the outcomes of the model and the algorithm are presented. When this could be done in a visually attractive way it would be easier for the users to present the results to executives and use the visuals to underpin the outcomes.

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Appendices

Appendix A – Matlab modelling exercise

This document presents the elaborate problem description, the model structure and the results from the modelling exercise as presented in chapter 8 of the report.

Why Matlab?

The software that is used to model this PAS case is Matlab. This mathematical calculation software is based on data caught in matrices and allows the user to write multiple interrelated functions that together form a model. The advantage of this way of working is that in case of adding objects or alternatives, the systems engineer only has to do this once.

Moreover, the search algorithm that will be tested in this research project has been written in Matlab. In order to be able to apply the algorithm on a real estate decision-making case using the PAS, the model that describes the stakeholders' input should also be written in Matlab.

Problem description

The problem description is based on a case from a previous pilot study with the PAS at Delft University of Technology (Arkesteijn, Valks, Binnekamp, Barendse, & De Jonge, 2015; Valks, Arkesteijn, Binnekamp, Barendse, & De Jonge, 2014), and is strongly simplified for the sake of this experiment. The supply of lecture halls of the university does currently not meet the demand in terms of capacity and functionality. More specifically, situations occur where some lecture halls are overcrowded during lectures and others are only used half with a small group of students. This is due to the fact that a suitable lecture hall is not always available at the time of the lecture. Also the location of the lecture hall plays a role as the scheduling department will try to accommodate students and teachers at- or close to the own faculty, but this is not always possible. Therefore students and teachers sometimes have to travel on campus quite a bit in between lectures.

In addition to the capacity problem, also the functionality of the lecture halls does not meet the demand. A lot of students want to use their laptops during lectures, however only a few lecture halls have sufficient power plugs. Also not all lecture halls feature a projector and only few dispose of a smart screen. Moreover, the seats are often placed in a fixed structure, which decreases the possibilities to use those halls for interactive lectures and collaborative activities.

The summary of this problem is that the capacity of the lecture halls is not able to accommodate the demands and requirements of the teachers and the scheduling department. The discrepancy in size and the traveling time between lecture halls hampers the effectiveness of both students and teachers. Moreover, most lecture halls are rather dated in terms of their features, which hampers the learning process of the students. In order to facilitate the current education style, a plan should be made to improve the characteristics of the portfolio of lecture halls to the current standards.

Translation of the problem description to operations research method

The demand is translated to a set of criteria accompanied by preference functions that establish the relation between the demand and the supply. It should be noted here that what is referred to here as a "criterion" is a "decision variable" in the PAS terminology, but as a "variable" has a different meaning in the Matlab environment, this word should be avoided. The preference functions are formulated for each decision variable and are defined by three points; the least preferable value of the variable (x_0, y_0), the most preferable value of the variable (x_1, y_1) and an intermediate value that determines the slope of the curve (x_2, y_2). The preference rating yielded by these functions shows the extent to which the supply meets the demand on a scale from 0 (lowest match) and 100 (maximum match).

Proposed changes in the supply lead to a new state that is meant to match supply and demand in the future. This new state gives a future preference rating that reflects this match.

The model requirements established in this experiment are the following; the model should be able to determine the preference rating per criterion for a set of potential future portfolio alternatives. It is able to present these preference ratings per demand criterion in order to show the decision maker how changes in the demand (i.e. the preference function) lead to a different preference rating of the supply and how a change in supply could accommodate the demand. It should also provide a weighted overall preference rating for each of the possible future supply states (i.e. the portfolio alternatives). These ratings should be provided in such a way that the user is able to visually compare them with each other and with the current supply rating.

The above is summarised in the table below, which shows a hypothetical set of objects (lecture halls) with a set of characteristics that was made up for this experiment. This is presented in a so-called Operations Research table that was adapted to this case. The criteria that are used to provide the imaginary portfolio with an overall preference rating are also partly made up. Because the table is meant to explain the principle, the data is not optimised in any way.

