

RISK MITIGATION IN LOCATION DECISION-MAKING



Colophon

Risk mitigation in location decision-making

Delft University of Technology
Faculty of Architecture and the Built Environment
Master Management in the Built Environment

Student

Name Jeroen Paul Meijler
Student number 4144562
Address Caan van Necklaan 23
2281 BA Rijswijk
Phone +31(O)6 - 81 77 16 58
Mail jeroenmeijler@hotmail.com | jeroen.meijler@eu.jll.com

Supervisors

1st mentor ir. M.H. Arkesteijn MBA
Faculty of Architecture and the Built Environment
Department of Management in the Built Environment
Assistant professor Real Estate Management & Development
m.h.arkesteijn@tudelft.nl

2nd mentor dr. ir. R. Binnekamp
Faculty of Architecture and the Built Environment
Department of Management in the Built Environment
Assistant professor Design & Decision systems
r.binnekamp@tudelft.nl

3rd mentor ir. R.P. de Graaf
Faculty of Architecture and the Built Environment
Department of Management in the Built Environment
Assistant professor Design & Decision systems
r.p.degraaf@tudelft.nl

Commissioner drs. Dirk Dubbeling
Faculty of Architecture and the Built Environment
Department of OTB - research for the built environment
Support
d.j.dubbeling@tudelft.nl

Company mentor Remco van der Mije, MSc.
Jones Lang LaSalle
Corporate Solutions - Strategic Consulting
Head of strategic consulting
remco.vandermije@eu.jll.com

Company mentor ing. Erik Geerdes
Engie Services Nederland
Manager vastgoed
erik.geerdes@engie.com

"There are three things that matter in property: location, location, location"

Lord Harold Samuel

"There is nothing permanent, except change"

Heraclitus

Preface

Before you lies the conclusion of my years at the Delft University of Technology. This thesis is the last step in graduating the master Management in the Built Environment at the Faculty of Architecture and the Built Environment. In this graduation research, I have combined the elements that characterised my journey as a student. My bachelor in Architecture taught me the designerly way of thinking. Gradually, step-by-step testing and refining the thesis and the computational model that is part of this research helped me in achieving a better result and allowed for approaching things from a different perspective.

The quantitative minor Finance helped me to gain more foundational knowledge on stock markets and risk management. Although sometimes quite daunting, the minor helped in becoming a real engineer, and certainly has become an important element in this final research. The thesis is at the intersection between real estate management and risk management, blending forecasting techniques and risk management with preference measurement.

During my master, a wide range of aspects of the built environment were discussed. This triggered my interest in corporate real estate management and strategic management specifically. Without this background, I would not be able to complete this thesis.

Here, I would like to take the opportunity to sincerely thank everybody that helped me in the process of writing this thesis. First of all, I would like to thank my main mentors, Monique Arkesteijn and Ruud Binnekamp, for guiding me and asking the critical questions that triggered me in digging further and explaining things more thoroughly. Beginning this thesis was difficult, and I was struggling finding the exact approach for this research topic. However, you have helped me to make a sound and complete report.

Secondly, I would like to thank Rein de Graaf, for his extensive knowledge on computational modelling. Even though I had some experience in coding, the help of Rein was indispensable and without his help it would be much harder to develop a functional model.

Lastly, special thanks go out to Erik Geerdes and the real estate team at Engie Services Netherlands, and Remco van der Mije and the JLL Strategic Consulting team. They have helped me test a model in development and enabled me to refine and improve the procedure.

Enjoy reading,

Jeroen Meijler
October 2017

Summary

Introduction

"Deciding where to locate all or part of your business in an uncertain world is critical to competitiveness and success." (Weeink, Frost, Duncan, & Carroll, 2017, p. 2). Location decision-making is a complex process carrying high risk if it is not done effectively. An ever-changing environment complicates the process even more, as decisions have a long-term impact and locations must be planned for the future.

Location decision-making is part of the Corporate Real Estate Management discipline, whose main objective can be defined as: "the management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation." (Krumm, Dewulf, & De Jonge, 2000, p. 32).

The added values Krumm et al. are referring to have been researched in multiple efforts over time. One of these added values consistently mentioned, risk control, is still underexposed in research (Bartelink, 2015, pp. 21-22), with only a few publications available on the topic of Corporate Real Estate Risk Management (see for example (Gibson & Louargand, 2002; Huffman, 2003, 2004; Simons, 1999). However, in studies it was found that companies that have an active risk management policy were 4,8% more financially valuable than comparable organisations that did not, with outliers up to 16% (Smithson & Simkins, 2005).

With the absence of research in Corporate Real Estate Risk Management, the importance of risk management is clearly underexposed. In location decision-making, the risks are evident. A wrong location decision not only has effects on the real estate costs, but on the entire business process. Location decisions have an impact on the company's ability to establish and maintain a competitive advantage (Rymarzak & Siemińska, 2012).

Location risks originate from a deviation in the preferences a company has for their real estate location and the actual characteristics of that location. Therefore, it is important to assess the match of a real estate portfolio with the business strategy and the preferences of the stakeholders involved. For this, use can be made of the Preference-based Accommodation Strategy design approach (PAS), developed by Arkesteijn and Binnekamp (Arkesteijn, to be published; Arkesteijn & Binnekamp, 2014; Arkesteijn, Binnekamp, & De Jonge, 2016; Arkesteijn, Valks, Binnekamp, Barendse, & De Jonge, 2015). This method allows the involved stakeholders to find the optimal real estate portfolio that matches best with the preferences and constraints indicated. However, PAS does not take into account the uncertainty of changes in location characteristics and preferences. Incorporating risks in a portfolio location decision-making process through an adaptation of the PAS design approach is therefore the topic of this research.

Research objectives and methods

The main research question of this research is:

how can risk management effectively be incorporated in a preference-based location decision-making process?

The objective of this research is to develop a framework that takes into account both demand preferences and risks of changing location characteristics. The development of such framework requires theoretical insights in multi-criteria decision making, preference-based decision making, location decision making, risk management and uncertainty. The

preparatory theoretical research is therefore based on three main elements of this research, location decision-making, preference modelling & decision modelling and risk management, preceded by a general introduction of corporate real estate management. These three elements are combined into a Location Decision-Making framework, which is an adaptation of the PAS design approach. This framework is tested in a pilot study, testing the effectiveness of the model.

Method

The research is conducted as a hybrid research, combining operational and qualitative research elements. This is because the main research question can be seen as a two-sided question. First of all, the question comprises of a design problem, requiring the development of an artefact (a framework for location decision-making) as to arrive at a solution. Secondly, the research question requires an answer on the effectiveness of the model. This effectiveness is tested by doing research in the form of a pilot study and evaluation interviews, where stakeholders are questioned on the ability of the model to answer to their specific needs in terms of a location decision. Combining these two elements results in a new Location Decision-Making (LDM) framework, that incorporates the element of risk in a preference-based location decision-making process, that is tested and evaluated in a pilot study in practice.

For the research, use is made of a literature study, the development of a model, a pilot study, interviews and workshops.

Introduction to the research field of corporate real estate management

Corporate Real Estate Management (CREM) originated some 250 years ago in response to the first industrial revolution that required special accommodation to manage the industrial activities. Over time, the role of CREM changed, becoming more strategic, and focussing on the added value of real estate to the corporate business. This led to the goal of CREM to be defined as: *"the management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation."* (Krumm et al., 2000, p. 32)

In 1993, Nourse and Roulac made the first attempts to discern added value through real estate, by providing 8 corporate strategies which were translated into corresponding real estate strategies. Over the years, multiple efforts have further developed the research into added values of real estate (De Jonge, 1996; de Vries, de Jonge, & van der Voordt, 2008; Den Heijer, 2011; Lindholm & Leväinen, 2006; Nourse & Roulac, 1993; Scheffer, Singer, & Van Meerwijk, 2006; Van der Zwart, 2011), resulting in the following 12 added values of real estate: (1) decreasing costs, (2) supporting user activities, (3) increasing (user) satisfaction, (4) improving quality of place, (5) supporting culture, (6) stimulating collaboration, (7) stimulating innovation, (8) supporting image, (9) increase flexibility, (10) increase real estate value, (11) controlling risk, and (12) reducing ecological footprint.

This research focusses on one of these added values, namely controlling risks. This is done through a framework that complies with the overall goal of CREM, in that it tries to find the real estate location that aligns best to the needs of the core business.

Location Decision-Making

Location decisions are part of the corporate real estate strategy of a company. This strategy is based on the corporate business strategy, the organisational characteristics of the company and the current real estate portfolio characteristics, showing the direct relationship between corporate real estate strategies and corporate business strategies.

The corporate business strategy brings forward demand criteria for real estate. This corporate strategy can be induced from the driving force a company has: the *raison d'être* for the company. Tregoe and Zimmerman identified nine driving forces, which determine the future product and market scope that define a business (Tregoe & Zimmerman, 1980).

The corporate business strategy can be developed from the driving force, which has a direct influence on the demands a company has for its real estate.

Each driving force and each company has their own unique set of demands for a location. These demands are unique to each company. However, in research, some basic criteria can be found that are often important for a company's real estate decision. In a research by Korteweg, it was found that accessibility by car, parking possibilities and representativeness of the location were the most important factors for location decisions (Korteweg, 2002). In a more recent research by Remøy and Van der Voordt, accessibility by car, representativeness and accessibility by public transport were mentioned as the most important factors (Remøy & Van der Voordt, 2013).

Although these researches provide a number of basic criteria that are often important for a company when deciding on the location, the demand preferences of a company are always specific for that company itself, due to their specific company strategy. Therefore, it is always important to define the relevant criteria for the company itself when developing a real estate strategy.

Preference modelling & decision modelling

In real estate decision making, often multiple criteria which can be conflicting have influence on the decision-making process. For this, Multi-Criteria Decision Analysis (MCDA) can be used. MCDA can be seen as a formal approach, which seeks to "take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton & Stewart, 2002, p. 2). Within real estate, several MCDA models exist. In their paper, Arkesteijn and Binnekamp evaluated a number of CREM and Public Real Estate Management models based on two main criteria of good models: (1) the use of mathematical operations, and (2) the types of scales used in relation to preference measurement (2014). In this paper, the authors concluded that no model existed that made use of mathematical operations whilst making use of proper scales for preference measurement.

Preference measurement and modelling is the translation from demands into a mathematical model, as "to enable the powerful weapon of mathematical analysis to be applied to the subject matter" (Campbell, 1920, pp. 267-268). Preference modelling is therefore the translation from an empirical system to a mathematical model. One of the difficulties of preference measurement is the principle of reflection (Barzilai, 2010). The principle of reflection states that only if in the empirical system a change in value can be measured and quantified, it is allowed to make this change in the mathematical system. When for example only the relative length of an object is known (object A is longer than object B), it is impossible to multiply the length of object A, as the exact length is unknown, despite it being possible in the mathematical model.

Correct preference measurement is done through strong scales. Such scales are constructed using two objects or points, which are the reference points for rating the preferences. Next, a preference curve can be constructed, which reflects the preference a person has. This curve is based on three objects or points. This follows from the formula used to generate a curve, namely $\frac{A-B}{C-D} = k$. 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). An example of such curve is found in Figure 1.

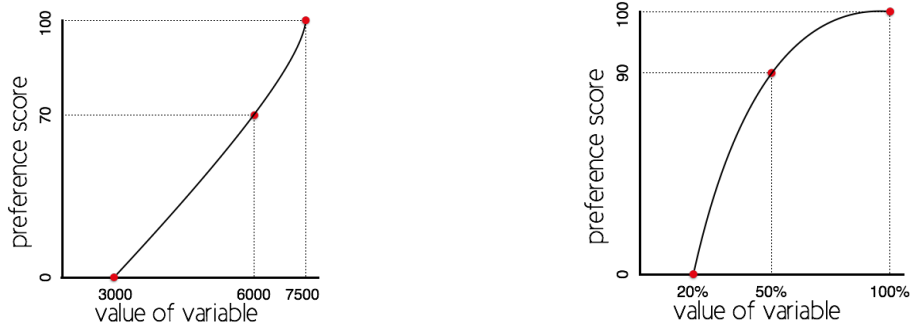


Figure 1: examples of a preference curve for two variables (own illustration)

As Arkesteijn and Binnekamp found that no decision model in real estate adhered to strong scales whilst allowing for the use of mathematical operations (adhering to the principle of reflection), the Preference-based accommodation strategy (PAS) design approach was developed (Arkesteijn et al., 2016, 2015).

PAS is a further development of the Preference-based design procedure developed by Binnekamp (2010). This procedure allows stakeholders, based on their preference, to design alternatives on a building level. PAS allows designing alternatives for an entire portfolio, finding the real estate portfolio that best matches the preferences set forward by the stakeholders involved.

The PAS design approach consists out of three main elements: the steps (procedural rationality), activities (structural rationality) and a mathematical model (substantive rationality). In the procedural rationality, consists out of 6 steps, which describe what the involved stakeholders should do and in which sequence. The structural rationality provides the approach of following these steps, dividing the steps in interviews (i) and workshops (w), in the form i-w-i-w-i. Finally, the mathematical model is the supporting tool, in which all information is fed, supporting the stakeholders to make a decision. The process of PAS is summarised in Figure 2.

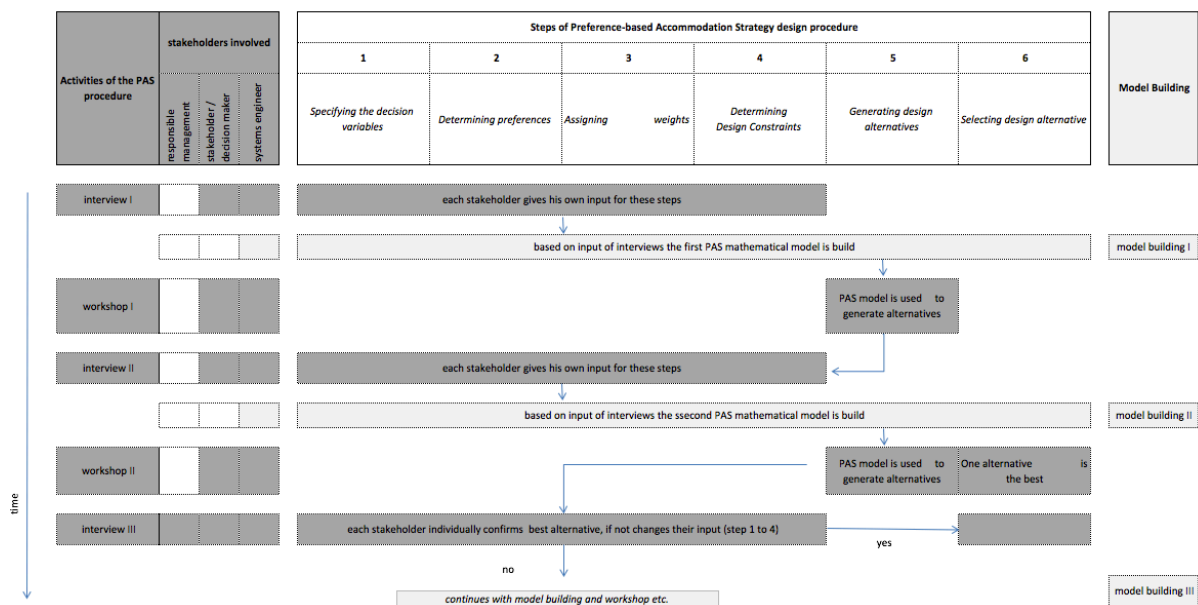


Figure 2: flowchart of the PAS design approach (Arkesteijn, et al. 2017)

The PAS design approach is a preference-based decision-making model that makes use of correct preference measurement and correct scales. Therefore, it is the ideal basis for the incorporation of risks in a preference-based decision-making process.

Risk management

Risk consist out of two elements: the probability of an event occurring, and the magnitude of loss/gain resulting from this occurrence (Rafferty, 1994). Although closely linked, a significant distinction between risk and uncertainty can be made. When dealing with risk, an outcome may or may not occur, but its probability of occurring is known, whereas when dealing with uncertainty, this probability is unknown (Sloman, 1995). Risk management can be seen as the identification of risks and acting on this identification process through activities and measures aimed at controlling the risks. For this, three main steps can be taken, within a larger risk management process visualised in Figure 3.

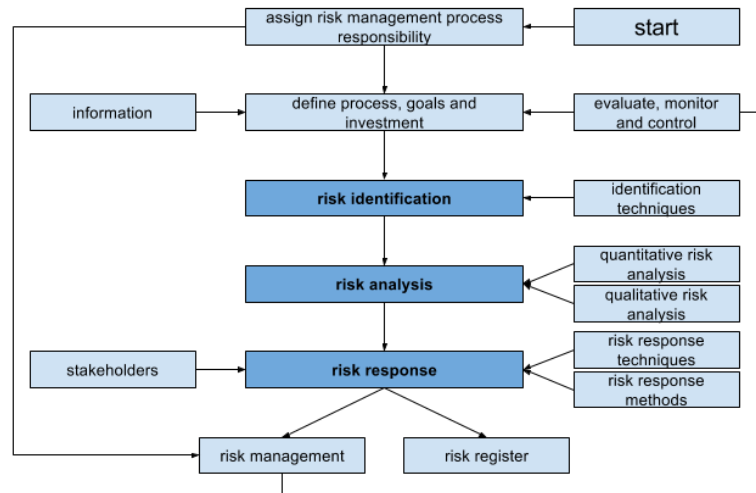


Figure 3: simplified version of the corporate risk management process (adaptation from (Merna & Al-Thani, 2010))

Risk identification

The first stage in risk management is the determination of the risks which are likely to affect the performance of a strategy. Risk identification consists of systematically mapping the risks in a project. For this, a wide range of tools are available, based on *stakeholder help, previous experience, diagramming techniques, testing and modelling* and other techniques. In this research, interviewing and expert opinions are used as the main risk identification techniques.

Risk analysis

Risk analysis is the second step of the risk management process. Analysis can be done both qualitative and quantitative. If data is available, quantitative analysis is often preferred, as risks are analysed numerically, resulting in a quantitative value for risk. This enables risks to be sorted by their impact and risk management performance can be observed closely. The objective of risk analysis is to provide an estimate of the expected outcome and its volatility or possible deviation from the expected mean, as this can be converted into a probability of event and the magnitude of gain/loss, defining the amount of risk. Such probability curve can be developed by using forecasting techniques.

For forecasting techniques, accuracy of the forecast is obviously stated as the most important criterion for selecting the appropriate technique (Yokuma & Armstrong, 1995). Next to this, timeliness, flexibility of the technique, ease of use and the possible incorporation of judgemental input are considered to be important criteria. Table 1 gives an overview of several forecasting techniques, ranked based on these criteria.

Table 1: Overview of forecasting techniques (own illustration based on (Armstrong, 2001; Chambers, Mullick, & Smith, 1971))

Category	Qualitative techniques				Time series analysis				Causal methods			
	Delphi method	Basic market research	Panel consensus	Scenario planning	Moving average	Box-Jenkins	Trend projections	Regression models	Econometric models	Input-output models	Life-cycle analysis	
accuracy	Very good	Fair	Good	Fair	Poor	Very good	Good	Very good	Excellent	Not applicable	Poor	
timeliness in providing forecasts	Very good	Fair	Good	Good	Poor	Good	Good	Good	Excellent	Very good	Fair	
flexibility	Depends on accessibility experts	High	Depends on accessibility experts	High	High	High	High	Low	High	Low	Medium	
ease of use	High	High	High	High	Medium	Medium	Medium	Low	Low	Low	Medium	
incorporating judgemental input	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes	

What should be noted, is that every model requires the use of accurate data, as results will never be reliable if incomplete or inaccurate data is used.

From the table, it follows that an econometric model is the best method for forecasting. However, econometric models require extensive modelling of a large number of variables which are interrelated. For the purpose of this research, this can be heavy-handed, as it requires identification of a large number of underlying variables and testing. Therefore, the Box-Jenkins forecasting technique, part of time series analysis is applied in this research. The method allows for making a probability curve.

A time series is a set of observations x_t , each one being recorded at a specific time t (Brockwell & Davis, 2002). The purpose of time series analysis is to draw inferences from the recorded time series. A simple time series process is $X_t = m_t + s_t + Y_t$, where m_t is a slowly changing function, known as the trend component. s_t is the seasonal component, with a known period d and Y_t is a residual random noise component that is stationary.

Stationarity implies that a process holds true to two statements (Tsay, 2005):

- (1) $\mathbb{E}[X_t] = \mu$ is independent of t
- (2) $Cov(X_{t+h}, X_t)$ is independent of t for each h

The basic time series model that is applied in this research, is the autoregressive integrated moving average model (ARIMA(p,D,q)). This model has a differencing component, allowing the time series to be made stationary. Differencing is done by observing the change between two observations, which is written as: $y'_t = y_t - y_{t+1}$. The autoregressive component considers the part of the model in which the value X_t depends linearly on its own past values X_{t-i} . The moving average component on the other hand considers the part of the model in which the value X_t only depends linearly on the current and various past values. Combined, the time series process can be defined as:

$$X_t = c + \varepsilon_t + \sum_{i=1}^p \varphi_i X_{t-i} + \sum_{i=1}^q \theta_i \varepsilon_{t-i}$$

where c is a constant value, ε_t is white noise and φ_i and θ_i are the parameters of the model. These parameters show the relative influence of that part of the equation. φ_i indicates how much the value X at time t is influenced by the value X at time $t-i$, which is the autoregressive element of the equation. θ_i on the other hand, is the parameter on the moving average part of the model, and indicates how much the value X at time t is influenced by the white noise at time $t-i$.

The time series model can be fitted to a time series process, by the means of various statistical tests (for example ACVF, ACF, PACF, ADF, BIC, see Section 7.8 and Appendix B for a detailed description) where the order of p and q is determined, and the parameters

c , ε_t , φ_i and θ_i are determined. The goal of this fitting process is to find a model that as closely as possible reflects the movements of the actual time series process.

Using the model, one can apply a Monte Carlo simulation as to develop a large number of potential scenarios. In this simulation, the white noise component ε_t is simulated a large number of times, making use of the probability distribution identified from historical data from the same variable. The Monte Carlo simulation draws a random number from this distribution, and applies this to the time series model. This process is repeated a large number of times, resulting in various scenarios which show risk.

Risk response

The appropriate response to a risk depends on the size of the risk and the risk attitude of the decision-maker (Gehner, 2006). In general, there are four types of control measures for responding to risk: avoid, reduce, transfer or accept. Avoidance is the prevention of the probability that the risk event occurs. Reduction implies taking measures to reduce the risk, for example by creating flexibility in the real estate portfolio. Transference of risk is placing the risk under the authority of another party, by for example by insuring. Acceptance of the risk is the last possible response, which is suited to risks with a low effect and a low probability.

Development of the Location Decision-Making framework

Answering the main research question requires the development of a framework, in which a location decision can be made whilst incorporating risk management. For this, the Location Decision-Making framework (LDM framework) is developed. The LDM framework is an adaptation of the PAS design approach, and is build out of three components, which help the user in making a location decision whilst taking into account risk. The model consists out of a procedure, activities and a mathematical model supporting the decision-making process.

The Location Decision-Making procedure

The procedure is a list of steps to be taken in order to come to a location decision. The procedure explicitly states how all relevant variables and stakeholders are introduced in the decision-making process using a step-by-step plan. The following steps make up the procedure:

- Step 1: Each decision-maker specifies the decision variable(s) that he/she is interested in.
- Step 2: Each decision-maker rates his/her 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 (x_0 , y_0).
 - 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 (x_1 , y_1).
 - 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 (x_2 , y_2).
- Step 3: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.
- Step 4: Each decision-maker/expert indicates for each decision variable whether there is a risk that the value of the decision variable will change over time.
- Step 5: Each decision-maker determines the design constraints he/she is interested in.
- Step 6: The decision-makers define the locations in consideration other than the current locations in the real estate portfolio.