	Preference rating		***Number of objects:***		***Number of characteristics:***		
Current state:	61		5		3		
Future state:	70						
Portfolio alternatives:	5						
Object number:	#1	#2	#3	#4	#5	Total	***Characteristics:***
Example:	102	278	334	98	289	1.101	Capacity (# seats)
	1	0	0	1	0	2	Flexible (1/0)
	13.770	-	-	13.230	-	27.000	Costs (EUR)
	Variable value (calculated from alternative)						***Preference rating***
Criterion 01	Total capacity			1101			96
Criterion 02	Percentage flexible			40%			45
Criterion 03	Average capacity			220			80
Criterion 04	Total Costs			27000			60

Table 5 - Problem statement in OR table

The model

The model in Matlab is built with two types of elements; initial data presented in matrices and scripts that contain a function that uses this data to make the required calculations. These scripts are also interrelated, as a part of them needs the output of others. The model structure is presented in figure 23.

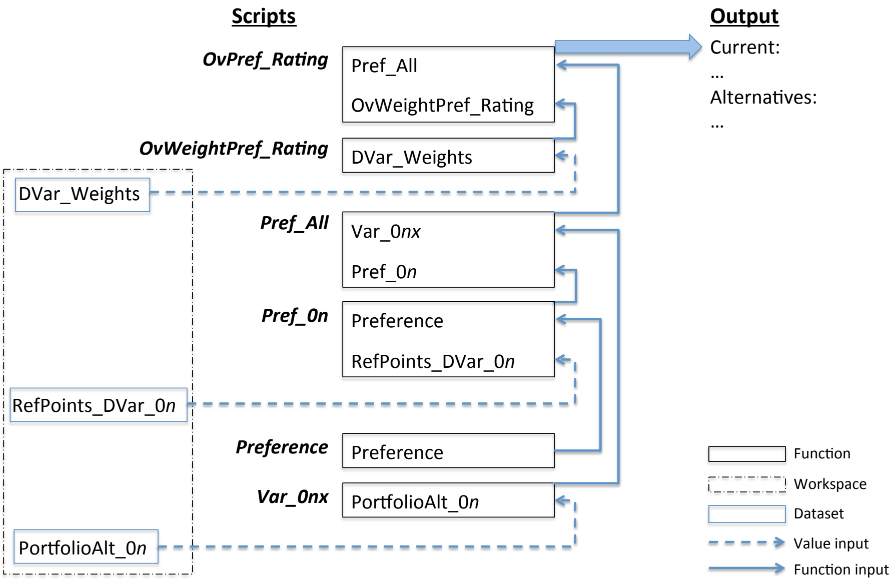


Figure 23 - Model structure (own illustration)

The structure should be read from top to bottom. The script OvPref_Rating provides the output of the model. The function in this script calculates the overall preference rating of the current portfolio and the portfolio alternatives. In order to do so, it invokes the output values from the function Pref_All (continuous line) and OvWeightPref_Rating. In the Matlab model this is written as follows:

```
function OverallPref_Rating = OvPref_Rating
%Calculates the overall preference rating per portfolio alternative
and presents all preference ratings

global PortCurrent
global PortAlt_01
global PortAlt_02
global PortAlt_03
global PortAlt_04
global PortAlt_05

OverallPref_Rating = [OvWeightPref_Rating(Pref_All(PortCurrent)),
                      OvWeightPref_Rating(Pref_All(PortAlt_01)),
                      OvWeightPref_Rating(Pref_All(PortAlt_02)),
                      OvWeightPref_Rating(Pref_All(PortAlt_03)),
                      OvWeightPref_Rating(Pref_All(PortAlt_04)),
                      OvWeightPref_Rating(Pref_All(PortAlt_05))
                      ];

disp('Current:')
disp(OverallPref_Rating(1,:))

disp('Alternatives:')
disp(OverallPref_Rating(2:end,:))

bar(OverallPref_Rating,'b','EdgeColor','k','LineWidth',1.5);
end
```

This function again calls for the data from dataset DVar_Weights (dashed line). The same holds for the relations between other functions in figure 23. All datasets are part of the workspace and are saved in a file called InitData.mat. When loading the workspace, this file is invoked and generates the required variables. The model is written in such a way that to implement a new portfolio alternative, only the script OvPref_Rating needs to be changed. When adding a decision variable, this still needs to be done in multiple scripts. An explanation of each element in the model is provided in the table below.