Step 7: The decision-makers jointly decide on an acceptable risk, formulated as a probability level between 0 and 1, that the alternative will not take a value lower than the corresponding preference score.

Step 8: The decision-makers jointly assign a weight to the current and future overall preference score of the portfolio.

Step 9: 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.

Step 10: Use an algorithm to yield an overall current and future preference score and one overall preference score.

Step 11: The decision-makers decide group wise based on the overall preference score of the alternative portfolios and insights in the risks of these portfolios.

The Location Decision-Making activities

The application of the steps in the procedure requires a number of activities with the involved stakeholders. The activities comprise of three interviews and two workshops, that alternate in the pattern I-W-I-W-I, just as the PAS design approach (Arkesteijn et al., 2015).

Interview I is held individually per stakeholder. In this interview the first 6 steps of the procedure are followed. The interview is semi-structured and has the goal of completing the first six steps of the procedure. In *Workshop I*, the system engineer shows the model and the results of the first steps taking in the first interview. The stakeholders are able to test the model, and to make location combinations as to get acquainted with the model. Moreover, the stakeholders jointly take step 7 and 8 of the procedure. The goal of the workshop is to provide insights for the stakeholders in how the model works. *Interview II* can be seen as a repetition of interview I, where the stakeholders are able to change their input stated in the first interview. This interview again completes the first six steps of the model. *Workshop II* shows the final results of the model. During the workshop, the stakeholders are once again able to design alternatives. At the end of the workshop, the mathematical model will calculate the best alternative. This alternative is fed back to all stakeholders. In *Interview III*, each stakeholder individually confirms that the alternative that is calculated as the best alternative, is indeed the accepted alternative. If this is not the case, the stakeholders are able to adapt their input once again, in a way similar to the first two interviews and the process is repeated once again.

The Location Decision-Making mathematical model

The mathematical model is the supporting tool in the decision-making process. The principal structure of the mathematical model can be found in Figure 4. The input is gathered using the interviews stated in the activities, and through data gathering by the system engineer. The model then calculates for each possible alternative whether the alternative is feasible according to the constraints set by the stakeholders. Following this check, the preference ratings for each decision variable for each alternative is calculated, resulting in an overall preference rating. This process is repeated for each of the scenarios in the model. The output of the model is an overall preference value for the current time period, a preference curve for the future time period, and an overall preference value, showing the match of the alternative with the preferences stated by the stakeholders.

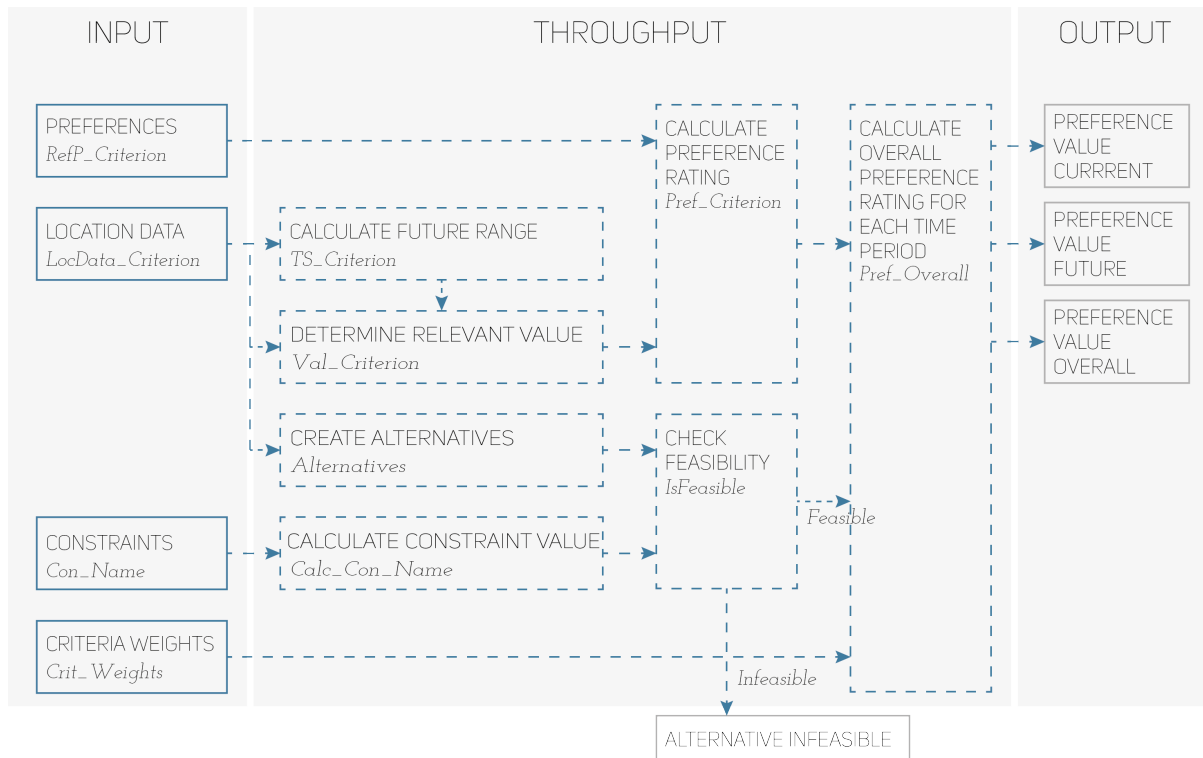


Figure 4: principal structure of the model (own illustration)

The best alternative is calculated by taking the overall preference rating of the current time period, and by calculating the overall preference rating of a future moment in time, by considering the preference score corresponding to an in step 7 specified probability level. These two values are then combined using the weights determined in step 8 of the procedure. The alternative that has the highest overall preference score, is selected as the best portfolio.

Pilot study of the LDM-framework

The LDM-framework is tested at a business case at Engie Services. Engie Services is part of the listed Engie group, one of the largest technical service providers in the Netherlands. Currently, real estate decisions are mainly cost driven. The number of locations in the portfolio have been reduced significantly, from over 90 to 56 at present. Currently seven locations in the South of the Netherlands are under review. The lease terms have been synchronised and the opportunity to consolidate these locations arose.

The Engie case consists out of the current 8 locations and 22 alternative locations. The subject owner selected (besides himself) 6 main stakeholders, that altogether make up for all four relevant perspectives identified by Den Heijer; policy makers, financial controllers, users, and technical managers (2011). In total 30 decision variables were identified by the stakeholders, combined with 7 constraints.

The activities were followed as described in the LDM-framework. In *Interview I* the stakeholders received a brief explanation of the goal of the process and the steps towards that goal. Furthermore, the first six steps of the procedure were followed. A complicating factor in this interview was the fourth step of the procedure, indicating whether there is a risk in the decision variable. The stakeholders had some difficulties in deciding on the risk factors. For this a real estate expert panel from the JLL research team was involved in the process as to add more detail to the input of step 4.

During *Model building I* the first iteration of the model was developed. All location data was gathered based on the lease contract of the current Engie locations and publicly available information from the other locations. The model was developed following the structure described earlier, providing a unique function for each preference score, tailoring

the model to the input of the stakeholders. In *Workshop I* the first version of the model was tested. The stakeholders were able to self-design their real estate portfolio and then test this alternative on alignment with the preferences. Moreover, the model was able to calculate which alternative received the highest preference score and therefore which alternative was the best fit with the preferences indicated.

After the first workshop the stakeholders were able to make changes to their input during *Interview II*. During these interviews 3 other stakeholders were involved in the process as well, broadening the scope of preferences. In the interviews in total 30 decision variables were determined and 7 design constraints were identified. During *Model Building II* these variables were included in the model. Moreover, the risk identification process was included in the model. This was tested in *Workshop II*, which had the same approach as the first workshop in that the stakeholders could self-design their alternative portfolios. In workshop II the model calculated the alternative with the highest preference score which had an increased preference score of +7.14 compared to the current portfolio. In *Interview III* the stakeholders indicated that the process indeed results in the selection of the best alternative based on the input provided.

Evaluation of the Location Decision-Making framework

Effective decision support systems rely on a successful collaboration between the system and the users of the system. Therefore, the users need to accept the system and trust the system (Riedel et al., 2010). For this the experiences with the system, the attractiveness of the system, and the perceptions of the effectiveness of the method can be evaluated.

The *experience* with the framework is in general evaluated as positive. The early involvement of the stakeholders in the process helped them to understand the model properly, and helped them to feel engaged in the process. However, some stakeholders indicated that the experience could be enhanced by making the mathematical model more interactive during the workshop, better supporting the discussion during these workshops.

The *attractiveness* of the system was evaluated as ambiguous. The stakeholders indicated that for the stakeholders themselves the system is attractive, as for them it was a positive experience. The stakeholders indicated that they understood how the model worked and they found it easy to select alternative locations and calculate the overall preference score. However, on the other hand the users indicated that the model is quite complex, which is partly caused by the nature of the model being a structured approach with a large number of variables and partly by the increased complexity of adding the risk analysis in the process. Furthermore, the amount of back-end modelling of the mathematical model makes the system less attractive according to the stakeholders. This can be dealt with in further research, improving the ease of applying the model to a specific case.

The system's *effectiveness* was considered positive, as the results of the system closely reflects the preferences of the stakeholders. The stakeholders agreed that the framework is an excellent supporting tool for solving complex real estate cases when multiple criteria are relevant. The stakeholders agreed that the results of the model comply with the preferences stated during the process.

Conclusions

This research is one in a line of researches on preference-based decision making in real estate, which all revolve around the preference-based accommodation strategy design approach developed by Arkesteijn et al. (2015). The main difference in this pilot study compared to previous iterations is the ability to forecast the future. This closely relates to the main research question, "**How can risk management effectively be incorporated in a preference-based location decision-making process?**"

The LDM framework, considering the pilot study conducted during this research, is an effective decision-making process which incorporates the risk of changing location characteristics in a preference-based location decision-making process.

Consisting out of three pillars (procedure, activities and model), the model answers to all three levels of rationality, forming a complete framework. The LDM framework has been built in an iterative process, involving the stakeholders closely from the start of development. The stakeholders indicated that this certainly was of added value and that the LDM framework helps them in making location decisions, based on their own preferences.

Recommendations for further research

In future research the LDM framework can be tested in other pilot studies. Next to this, some other recommendations are to be made.

First of all, a more visual support to the model can improve the ease of use of the model, and the system acceptance. Including a map in the graphical user interface could help in understanding better where the locations are. Moreover, making the map interactive, visualising location data can help the user in understanding the relationship between the overall preference score and the location data better. In the pilot study it was also mentioned that a more interactive model would help in making decisions easier as the iterative loop is significantly shortened when the model directly reflects the changes made.

Testing the model on a case that lies in the past could help in validating the framework. The future values that come out of the model can be compared to the actual values as to test whether the model approximates the developments correctly. Moreover, it can determine whether the decision that was made is the correct decision according to the model.

An important last recommendation for further development is to substitute the Lagrange curve for a cubic Bézier curve. This approach better approximates the empirical system and prevents wrong decisions to be made based on incorrect mathematics. It should be noted however, in order to not increase the complexity of the framework, the substitution should be accompanied by a graphical interface which allows the decision-maker to quickly determine the curve without much difficulty.

Readers guide

This report consists of five parts which represent four stages of this research thesis. The first part presents the reader the main problem that is subject of this thesis and the approach of solving the problem.

Chapter 1 introduces the problem of the risks in location decision making for corporate real estate managers. Furthermore, it explains the relevance of the research.

Chapter 2 outlines the research that is conducted. First, the objectives are described followed by the main research question and sub-questions. The approach is discussed in the methodology and research instruments.

Part II describes the necessary background for this thesis. It explains the main elements in detail, providing the theoretical underpinnings for this research.

Chapter 3 describes the world of Corporate Real Estate Management in general as to get acquainted with the research field this thesis is in. The concept of added values is explained here as well.

In *Chapter 4* the location decision-making process for real estate is explained. Here, the reasons for locating in a certain place are set out. These drivers closely interrelate with the driving forces for a company.

Chapter 5 illustrates what preferences are and how they can be measured. This way the drivers described in chapter 4 can be translated into measurable units.

Chapter 6 explains how preferences can be used in decision making by the use of a model. The general theory behind such models is explained and special emphasis is put on the Preference-based accommodation strategy tool, which is can be seen as the starting point of the new framework.

In *Chapter 7* a new perspective is added: risk. The theory of risk is explained, as are several tools for identifying and assessing risk. Through this process, the best way to incorporate risk in a multi-criteria decision making model is researched.

Chapter 8 of this thesis completes the theoretical framework by considering which aspects of a decision support system such as the one developed in this thesis makes them effective.

Part III describes the development of the Location Decision-Making (LDM) framework as an adaptation of the PAS design approach.

In *Chapter 9* the development of the framework is described including an extensive description of the framework itself. This explanation is build out of the three main elements of the framework: the LDM procedure, the LDM method, and the LDM mathematical model.

Part IV describes the pilot study, where the framework is tested.

Chapter 10 gives an introduction to the pilot study, providing insights in the company where the pilot is held and the current decision-making process. Next to this, the case to which the model is applied is described, as to explain which problem is solved by using the LDM-framework.

Chapter 11 presents the actual pilot study itself. The steps that have been taken are described, which is evaluated in *Chapter 12*, answering the second set of sub-questions.

Part V of this thesis places the research into perspective, giving a reflection of the development of this model in relation to previous pilot studies with the Preference-based Accommodation Strategy procedure. Also, the added value of the research is presented. This is both discussed in *Chapter 13*.

The final conclusions, discussions and recommendations are put forward in *Chapter 14*, in which the answers to the sub-questions are summarised and the main research question is answered.

Key terms list

Term	Explanation
CREM	Corporate Real Estate Management
CRERM	Corporate Real Estate Risk Management
DSS	Decision Support System
LDM-framework	Location Decision-Making framework, the framework that is developed in this thesis.
Time Series	A series of data measurements over time, with equal time steps between the data points.
Iteration	"the repeated application of a common method or technique at different points in a design process" (Dym, Little, Orwin, & Spjut, 2009, p. 26)
PAS design approach	Preference-based Accommodation Strategy design approach, a method developed by Arkesteijn et al. (2015), on which the LDM-framework is based.
ARIMA (p,D,q)	Autoregressive integrated moving average model. A time series model that can be fitted to a time series process, mimicking the movements of this process.

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PART I: INTRODUCTION

1. Introduction

"Deciding where to locate all or part of your business in an uncertain world is critical to competitiveness and success. The intensifying war for talent is raising the stakes even higher given the role of real estate in attracting and retaining talent and maximising its productivity. Navigating the multiple push and pull factors of competing locations can be challenging" (Weeink et al., 2017, p. 2). Location decision making is a complex process carrying high risk if it is not done effectively. An ever-changing environment complicates the process even more as decisions have a long-term impact and locations must be planned for the future.

1.1 The conflict of location decision-making

Location decision-making is part of the larger field of Corporate Real Estate Management (CREM) (De Jonge, Arkesteijn, Vande Putte, De Vries, & Van der Zwart, 2009). The main objective of CREM is defined by Krumm et al. (2000, p. 32) as:

"the management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation."

One of the added values in CREM is risk control, which is still underexposed in research (Bartelink, 2015, pp. 21-22). First publications on Corporate Real Estate Risk Management (CRERM) originate from 1999 to 2004, in which Simons (1999), Gibson & Louargand (2002) and Huffman (2003, 2004) published articles on the topic of CRERM.

In contrast, corporate risk management is present in the majority of the large companies (Bodnar, Giambona, Graham, & Harvey, 2014). In an evaluation of the added value of corporate risk management, Smithson and Simkins found that companies which have an active risk management policy were 4,8% more financial valuable than comparable organisations who did not (2005), with outliers up to 16%. Examples of such risk policy are operation risk policy (e.g. structural failure of a key facility) or competitive risk policies (e.g. a change in the government's planning policy restricting future growth). Given the substantial costs involved in real estate, often being the second largest cost after labour costs (Weeink et al., 2017, p. 7), risk management in the field of real estate can be a contributing factor to the company's overall performance.

In location decision making the risks are high. A wrong location decision not only has effects on the real estate costs, but on the entire business process. Location decisions have impact on a company's ability to establish and maintain a competitive advantage (Rymarzak & Siemińska, 2012). Therefore, it is of importance to take risks into account when deciding on a location. Creating a robust real estate portfolio, that is still favourable in a number of years, lowers risks significantly.

Location risks originate from a deviation in the preferences a company has for their real estate location and the actual characteristics of that location. Therefore, it is important to assess the match of a real estate portfolio with the business strategy and the preferences of the stakeholders involved. For this, use can be made of the Preference-based Accommodation Strategy design approach (PAS), developed by Arkesteijn and Binnekamp (Arkesteijn, to be published; Arkesteijn & Binnekamp, 2014; Arkesteijn et al., 2016, 2015). This method allows the involved stakeholders to find the optimal real estate portfolio that matches best with the preferences and constraints indicated. However, PAS does not take into account the uncertainty of changes in location characteristics and preferences.

Risk in location decision making arises due to uncertainty. The world is constantly evolving and subject to change. How the world will evolve in the future is per definition uncertain. However, location decisions are long-term, and have to take the future into account and

need to respond to the uncertainty prevailing. This exposes the company to a risk that the future unfolds differently than anticipated.

Uncertainty is often expressed in terms of probability (Morgan, Henrion, & Small, 1992). Probability shows the expectancy of an event actually happening. When multiple events are considered, in this case a range of values of a variable, each value is assigned with a probability of occurrence. This way, it becomes possible to assess the risks in location decisions. Using this probability assessment, risks in location decisions can be managed, which adds value to the company. Incorporating these risks in portfolio location decision making through PAS is therefore the topic of this research.

1.2 Societal and scientific relevance

In doing research, it is important to be aware of the relevance of the research itself. In this regard, the question is what the added value of the research is for society, and what it contributes to the scientific body of knowledge. These questions are answered below.

1.2.1 Societal relevance

Location decision-making is an important aspect in corporate real estate management. The location decision marks the start of a new real estate life cycle, and has a large impact on the business of a company. In interviews with stakeholders in practice, it is found that the scientific background of location decisions is often lacking. Ad-hoc decisions or poor judgement can have severe negative consequences for a company. Recently, a new focus on location decision making can be observed in the market, see for example Weeink et al. (2017) and van der Mije (2017), showing the need for more well-founded decisions.

This research answers part of the need for a more structured and well-informed choice. The framework allows individual companies to make location decisions, taking into account risks. The framework adds value for a company by controlling these risks, and making the decision-making process more transparent and objective.

The end result of the framework is a portfolio that best matches the demands brought forward by a company. Therefore, it leads to better alignment of the corporate real estate strategy and the business strategy, now and in the future. This implies that the real estate supports the company better, potentially increasing the overall performance of the company.

1.2.2 Scientific relevance

The scientific field of corporate real estate is limited, as few researchers worldwide are focussed on CREM (Heywood, 2011). In addition, in this specific research field, corporate real estate risk management (CRERM) is researched even less, despite the potential significant negative consequences of real estate decisions. This research focusses on this gap in literature where corporate real estate management and corporate risk management intertwine.

Moreover, this research links CRERM to the scientific field of quantified forecasting. If risks and scenarios are analysed in a decision-making process, the assessment is often qualitative, making use of best-guesses and estimations. This research incorporates time series analysis in the real estate risk assessment, by means of modelling the time series and forecasting.

The framework is based on the PAS design approach, developed by Arkesteijn (Arkesteijn et al., 2015). This procedure is the first procedure in CREM that combines a structured approach towards selection of the best portfolio with correct preference measurement (Arkesteijn & Binnekamp, 2014, p. 94; Arkesteijn et al., 2015, p. 103). This research extends this model with risk analysis, building on existing theories. The combination of the PAS procedure and other scientific fields provides the scientific relevance of this research.

1.3 Utilisation potential

This research is an applied research. This implies that a problem in practice is to be solved. For this an artefact is created, in the form of a framework. This framework should contribute to solving the problem in practice. Therefore, the utilisation potential of the research is an important factor as well.

The final result of this research is a framework for making location decisions on a portfolio level. The framework consists of three elements: steps (procedural rationality), activities (structural rationality) and a mathematical model (substantive rationality), based on the research of Arkesteijn (forthcoming). The framework is based on previous research on preference-based decision making. The framework is tested in a pilot study and evaluated on the applicability and usefulness of the model. Although the framework can be used in every company, the analytical data on time series is specifically generated for the pilot study company. This hampers the use of the empirical data generated in this research outside the scope of this research, with the exception of using the input as an expert system. The operational part however, the framework itself, can be used by every company facing location decision-making.

2. Research plan & methods

The main research question of this thesis is: how can risk effectively be incorporated in a preference-based location decision-making process? Answering this research question involves a hybrid research approach, with an emphasis on operational modelling. The expected end result is a framework that supports companies in making location decisions while explicitly taking into account the risk of changing location characteristics.

2.1 Research objectives

Location decisions are difficult to reverse, as this has significant consequences. A wrong location decision not only has effects on the real estate costs, but on the entire business process. For example, staff that was hired for the new location may be reluctant to move to a new premise, disrupting the business process. Therefore, making location decisions are important in the CREM process.

Location decisions are decisions made in companies to select a location for (part of) the company. These decisions are based on numerous criteria, which are specific to the company itself (e.g. availability of skilled employees or accessibility with public transport). These criteria are the preferences a company has and are therefore called demand preferences.

As location decisions are planned for the long-term and therefore the future, not only the current characteristics of a location should be taken into account when evaluating different options. The world is subject to change which brings the risk of changing location characteristics. This can result in locations not being suitable for a company in the future. The risk of this change should be taken into account as well in the decision-making process.

The objective of this thesis is to develop a framework that takes into account both demand preferences and risks of changing location characteristics. The development of such framework requires theoretical insights in multi-criteria decision making, preference-based decision making, location decision making, risks and uncertainty. Next to this, a pilot study is conducted as a proof of concept of the framework. The pilot study is also used as a method to evaluate the framework on its applicability and usefulness.

2.2 Research questions

The research questions of this thesis are formulated using the theoretical knowledge generated from academic literature and reports from practice. The main research question that is answered in this research is:

How can risk management effectively be incorporated in a preference-based location decision-making process?

The research question is build up out of two elements. First, a framework is developed based on the preference-based accommodation strategy design approach in which risks are incorporated. This framework will be referred to as the preference-based location decision-making framework (LDM). The second element consists of testing and evaluating the method, where the process is tested and reflected upon using a pilot study. This provides a proof of concept of the approach. Both elements have a number of sub-questions which are explained below.

2.2.1 Sub-questions developing the framework

In developing the framework knowledge is required on a number of research fields. This allows for a method to be made which takes into consideration risk management and is based on preference-based decision-making. For this, the following sub-questions have been developed:

- What are location decisions based on and how are location decisions currently made?
- How can preferences be quantified and modelled?
- What are the recent trends and developments in real estate decision making processes?
- How can risk be assessed, managed and quantified?
- How can risk be incorporated in a preference-based location decision-making process?

These sub-questions provide the basis for development of the framework. The questions relate to the three main pillars of this research: risk management, location decision-making and preference modelling. These sub-questions are answered by conducting a literature study. The last sub-question requires the development of a new framework in which the three pillars are combined into one framework.