Elements:	**Description:**	**Invokes:**
Scripts		
OvPref_Rating	Calculates **overall preference rating** for each portfolio alternative. And provides this as output of the model.	Pref_All OvWeightPref_Rating
OvWeightPref_Rating	Calculates the **weighted overall preference rating** for each portfolio alternative from the individual decision variable preference ratings that are calculated by Pref_All.	DVar_Weights
Pref_All	Calculates a set of individual decision **variable preference ratings for each portfolio alternative** by providing the function Pref_0n with the required x-value input from Var_0nx and presents this in an array.	Pref_0n Var_0nx
Pref_0n	Calculates the **preference rating for decision variable 0*n*** by using the function Preference with input from RefPoints_DVar_0n and an additional x-value.	Preference RefPoints_DVar_0n
Preference	Produces an interpolation of the three given reference points in RefPoints_DVar_0n, in order to calculate the preference rating with a given x-value input.	-
Var_0nx	Calculates the **input value x** for each decision variable 0n based on the portfolio alternative data in PortfolioAlt_0n.	PortfolioAlt_0n
Datasets		
DVar_Weights	Contains the **relative weights of the decision variables**.	-
RefPoints_DVar_0n	Contains the three given **reference points** (x0,y0; x1,y1; x2,y2) for calculating the preference rating for each decision variable. (the model contains 4 decision variables)	-
PortfolioAlt_0n	Contains the data on the criteria that are defined for each **individual portfolio alternative**, including the current portfolio state. (the model contains 1 current portfolio and 5 portfolio alternatives)	-

Table 6 - Description of the model elements

The decision variables that were used, combined with the given reference points for the preference curves and weighing are presented in table 7.

Criterion	**Preference curve reference points**	**Weight**
Total capacity	x0, y0 = 200, 0; x1, y1 = 1.200, 100; x2, y2 = 500, 60)	15%
Percentage flexible	x0, y0 = 0, 0; x1, y1 = 90, 100; x2, y2 = 30, 50)	25%
Average capacity	x0, y0 = 0, 0; x1, y1 = 185, 100; x2, y2 = 350, 0)	20%
Total costs	x0, y0 = 80.000, 0; x1, y1 = 0, 100; x2, y2 = 35.000, 40)	40%

Table 7 - Criteria, preference rating and weight

Assumptions

Several assumptions are made to make the model work. The portfolio alternatives are generated randomly, with different capacities per lecture hall for which no costs are calculated. The only costs that are calculated are the costs to make a lecture hall flexible. These costs are EUR 135 per seat and are also calculated for one of the lecture halls in the current portfolio that was recently renovated as a pilot.

Results

The initial result that is obtained with the input provided above is presented in the table below. The model provided the output in two different segments; the preference rating of the current portfolio and the ratings of the alternatives. The bar graph makes it possible to easily compare the outcomes of the model and select the one with the highest preference rating. The first bar in this graph represents the current portfolio rating, the bars to the right present the preference rating for the alternatives. The output is in accordance with the requirements as stated before.

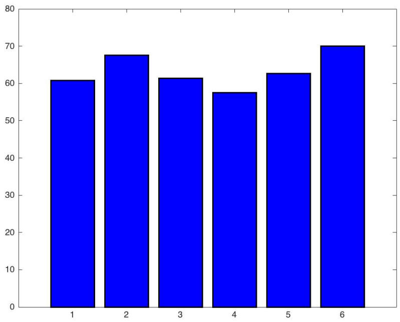
Overall preference ratings		***Individual preference ratings for best alternative (#6)***	
Current: 1. 60.8154 Alternatives: 2. 67.6351 3. 61.4031 4. 57.6282 5. 62.6873 6. 70.0619		Total capacity (15%)	100.0000
		Percentage flexible (25%)	62.9630
		Average capacity (20%)	93.6346
		Total costs (40%)	51.4857

Table 8 - Model output, list and graph

This table shows that the alternative under number six is the best solution given the preference ratings and variable weights. When looking at the characteristics of alternative six, this outcome fits the expectations. The number of flexible halls is quite high with relatively low costs and as these two variables have the highest weighing, respectively 25% and 40%, it receives a high preference rating. Small changes in the weighing (changes of about 2-5% per decision variable), do not influence the spread in preference ratings. The sensitivity of the outcomes to this is only numerical and quite low.