2.2.2 Sub-questions testing and evaluating the framework

The next step of developing a framework is to test and evaluate the framework. This provides insight in the applicability and usefulness of the method. Testing and evaluating the model also provides the proof of concept through a pilot study. For this the following sub-questions have been developed:

- How can decision-making tools be evaluated?
- How is the framework perceived by the stakeholders in practice?

Answering these questions allow for answering the main research question, as the end result is a framework that incorporates risk effectively in a preference-based location decision-making process.

2.3 Conceptual model

The main research question and all sub-questions can be distilled into two main parts. The first part is the input required for making the framework. This part can be divided into three elements: preference modelling, location decision making and risk management. These three scientific fields combined provide the theoretical underpinnings on which the framework is created.

The second part of this research is the development of the framework itself. This framework is based on the research of Arkesteijn et al. (2015), and consists out of steps (procedural rationality), activities (structural rationality) and a mathematical model (substantive rationality). This framework results in a location decision. This is visualised in Figure 5.

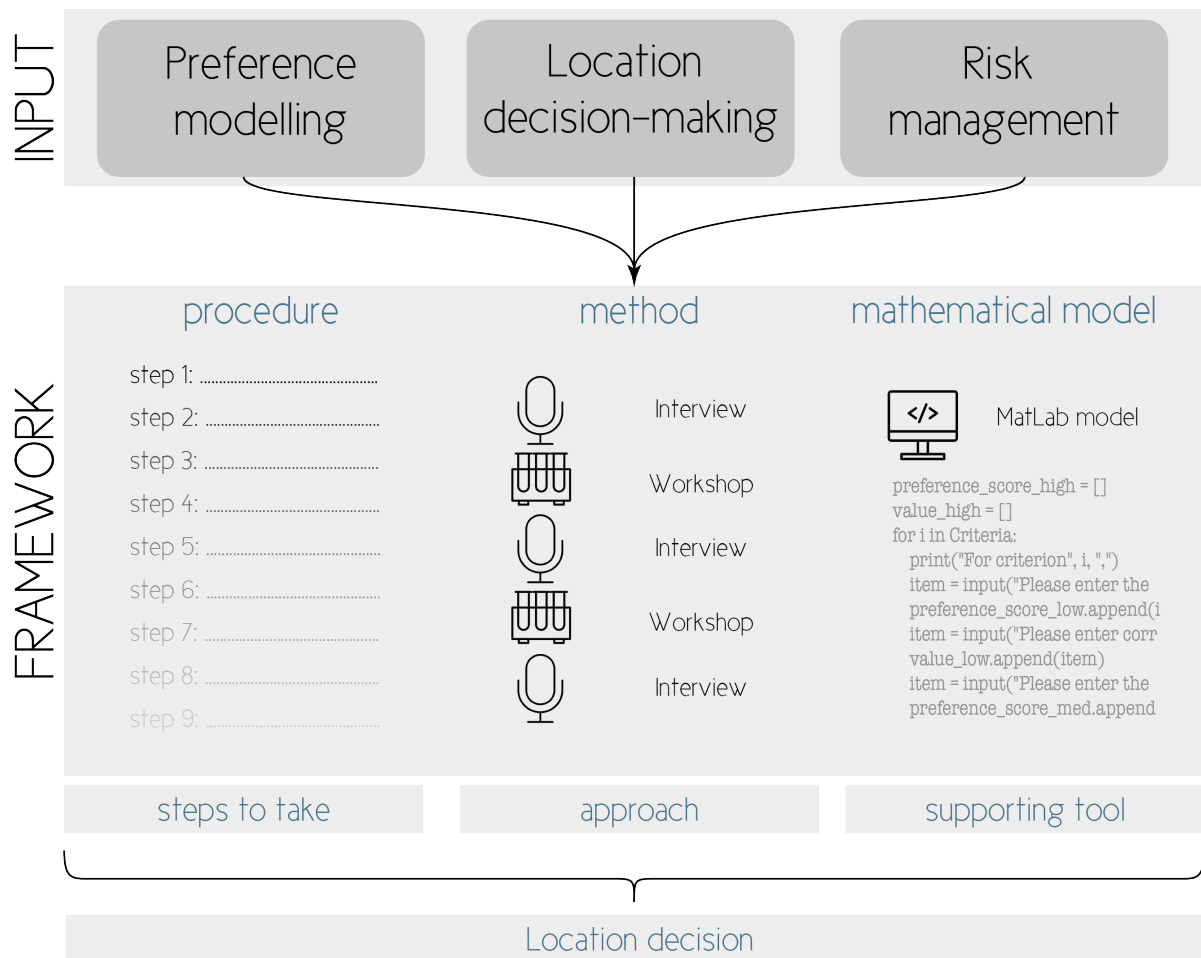


Figure 5: Conceptual framework of this research (own illustration based on (Arkesteijn et al, 2015))

2.4 Methodology

When considering the main research question, it follows that the research is an operational research project. This is due to the fact that answering the research question requires the development of an artefact. The development of an artefact to solve a problem is considered an operational or formal research process (Barendse, Binnekamp, De Graaf, Van Gunsteren, & Van Loon, 2012, p. 1). In this case, the artefact is a framework.

From this it follows that the operational research procedure should be used. Ackoff and Sasieni (1968) developed such procedure which consists out of the following five steps:

1. Formulating the problem
2. Constructing the model
3. Deriving a solution
4. Testing the model and evaluating the solution
5. Implementing and maintaining the solution

In this process, steps two to four are repeated several times as to iteratively develop and refine the model. Step 5: Implementing and maintaining the solution will not be taken in this thesis. The steps defined by Ackoff and Sasieni can be seen as a design process where an artefact is created. Dym and Little developed a more extensive model based on this process (Dym et al., 2009). This model follows the same five steps of the model of Ackoff and Sasieni, be it more detailed. The structure of this model is shown in Figure 6.

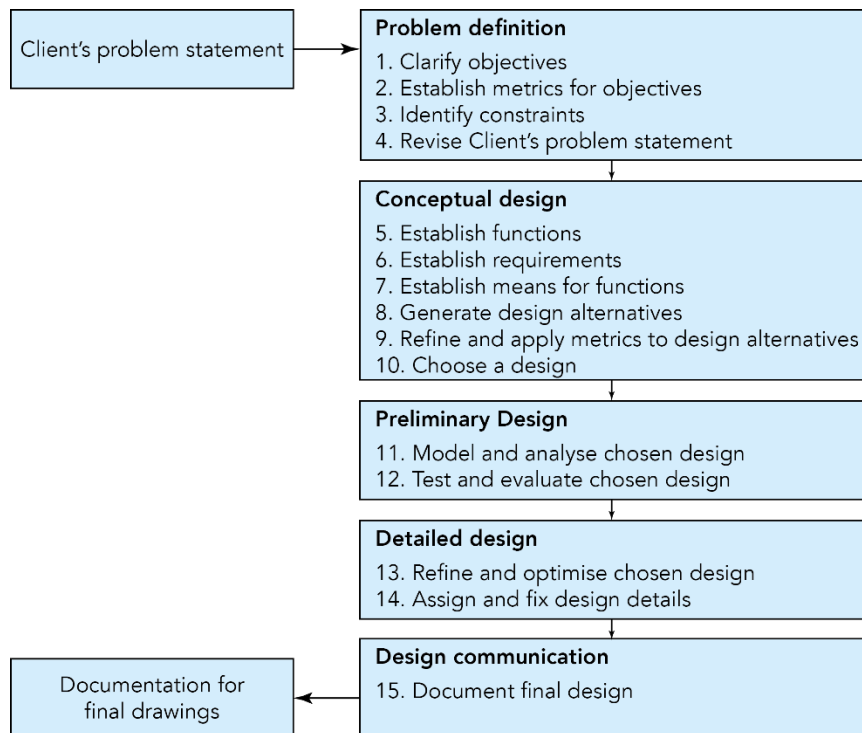


Figure 6: the design process (own illustration based on Dym et al., 2009, p. 25)

Following the procedure requires input that is obtained empirically as the problem should be defined. However, in the scope of this research the empirical input is considerably larger. This empirical input comprises of the identification and analysis of risk of changing location characteristics. Moreover, the procedure is tested in a pilot study in which the insights are also obtained empirically. Therefore, only following a design process and operational research methods is insufficient. Answering the research question therefore requires a hybrid research methodology combining both operational research and empirical research.

In a hybrid methodology, a cyclical process is followed in which the empirical research process is linked to the formal process. Barendse et al. (2012) developed a model showing this process showing the interrelationships between the two research methods. This model can be found in Figure 7. The model shows two iterative loops which are linked at four points in the process. The process starts at the formulation of the client statement which results in the problem definition. After this the model specifications are designed as to make a conceptual design. During this process, in the empirical cycle, a hypothesis is developed which is tested. In this research, the hypothesis is that location characteristics are prone to change. The results from the empirical research are used as input for the operational model. This interaction is visualised in Figure 7. Next, the model is tested and evaluated, enabling the researcher to refine and optimise the design. The last step is to use the model.

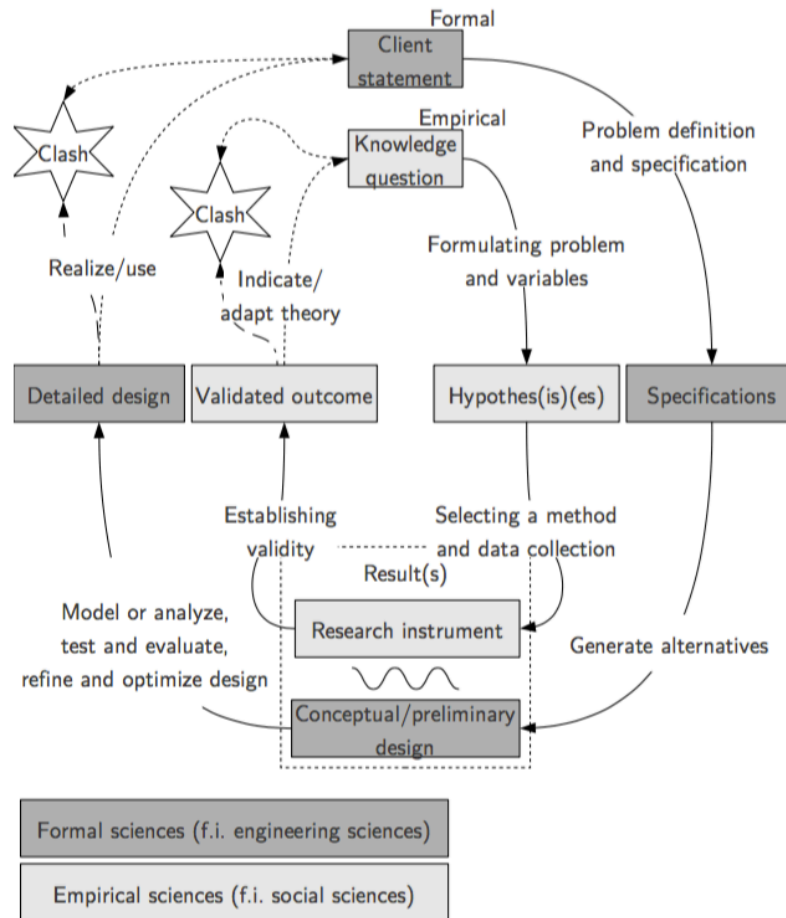


Figure 7: the formal and empirical research cycle combined (Barendse et al., 2012, p. 6)

The operational component of this research is significantly larger than the empirical component. Therefore, the operational design process is taken as leading for the research approach.

2.5 Research instruments

This research makes use of both operational and empirical research instruments. First of all, a literature study is used to create a theoretical framework prior to developing the LDM framework. The second research instrument is the development of a mathematical model which operationalises the framework and allows for using this framework. The framework is then tested in a pilot study where interviews and workshops are used to obtain the necessary data and to test and evaluate the model.

Literature study

A literature study is conducted as to gain insight in the field of corporate real estate management and location decision making specifically. This information is used to analyse the current process and the research field. Next to this literature has been reviewed on risk and uncertainty as to find how a manager can deal with uncertainty and risk. The last part of the literature study consists of an analysis of preference based strategy alignment.