Larger changes in the weighing however, have quite a big influence on the outcome. A shift of the weight away from costs to flexibility results in changing preference ratings as shown in the table below.

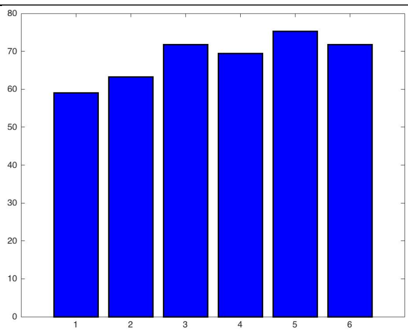
Overall preference ratings		***Individual preference ratings for best alternative (#5)***	
Current: 1. 59.0396 Alternatives: 2. 63.2438 3. 71.7949 4. 69.4551 5. 75.3322 6. 71.7835		Total capacity (15%)	93.1063
		Percentage flexible (40%)	96.2963
		Average capacity (20%)	99.2425
		Total costs (25%)	11.9969

Table 9 - Model output, list and graph

Although the most preferred alternative (#5) has a rather low preference rating for the total costs, it still receives the highest preference rating. This can be attributed to the low weight of the cost variable in the total rating. This shows that the influence of the weighing on the overall preference ratings is quite large. The alternative with favourable characteristics for the criterion with the highest weight is likely to become the alternative with the highest overall preference rating.

Appendix B - Technical model explanation

This document provides a brief instruction to the use of the model and explains all functions and variables and how they are interrelated.

Instruction

Step 1

Extract the zip-file in an empty directory/folder and select that folder in MatLab under Current Folder.

On the left a list of functions, workspaces and other files are displayed.

Step 2

Run script Load_Workspace.m to load the workspace saved in InitData (containing all necessary variables) into memory. The script also clears the current workspace, the command area and runs several functions that generate output data to make sure this is up to date. When the workspace is loaded into memory, the variables are listed in the workspace window.

Model structure explanation
In the model two parts can be distinguished. One calculates the overall preference rating for a portfolio alternative. The other part generates all physical values and preference ratings per location per criterion and calculates the overall preference rating per location. This data is to be used by the stakeholders in the workshop to design portfolio alternatives.

Overall portfolio preference rating

The main functions for this part, together with the important variables are briefly described in the table below. The column with the title "Calls", shows which other functions or variables the script calls for. The next column presents which of the other scripts call for that script or variable.

#	Elements:	Description:	Input:	Calls:	Called by:
	Script/function:				
1	Load_Workspace.m	Loads the workspace into memory by initialising InitData, which contains all the necessary variables.	-	-	-
2	Port_OvWeightPref_Rating.m	Function that calculates the overall weighted preference rating of a given portfolio alternative.	V1	3, 4, V2-4	-
3	IsFeasible.m	Tests the portfolio design for meeting the design constraints.	V1	-	2
4	Port_Pref_All.m	Function that calculates the preference ratings per criterion for a given portfolio alternative.	V1	5	2
5	Port_Pref_*n*.m	Function that calculates the portfolio preference rating for criterion *n*, based on the corresponding average physical value for a particular portfolio alternative.	V1	6, 7, V6	4
6	Port_Val_*n*.m	Function that calculates the average physical value for criterion *n*, based on the individual physical location values in a particular portfolio alternative.	V1	V5	5
7	Preference.m	Function that generates an interpolation of the three given reference points in V6, in order to calculate the preference rating with a given physical value input.	V6, 6	-	5
	Variables:				
V1	IN_Portfolio.m	Contains all locations that can be switched on (1) or off (0) in a certain portfolio alternative.	-	-	2-6
V2	DVar_Weights.m	Contains the relative weights of the decision variables.	-	-	2
V3	Stakeholder_Weights.m	Contains the weights assigned to the stakeholders involved. (only one in this case)	-	-	2
V4	DVar_StakeholderCrit_match.m	Matches a criteria weight to a stakeholder weight by providing the corresponding index number of the stakeholder weight in V3.	-	-	2
V5	LocData_*n*.m	Contains the physical data per location for criterion *n*.	-	-	6
V6	RefP_LOB_*n*.m	Contains the three given reference points (x0,y0; x1,y1; x2,y2) given by the stakeholder that determine the preference function for criterion *n*.	-	-	5

Table i - Description of the model elements, for calculating the overall portfolio preference rating

Overall location preference rating
The table below presents the most important functions and variables of the second part of the model.

#	Elements:	Description:	Input:	Calls:	Called by:
	Script/function:				
1	Loc_Data_All.m	Script that obtains all physical values per criterion, calculates all preference ratings per criterion and calculates the overall weighted preference rating for all locations.	-	2	-
2	Loc_Data.m	Function that obtains the physical value per criterion, calculates the preference rating per criterion and calculates the overall weighted preference rating for a particular location.	Location #	4, V2-6	1
3	Loc_Ranking.m	Script that obtains all location names/codes and their preference ratings and ranks them based on descending rating.	-	1	-
4	Preference.m	Function that generates an interpolation of the three given reference points in V6, in order to calculate the preference rating with a given physical value input.	V6, 6	-	5
	Variables:				
V1	IN_Portfolio.m	-	-	-	-
V2	DVar_Weights.m	Contains the relative weights of the decision variables.	-	-	2
V3	Stakeholder_ Weights.m	Contains the weights assigned to the stakeholders involved. (only one)	-	-	2
V4	DVar_Stakeholder Crit_match.m	Matches the criteria weights to the required stakeholder weight.	-	-	2
V5	LocData_*n*.m	Contains the physical data per location for criterion *n*.	-	-	2
V6	RefP_LOB_*n*.m	Contains the three given reference points (x0,y0; x1,y1; x2,y2) given by the stakeholder that determine the preference function for criterion *n*.	-	-	2
V7	Locations_Values.m	Output from 1 and presents all physical location values.	-	-	-
V8	Locations_Ratings.m	Output from 1 and presents all location preference ratings	-	-	-
V9	Locations_OvWeightPref_Ratings.m	Output from 1 and presents all location overall preference ratings.	-	-	-
V10	Locations_ Ranking_by_ Rating.m	Output from 3 and presents all locations ranked by their respective preference rating.	-	-	-

Table ii - Description of the model elements for calculating the location specific preference ratings

GUI function
In addition to the functions described above, there is also a function called *Main20.m* that is used to initiate the Graphical User Interface (GUI). In this interface, the users can design portfolio alternatives and calculate the overall preference rating. The code in *Main20.m* makes use of all functions in the upper table i. The document *Main20.fig* only contains the visual design of the GUI.

Step 3
The functions from the table are described below.

Port_OvWeightPref_Rating

Syntax	Port_OvWeightPref_Rating(StateVector) The state vector is an alternative in the form (x_1,...,x_{32}) where x_j is the state of location j, that can be switched on (1) or off (0) in the alternative.
Return value	This function returns the overall weighted preference rating based on the average physical values for all criteria in the portfolio, taken into account the design constraints.

Port_Pref_All

Syntax	Port_Pref_All(StateVector) The state vector is an alternative in the form (x_1,...,x_{32}) where x_j is the state of location j, that can be switched on (1) or off (0) in the alternative.
Return value	This function returns the portfolio preference ratings for all criteria, based on a given portfolio.

Port_Val_All

Syntax	Port_Val_All(StateVector)
Return value	This function returns the average physical values for all criteria, based on a given portfolio.

IsFeasible

Syntax	IsFeasible(StateVector) The state vector is an alternative in the form (x_1,...,x_{32}) where x_j is the state of state of location j, that can be switched on (1) or off (0) in the alternative.
Return value	This function returns the value 1 if the state vector meets all constraints, i.e. is feasible and 0 if the state vector does not meet all constraints.

Loc_Data

Syntax	Loc_Data(pLocation) pLocation is the location index number from the list of locations as used in this model.
Return value	Given the location index number, this function returns three elements for each location: • The overall weighted preference rating for this location • The physical values for each criterion. • The preference rating for each criterion, based on this physical value.

Loc_Data_All

Syntax Loc_Data_All()

Return value This script provides the function Loc_Data with the input, all location index numbers, in order to obtain the return values from this function for all locations. These numbers are stored in the following variables:

- The overall preference ratings are stored in Locations_OvWeightPref_Ratings
- The physical values are stored in Locations_Values
- The preference ratings are stored in Locations_Ratings

Loc_Ranking

Syntax Loc_Ranking()

Return value This script returns the location names, together with the location overall weighted preference rating in a ranking with descending preference rating. This is stored in the variable Locations_Ranking_by_Rating.