Model development

A mathematical model is developed as an operationalisation of the proposed procedure of this thesis. The model is built in an iterative sequence following the steps of a formal research process as described in section 2.4. The model is developed in Matlab, a mathematical calculation tool based on matrices which enables a model based on

interrelated functions to be developed, simplifying the process of adding objects and alternatives.

Pilot study

The framework is tested in a pilot study. This pilot study has the aim of providing a proof of concept of the procedure and the model. For this the pilot study is conducted at Engie Services Netherlands. The pilot study is conducted using the method of Arkesteijn (2015). This method comprises of five activities; three interviews (i) and two workshops (w), which are completed in the sequence i-w-i-w-i. This approach of developing a model was used successfully in tests with the PAS procedure and was evaluated positively (Arkesteijn et al., 2015, p. 107,118).

Interviews

The interviews are used to obtain input for the model and are held with each stakeholder individually. The procedure is explained to the stakeholders, after which the procedure is followed allowing the stakeholders to provide the input of the model.

Next to this the interviews serve the purpose of evaluating the framework. The evaluation is done by assessment of the framework based on four criteria suggested by Joldersma and Roelofs (2004), as did Arkesteijn (2015). The first criterion is *experiences with the method*, which measures the impact of the method based on the user's experience. The second criterion is the *attractiveness of the method*, which relates to the confidence in the methods and outcomes. *Participants' perception of effectiveness of the method* and *observers' perceptions of the effectiveness of the method* provide the third and fourth criteria. These criteria inquire on how much the model contributes to the results and on the level of quality of the results.

Workshops

The workshops are used to present the framework to the stakeholders and allowing them to use it. During the workshops the system engineer is able to observe the effectiveness and efficiency of the framework.

PART II: THEORETICAL FRAMEWORK

3. Corporate Real Estate Management

This thesis can be placed in the scientific field of corporate real estate management. Corporate real estate management has evolved from finding a building to a strategic management process of the fifth resource; real estate. The objective of corporate real estate management is to align the real estate strategy to the company strategy through the use of added values, of which one is controlling risks. This chapter serves as an introduction to the field of corporate real estate management.

3.1 History and theory of corporate real estate management

Theories on real estate management in general focus on the match between demand for, and supply of space (Den Heijer, 2011). Corporate Real Estate Management (CREM) was originally defined as the range of activities undertaken to attune corporate real estate optimally to corporate performance (Krumm et al., 2000).

Corporate Real Estate Management originated some 250 years ago in response to the first industrial revolution that required special accommodation to manage the industrial activities, closing the era where real estate merely consisted of housing, churches and governmental buildings. This marked the start of specialised real estate departments finding real estate that matched the core businesses of the companies. From the sixties on, companies started expanding on a global scale, requiring large financial resources to be poured into the core activities, forcing corporate real estate (CRE) managers to show their added value to the company for the first time (Krumm et al., 2000). Managing corporate real estate therefore has gradually changed from reducing costs to effectively supporting the primary processes and adding value to the goals of the company (Joroff, Louargand, Lambert, & Becker, 1993). This has led to recognition of corporate real estate as the fifth resource next to human resources, capital, technology and information (Krumm et al., 2000). Joroff et al. (1993) described the changing role of CREM in five evolutionary stages which can be found in Figure 8.

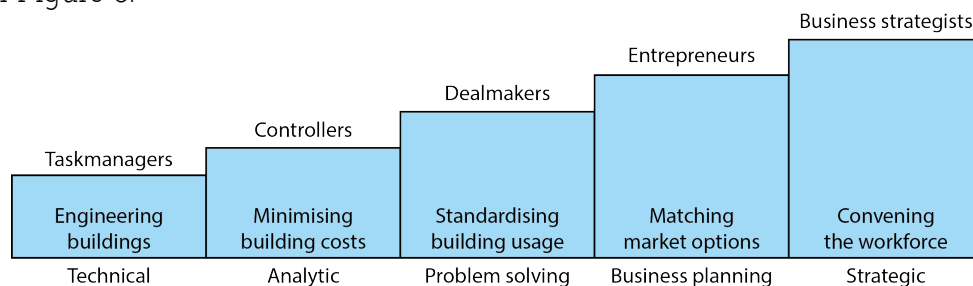


Figure 8: corporate real estate competency shifts (Joroff et al., 1993)

The first stage shows the original role of CRE managers, supplying the corporation's need for physical space. The controller stage adds the goal of minimising costs of real estate and tries to benchmark real estate in order to control it. The dealmaker, stage three, creates value for the business units and no longer specifies the building in the way its internal clients want but standardises the building use in order to get a flexible deal (Den Heijer, 2011). The entrepreneur functions as an internal real estate company looking at the firm's competitors and offers similar real estate alternatives to the business units. The business strategist is the last stage of the corporate real estate manager and anticipates business trends and monitors their impact. The strategist focusses on the institutional mission and tries to add value to this mission through the use of real estate.

The model of Joroff is additive in nature, implying that the business strategist also focusses on for example the minimisation of building costs. Although the stage a company and its CREM department is in differs per company it is believed that most organisations find themselves in the third or fourth stage in the model (Krumm et al., 2000).

The goal of CREM is to "maximise the corporate real estate's contribution to the corporate bottom line and the long-term health of the corporation" (Huffman, 2003, pp. 32-33).

Krumm et al. (2000, p. 32) use a more elaborated definition of the purpose of CREM: *'the management of a corporation's real estate portfolio by aligning the portfolio and services to the needs of the core business (processes), to obtain maximum added value for the business and to contribute optimally to the overall performance of the corporation.'* In his assessment of several approaches for aligning CRE and organisational strategies, Heywood uses a definition of alignment based on the Shorter Oxford Dictionary definition: *"alignment is the bringing into harmony things that differ or could differ [...] by making them consistent or in agreement with each other"* (Heywood, 2011, p. 2). Kaplan & Norton, in their book *'Alignment'*, see alignment as the continuous *"search for ways to make the whole more valuable than the sum of its parts"* (Kaplan & Norton, 2006, pp. 26-27). This definition immediately shows the purpose of alignment, as it implies the support of a common purpose, synchronising decisions and processes in timing and direction (Shiem-shin Then, Tan, Fonseca Santovito, & Anker Jensen, 2014). In the field of CREM, alignment can be defined as the synchronisation of the real estate strategy with the corporate/business strategy with the purpose of adding value to the company.

3.2 Adding value

Using the definition by Krumm et al., a corporate real estate manager should focus on adding value to the company. In 1993 Nourse and Roulac made the first attempts to discern added value by real estate related operating decisions by aligning real estate decisions with the corporate strategy, stating that real estate decisions are only effective if they support the overall business objectives (Nourse & Roulac, 1993). Nourse and Roulac provided 8 corporate strategies which were translated into corresponding real estate strategies.

Three years later De Jonge listed seven elements of added value that contribute to the transformation of real estate from "costs of doing business" to a true corporate asset (Krumm, 1999). The seven elements are increasing productivity, cost reduction, risk management, increase of value, increase of flexibility, changing the culture and PR and marketing. These elements are similar to those of Nourse and Roulac, combining several elements and adding one new added value of real estate: risk management.

Lindholm and Leväinen (Lindholm, Gibler, & Leväinen, 2009; Lindholm & Leväinen, 2006) used the added values of Nourse and Roulac and De Jonge as a starting point and researched the use of added values in practice, finding seven added values of real estate which relate to the goal of increasing shareholders value. With this list, Lindholm and Leväinen redefined several aspects of the list, whilst retaining the overall goals of adding value.

Whilst Lindholm and Leväinen used a shareholders perspective on adding value, De Vries et al. (2008) introduced the stakeholders perspective and divided nine added values over three core organizational performance aspects; profitability, productivity and distinctiveness (de Vries et al., 2008). The nine added values were (1) reducing costs, (2) controlling risks, (3) expanding funding possibilities, (4) enhancing flexibility, (5) increase productivity, (6) stimulating innovation, (7) improving culture, (8) supporting image, and (9) increasing satisfaction.

In her dissertation, Den Heijer (2011) reviewed the literature on added value, and divided them using four different stakeholder perspectives; (1) the strategic perspective of the policy maker, (2) the financial perspective of the controller, (3) the functional perspective of the user and (4) the physical perspective of the technical manager. An overview of all added values defined by the authors mentioned in this section can be found in Table 2.

Table 2: Lists of added value of real estate (Van der Zwart, 2011 based on (De Jonge, 1996; de Vries et al., 2008; Den Heijer, 2011; Lindholm & Leväinen, 2006; Nourse & Roulac, 1993; Scheffer et al., 2006))

Nourse & Roulac	De Jonge	Lindholm	Scheffer et al	De Vries	Den Heijer
1993	1996	2006	2006	2008	2011
Real Estate Strategies	Added Values	Real Estate Strategies	Added Values	Real estate added values	Added values of Real Estate
Occupancy cost minimalization	reduce cost	reduce costs	cost reduction	reducing costs	decreasing costs
Facilitate and control production, operations and service delivery	improve productivity	increase productivity	increasing productivity	increase productivity	supporting user activities
Promote Human resource objectives		increase employee satisfaction		increasing satisfaction	increasing (user) satisfaction
	improve culture		changing the culture		improving quality of place
Facilitate managerial proces and knowledge work		increase innovation		improving culture	supporting culture
				stimulating innovation	stimulating collaboration
Promote sales and selling proces	marketing	promote marketing and sale	PR and marketing	supporting image	supporting image
promote marketing message					
Flexibility	increase flexibility	increase flexibility	increase of flexibility	enhancing flexibility	increase flexibility
Capture real estate value creation	improve availability of finance (increase of value)	increase value of assets	increase of value	expanding funding possibilities	increase real estate value
	risk management		risk control	controlling risks	controlling risk
					reducing ecological footprint

What can be found is that the list of added values remains more or less constant over time, with some minor changes in the scope and names of each added value. There is one added value that was added since the original set of real estate strategies of Nourse and Roulac: reducing the ecological footprint. This shows the increased awareness for sustainability in recent years.

In literature, risk control or risk management is consistently mentioned in research regarding added values of real estate. This shows that risk management is an area important in real estate decision making.

3.3 Conclusions

Corporate real estate management (CREM) is the scientific field in which this research can be placed. CREM is the synchronisation of the real estate strategy with the corporate/business strategy with the purpose of adding value to the company. The goal of the LDM design approach complies with this goal, in that it tries to find the real estate location that optimally suits the corporate business strategy. This synchronisation process is described in a number of added values of corporate real estate management, which evolved over time. One of the added values consistently mentioned is risk control/management. The incorporation of this added value in the PAS design approach is the topic of this thesis.

4. Location decision-making in real estate

Location decision-making is part of corporate real estate management. Location decisions are driven by strategic choices of the company, and is based on the demands and preferences of a company. This chapter answers the sub-question: "what are location decisions based on and how are location decisions currently made?"

4.1 Location decisions and the corporate business strategy

Location decisions are part of the corporate real estate strategy of a company. This strategy is developed based on input on three aspects; the real estate portfolio characteristics, the organisational characteristics and the corporate business strategy (Rovers, 2017). This shows the direct link the corporate real estate strategy has with the corporate business strategy. This alignment can be seen in Figure 9.

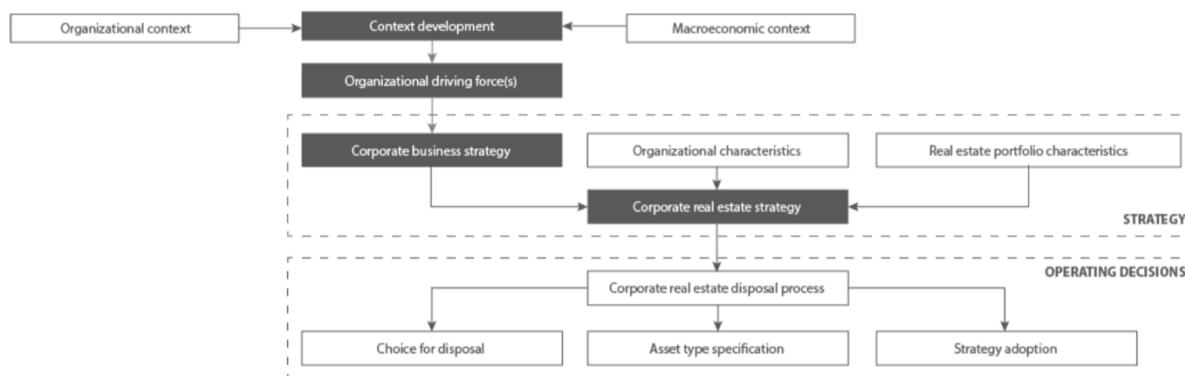


Figure 9: Alignment of corporate business strategy and corporate real estate strategy (Rovers, 2017; based on Nourse & Roulac, 1993)

From the corporate business strategy, the desire to move to a location can come forward. Each company has its own specific reasons for optimising their portfolio. However, motivations for taking locations decisions can broadly be categorised in one of four categories, based on the work of Dunning (1977) and Franco et al. (2008):

- Market seeking: accessing a new market or expanding in an existing one.
- Resource seeking: focussing on natural resources and human resources like talent clusters.
- Efficiency seeking: rationalising the footprint of established activities.
- Strategic asset seeking: acquisition or sourcing of new or auxiliary technologies and intellectual property rather than exploiting existing resources.

4.2 Driving forces for the corporate business strategy

As described in the previous paragraph, a location decision is part of the corporate real estate strategy of a company. This strategy is, amongst other things, the result of the corporate business strategy and the translation of the demand criteria for real estate. Demand criteria for real estate are based on the core process of the company, as real estate is a means to support the core business. The core business and the mission statement of the organisation can be formulated in terms of driving forces. These driving forces determine the strategy of a company, and therefore indirectly determine at which location(s) the company should be or wants to be. Furthermore, a change in the driving force of a company can have an effect on the operating decisions in the real estate strategy.

The theory of driving forces originates from the work of Tregoe and Zimmerman, which has been acknowledged as element of alignment of real estate strategies and corporate strategies by amongst others Nourse and Roulac (1993) and Scheffer, Singer and van Meerwijk (2006). Tregoe and Zimmerman identified nine driving forces, which determine the future product and market scope that define a business, which are grouped in three

categories: (1) Products/markets, (2) Capabilities and (3) Results. An overview of the driving forces can be found in Table 3.

Table 3: Driving forces of corporate strategy (Tregoe & Zimmerman, 1980)

CATEGORY	DRIVING FORCES	EXPLANATION
PRODUCTS/MARKETS	(1) Products offered	Defines business strategy by its products and products similar to existing ones.
	(2) Market needs	Defines the business by attempting to serve particular needs of particular segments of the market.
CAPABILITIES	(3) Technology	Defines business by attempting to provide products, services, and markets derived from its technological expertise.
	(4) Production capability	Defines business by attempting to provide products and services that can be produced using its production capabilities.
	(5) Method of sale	Defines business by attempting to provide products and services that can be sold by the company's way of convincing the customers to buy.
	(6) Method of distribution	Defines business by attempting to provide products and services that can be sold by the company's distribution system.
	(7) Natural resources	Defines business by attempting to provide products and services that are generated from its control and use of particular resources.
RESULTS	(8) Size/growth	Defines business by attempting to provide products and services that meet new size or growth objectives.
	(9) Return/profit	Defines business by attempting to provide products and services that will meet its targeted return or profit measures.

According to Tregoe and Zimmerman, usually only one of the driving forces is the main determinant of what a business does. However, Nourse and Roulac state that multiple driving forces could be used: "The driving force of a company may change over time with changes in the environment, markets and other forces that determine business direction and competitive position" (Nourse & Roulac, 1993, p. 478).

4.3 Driving forces and location decision preferences

4.3.1 Driving forces for location decisions

As described in the previous paragraph, the corporate real estate strategy follows from the corporate business strategy, the organisational characteristics and the real estate portfolio characteristics. In her research O'Mara underpins this link, pulling apart the corporate business strategy into the industry forces and the environmental constraints and opportunities.

O'Mara provides a framework for this, in which the demands are categorised (O'Mara, 1999). This diagnostic framework can be found in Figure 10.



Figure 10: Diagnostic framework for corporate real estate decision making (O'Mara, 1999, p. 191)

As can be observed, O'Mara divided demands in strategic environment and organisational demands respectively. These are then divided in two sets of categories each. The strategic environment takes into account the industry forces, in which variables such as number of customers, rivalry between firms or barriers to entry are important. The second category in the strategic environment are the environmental constraints and opportunities. This category reflects for example the regulatory framework persistent in the location, and financial resources available.

In the organisational demands, both structural and cultural demands can be found. Under structural demands, the work process and demographics can be found, whereas the cultural demands reflect history, corporate culture and senior management preferences.

4.3.2 Location preferences

The preferences for a location are, just as the corporate business and real estate strategies, unique to a company. However, several important categories can be distinguished when deciding for a location. In his research in practice, Weeink et al. (2017) describe seven common drivers of location decisions, and dubbed them the 'magnificent seven'. These seven drivers are explained below.

Talent and skills

The quality of talent is critical to business success. Real estate location decisions are driven by positioning real estate to attract and retain talent. This can mainly be found in the desire of being centrally located. The focus on talent and offices in city centres is driven by demography, immigration and globalisation, working practices such as flexible working, sustainability and improvements in accessibility. Alignment to the new geography of talent is a driver of choosing a certain location.

Real estate

Real estate is generally the second largest business expense, following labour costs. Using the resource efficiently and optimally can therefore yield significant financial benefits. Companies can use location decision-making to align to new corporate strategic drivers such as a demand for new capacity, consolidation or mergers, redeployment, resizing or decentralisation.

Clusters

Clusters are ecosystems which help drive innovation, knowledge sharing and collaboration. Clusters are linked to large talent pools and concentrations of customers and suppliers. Access to shared sources can decrease real estate costs and stimulate innovation. However, locating in a cluster can be expensive. Therefore, the positive and negative aspects of clusters must be balanced.

Regulation and taxation

Corporate tax rates vary between countries and jurisdictions. A lower tax rate can have a beneficial impact on the company. Moreover, regulation can play a role in the

attractiveness of a location. Change in labour laws can for example alter the access to talent. Considering future regulatory changes are therefore important.

New visions

A change in the way a company works can be a catalyst for location changes. A new business strategy can create new requirements for the real estate portfolio. Moreover, technological changes have altered the way of working, resulting in offices becoming more user focussed.

City dynamism

Cities are more actively responding to the changing social and corporate dynamics. Mayor cities are becoming more active in promoting their cities, which can result in grants, incentives or attraction of talent. Although city dynamism is rarely the leading driver of location decision, the way a city develops can be a push or pull factor in the decision.

Accessibility

Accessibility can be defined on various levels. However, on each level it plays a role in location decision making. Accessibility can relate to the ability to access new markets and customers, or physical and natural resources. Moreover, transportation accessibility can also be a key driver, as it is critical to the supply chain speed or accessibility of talent.

These elements form the most important drivers of location decisions. These demands can be put in the diagnostic framework of O'Mara, which can be found in Figure 11.

industry forces	Clusters
environmental constraints & opportunities	Accessibility City dynamism Regulation and taxation
structural demands	New visions Real estate Talent and skills
cultural demands	

Figure 11: Drivers categorised following O'Mara's framework (own illustration)

What can be observed is that cultural demands are not considered in the drivers found by Weeink. This can be explained by the fact that most cultural demands are already embedded in the selection of location alternatives. The history of the company often constraints the possible locations, as from a historical perspective, the company for example could want to stay in a certain city limiting the set of alternatives.

The drivers mentioned here can be translated into specific demands. The driver can be seen as a cluster of demands. For example, accessibility can be translated into distance to major public transportation hub, distance to the nearest highway, travel time to the nearest airport, distance to suppliers et cetera. However, again it is important to note that the drivers mentioned in this section provide an overview of the most common drivers for location decisions. The demands can be company specific and should always be stated by the company itself.

As part of the PhD thesis of Korteweg (2002), research was conducted regarding accommodation factors playing a role in deciding on a new office on both location level and building level, which can be found in Table 4. The dataset was obtained by conducting two surveys, targeting office users in the Amsterdam region in 1988 and 1991. Here, it is found that the main criteria for a new office location on building level are representativeness, the size and price, whereas on location level the main criteria are parking possibilities, accessibility by car and representativeness of the location.

Table 4: Demand preferences of offices on location and building characteristics (Korteweg, 2002).

Location characteristics	Survey 1988	Survey 1991	Building characteristics	Survey 1988	Survey 1991
Accessibility by car	95%	85%	Size	64%	50%
Proximity highway	76%	65%	Flexible space usage	58%	43%
Parking possibilities	95%	88%	Expansion possibilities	39%	40%
Accessibility by public transport	68%	69%	Single tenant	24%	14%
Proximity railway station	44%	46%	Recognisability	63%	45%
Proximity city centre	13%	25%	Representativeness	87%	82%
Proximity other offices	19%	18%	Appearance	62%	61%
Proximity stores	20%	16%	Height	11%	-
Proximity facilities	21%	17%	Rental / buy price	69%	62%
Proximity clients	31%	28%	Service and energy costs	44%	42%
Proximity airport	49%	33%	Automatisation facilities	50%	39%
Representativeness location	70%	72%	Security	58%	52%
Visibility from highway	20%	12%	Airconditioning	20%	26%

More recently, Remøy and Van der Voordt (2013) researched office user preferences based on the Delphi-method targeting 18 experts from practice. A list of six location characteristics and 15 building characteristics were ranked using three office user profiles: urban specialists, the status-sensitive professional and the ordinary tenant. However, as opposed to Korteweg, one of the main characteristics, size was not included in the research. In location characteristics, the most important aspects were (1) accessibility by car, (2) Representativeness and (3) Accessibility by public transport. On building level, the top 5 was (1) parking, (2) representativeness exterior, (3) efficiency space usage, (4) division flexibility and (5) representativeness interior. These ranks both refer to the ordinary tenant category (Remøy & Van der Voordt, 2013).

Furthermore, in literature an extensive list of performance measures can be found, each referring to a certain type of demand in literature. The literature regarding performance measures or Key Performance Indicators studied, is in alphabetical order Appel-Meulenbroek & Feijts (2007), Dalderup (2014), the NEN-8021 norm, Riratanaphong (2014), Verhoeff (2014), Vermeer (2007), and Zaghdoud (2013). The full list can be found in Appendix A: List of key performance indicators. This list is categorised using the CRE strategies identified by Gibler and Lindholm (2012) and clustered per demand.

These researches provide a number of basic criteria that are important for a company. Physical characteristics such as size and representativeness play a role, just as other (financial) characteristics such as rental costs and service costs. However, the demand preferences of a company are always specific for that company itself, due to their specific company strategy. Therefore, it is always important to define the relevant criteria for the company itself when developing a real estate strategy. A list of performance criteria can however be used as an expert system, as to prevent uninformed decisions.

4.4 Conclusions

In this chapter, the sub-question “what are location decisions based on and how are location decisions currently made” is answered.

Each company has their own process of making location decisions, each with their own unique set of requirements and/or preferences. However, a number of common grounds can be found. Where a company decides to locate is mainly dependent on the driving forces

of the company: what is the *raison d'être* of the company and what should it pursue (Tregoe & Zimmerman, 1980). These driving forces can then be translated into location characteristics. Demographics, environmental constraints or availability of workforce are examples of such characteristics.