Port_Pref_*n*

Syntax Port_Pref_*n*(VariableValue)

Return value Given a physical variable value, this function returns the corresponding preference for criterion *n*.

Port_Val_*n*

Syntax Port_Val_*n*(StateVector)

The state vector is an alternative in the form $(x_1,...,x_{32})$ where x_j is the state of location j, that can be switched on (1) or off (0) in the alternative.

Return value This function returns the value of the physical variable for criterion *n*, based on the average location data for each portfolio design alternative.

Appendix C – Evaluation interview protocol

After each workshop, an evaluation interview was held with each of the stakeholders individually. The interview comprised of an evaluation of the process up to that point. This document presents the interview protocol that is used for this, preceded by a brief explanation.

Explanation protocol

The first question covers the first three characteristics in the checklist in chapter 7 of the report, together with the fifth. The latter is covered specifically in a sub-question. This question provides indicators for the first category in the evaluation structure by (Joldersma & Roelofs, 2004), the users' experience with the tool.

Question two and three cover the aspects 4, 7-9 and 11 from the characteristics checklist. Characteristics 4 and 11 are covered in sub-questions to respectively question two and three. Both questions provide indicators for the attractiveness of the model, which is the second aspect in the evaluation structure.

The fourth question is about aspect 12 of the characteristics list and covers aspect 13 in a sub-question. The question provides indicators for the last element in the evaluation structure, the effectiveness.

The characteristics 6 and 10 are not covered in the questionnaire, as they are not expected to add a lot of value for the aspects in the evaluation structure they cover.

Intro

The interview takes about 30 minutes. Do you agree when I record it?

This part of the interview is meant to identify how you experienced the workshop with the PAS model, and the process prior to this, including the information provided beforehand and the preference function interviews. A part of the questions will focus on your confidence in this method with respect to the extent it fits its intended purpose and how it works and its effectiveness in achieving its goals.

Evaluation questions

Main question	Follow-up questions
1. Do you think there were sufficient iterations in the model development process to review the model and to discuss and adapt the input and the model itself? (Characteristic 1-3, 5)	- If not; how does this make you feel about your involvement in the model development? o To what extent do you think that it hampered the process of gaining insight in the decision variables you find important and their influence on the outcome? o To what extent do you think it hampered the development of your preferences? o How would you rather have seen this process? - If yes; how does this make you feel about your involvement in the model development? o To what extent did it help you to gain insight in the decision variables you find important? o To what extent do you think it helped to develop your preferences? o Do you have suggestions for improvement? - How does the process influence your acceptance of the model and its outcomes? - To what extent did the process help you to gain insight in how the model roughly works and how does this influence your trust in the system?
2. To what extent do you think the model complexity reflects the real life decision-making process? *(i.e. the number of variables, formulation and simplifications)* (Characteristic 4, 7-8)	- If not; what causes for this would you indicate? (relation with iteration/involvement?) o How could this be improved in the future? - If yes; how was this right level of complexity achieved? o Were there moments you believed the model was too complex/too simple and how was this solved? o Do you have suggestions for improvement? - How does the complexity influence your acceptance of the model? - Are the model variables sufficiently calibrated with your preferences? o How does this influence your trust in the system?
3. What is your perception of the usefulness of the model? *(useful to perform the task assigned to it)* (Characteristic 9, 11)	- If not; could you indicate what causes this? o How could this be improved in the future? - If yes; is there a specific element that induced this? o What advantages do you think the model provides in practice? o Do you have suggestions to improve this further? - How do you think about the ease of use of the model? o Why do you think this? o How could this be improved? - How does this influence your acceptance of the model?
4. To what extent do you think the model performs as you expected? (Characteristic 12, 13)	- If not; what causes this? (relation with participation?) o Do you think your expectations were particularly high, or the performance rather low? o How does this affect the effectiveness of the model? o How could it be improved? - If yes; Do you think your expectations were particularly low, or the performance quite high? o Do you have suggestions to improve this further? - Does the model sufficiently justify its overall outcome? o If so, do you think this is useful and why? - How does this influence your trust in the system?