In general, seven overarching elements can be identified that play a role in location decision making (Weeink et al., 2017): talent and skills (the availability of the necessary talent and workforce), real estate (availability of the right quality of real estate, in the right size, for the right price), clusters (availability of preferred amenities in the vicinity of the location), regulation and taxations (legal regulations that favour the business process), new visions (changes in the business strategy), city dynamism (the positive or negative way a city is developing), and accessibility (access to your required network in terms of clients, personnel, current locations).

Location decisions are currently made based on a unique combination of requirements. In research, it is found that location decisions are often based mainly on accessibility by car, representativeness of the location and accessibility by public transport (Korteweg, 2002; Remoy & Van der Voordt, 2013).

5. Demand, preferences and preference measurement

Demand for a product is defined as the quantity that customers are willing and able to buy at each and every price, all other things being unchanged. In real estate, demands are influenced by the business strategy, to which the real estate portfolio should align. This chapter aims to answer the sub-question: How can preferences be quantified and modelled? For this, first a general introduction of demand and preferences is given, before describing the approach of preference measurement

5.1 Demand theory in economics

In economics, the demand for a certain product is defined as “the quantity that customers are willing and able to buy at each and every price, all other things being unchanged.” (Gillespie, 2014, p. 39). This implies that the demand for a certain product is linked to the costs and forms a curve, known as the demand curve. It is both dependent on what the customer wants and what they can afford, and is therefore dubbed ‘effective demand’.

In economics, the demand is related to the price, and is dependent on several factors such as the price level, the customers’ incomes, the price of substitute products, the price of complementary products, the number of customers in the market and several other factors (Gillespie, 2014). The result is a demand curve as can be seen in Figure 12. Here, the demand Q_1 in units is a result of the price P_1 .

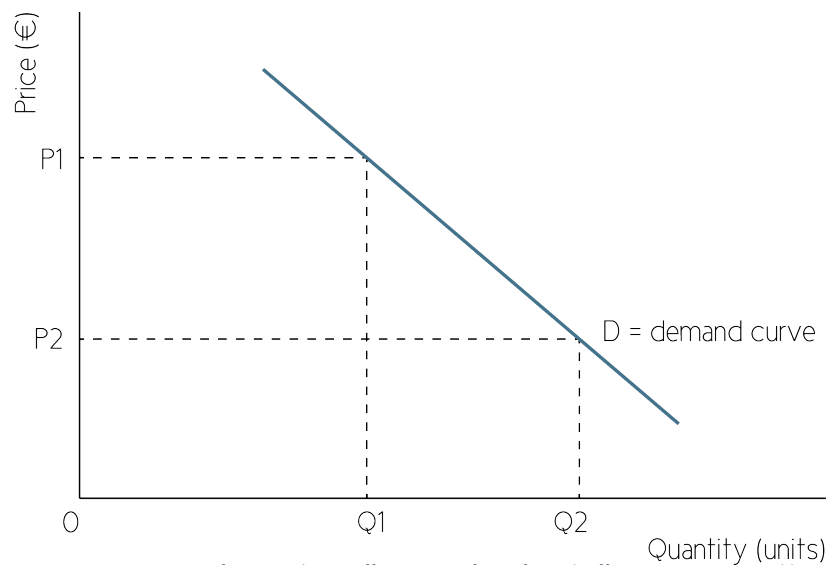


Figure 12: Demand curve (own illustration based on (Gillespie, 2014, p. 40))

The demand curve is often sloped due to the law of diminishing marginal utility. This law states that the extra utility of another unit of product is lower than the utility of consuming the previous one. A consumer will move along the demand curve when only the prices changes and everything else remains equal. However, the demand curve itself could also shift, when one of the underlying factors changes. A change in income, change in number of customers or a change in the price of substitute products are examples of such a change.

To estimate the likely demand for products in the future, in economics use can be made of the elasticity of demand. This elasticity examines the sensitivity of demand in relation to a number of other factors and can be defined as:

$$\text{Demand elasticity} = \frac{\text{Percentage change in the quantity demanded}}{\text{Percentage change in a variable (e. g. price or income)}}$$

5.2 From demand to preferences in real estate

The demand of a company is based on the preferences of that entity. The overall demand for a specific building is based on the demand preferences of all companies and the match of the building with these preferences. Therefore, it is important to consider the demand preferences in real estate. The stakeholders of a company provide their desires for the office they wish to occupy, which is their preference.

In practice, preferences for real estate have long been dictated by location and physical characteristics of real estate (Leishman & Watkins, 2004). Today, these characteristics are still important. However, with the evolution of CREM the criteria for location decision-making increased simultaneously, such as social, financial and virtual values (Niemi & Lindholm, 2010). As the number of variables increased in size and the information regarding preferences are important for deciding on a real estate strategy, the necessity for methods for measuring the preferences arose. Difficulty of preferences is that these are per definition subjective (Barzilai, 2010, p. 59). The term preference refers to the liking of a person, and can be seen as prioritised needs and requirements (Niemi & Lindholm, 2010, p. 36). The measurement of preferences can therefore be seen as an identification process of the needs and requirements including a prioritisation of these values.

5.3 Measuring preferences

The objective of measurement was formulated by Campbell as *"to enable the powerful weapon of mathematical analysis to be applied to the subject matter"* (Campbell, 1920, pp. 267-268). This analysis allows for judgement of how well certain aspects perform. Measurement therefore makes it possible to evaluate a decision (beforehand) on their fit with the demands.

Preference measurement involves the translation from an empirical system to a mathematical model. The empirical system are the objects in real life which are being measured. These objects are measured on certain properties (e.g. preference), which is the translation from the property of an object into a numerical value, or a scale, in the mathematical model. This translation allows for the application of certain mathematical operations, which cannot be applied in the empirical model (Barzilai, 2010, p. 2).

One of the difficulties of preference measurement is the principle of reflection (Barzilai, 2010). This principle states that: *"operations within the mathematical system are applicable if and only if they reflect corresponding operations within the empirical system"* (Barzilai, 2010, p. 5). This means that, in order to have a mathematical system that is a valid representation of the empirical system, the mathematical system must be homomorphic to the empirical system. If for example the measurement of two objects is only relative, e.g. object I is longer than object II, but one is unaware of how much longer object I is to the second object due to for example the unavailability of a measuring tape, it is impossible to conduct mathematical operations on the mathematical system. For example, a multiplication of 2 is impossible, as one does not know the length of the object. Even though in the mathematical system it is possible to do such operation, it does not reflect a corresponding empirical operation, and therefore the operation is extraneous and invalid (Barzilai, 2010, pp. 4-5).

Furthermore, Barzilai states that only scales which allow the operations of addition and multiplication are scales that are useful (Barzilai, 2010). These scales are defined as proper scales: *"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). In an assessment of a number of MCDA methodologies, Binnekamp (2010) found that only the preference-function modelling methodology as developed by Barzilai (1997) allows for the mathematical operations necessary and makes use of proper scales.

On this scale, a preference curve can be constructed, which reflects the preferences one has. In the preference-function modelling (PFM) methodology of Barzilai, preference curves are constructed using three objects or points. This follows from the formula used to generate a scale, namely $\frac{A-B}{C-D} = k$. 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). The necessity for three preference points is illustrated through the following example:

Suppose someone is looking for a new apartment. He is willing to travel to his work. He prefers to travel 10 minutes. This value is the empirical value, that is translated into the mathematical value on the scale. This results in the "scale" value of 100, which is the highest value. However, he also states that he is willing to travel a bit further, at the most 30 minutes. This value can then also be translated into a mathematical value of 0, being the lowest value. But what if the person is able to choose an apartment that requires 20 minutes of traveling. The question is how high does this option score on preference? One could say 50, as it is halfway between the most preferred and least preferred option. However, maybe the person doesn't really mind to travel a bit longer than 10 minutes, and is totally fine with travelling 20 minutes, but just has the 30 minutes as a maximum. One cannot say definitively what the preference score of the apartment is.

When three points are identified, a proper curve can be derived, which allows for measurement of every empirical value. This is done by fitting a curve through the three points. In operations research, Lagrange curves are often used for this (Binnekamp, 2010, p. 101). This way, a constant curve can be distinguished. A Lagrange curve interpolates between a number of polynomials. It is a polynomial $P(x)$ of degree $\leq (n - 1)$ that passes through n points, in this case three (Arkesteijn et al., 2015, p. 104). Therefore, in this procedure, the curve can be calculated using:

$$P(x) = \left(\frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} \right) * y_0 + \left(\frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} \right) * y_1 + \left(\frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} \right) * y_2$$

The result is a curve, that goes through the three points that are to be distinguished. This is illustrated in Figure 13. Now, every value of a variable, can be translated to a preference score.

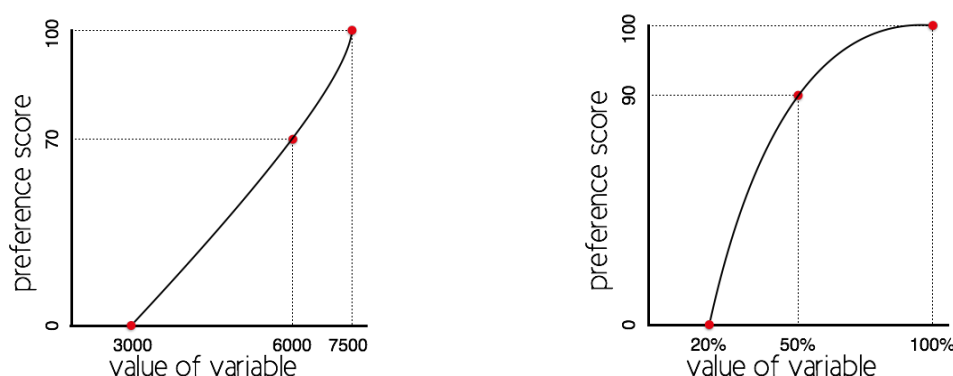


Figure 13: examples of a preference curve for two variables (own illustration)

5.4 Two types of preferences: stated and revealed

Of importance in preferences, is that there is a difference between stated and revealed preferences. A stated preference is the identification by a stakeholder of what he/she prefers

and would like (Nicholson & Snyder, 2012). This is in contrast to the revealed preferences, which are observed from actions and can only be identified after a decision has been made (Samuelson, 1938). Therefore, revealed preferences can only tell something about the past demand, in contrast to stated preferences which can apply to the current demand and future demand.

In the revealed preference theory, originally developed by Samuelson (1938), observed behaviour (e.g. a person buying a product) is used as an approximation of the individual's utility function or demand curve. The person is expected to follow Samuelson's principle of rationality in that the person is maximising the utility function. Therefore, if the person chooses product A over B, product A is *revealed preferred* over product B. This implies that at under any different price-income arrangement, B can never be revealed preferred over A (Nicholson & Snyder, 2012, p. 175). When product B is chosen however, this implies that the buyer could not afford product A. If all these points are combined, a concave function follows, which is the utility function. In CREM, both stated and revealed preferences can be found. However, in the formulation of preferences, stated preferences are used, as no decision is made yet.

5.5 Connecting preferences to adding value

Preferences in real estate are often derived from main drivers of the stakeholders and answering to these demands should result in adding value to the company. According to the shareholder value theory, one of the main accepted theories regarding corporate governance, value to a firm is created by maximising the wealth of shareholders (Lazonick & O'Sullivan, 2000). As to reach this goal, strategic planning is developed, of which corporate real estate management is part.

When making a real estate strategy, several performance measures are to be computed, derived from the company's strategy (Keegan, Eiler, & Jones, 1989). These measures are used to assess and ensure companies reach their aims and objectives. Lindholm et al. developed a model, linking the end goal of maximising shareholder wealth to two main drivers for this maximisation; profitability growth and revenue growth (Lindholm et al., 2009).

Next, the study identified seven real estate strategies which influence the profitability growth or revenue growth, based on the added values discussed in section 3.2. In 2012, Gibler and Lindholm updated this model with an eighth strategy, including a recent focus on sustainability into the model (Gibler & Lindholm, 2012). In 2011, Den Heijer made a new distinction in the added value list, explicitly mentioning the controlling of risk as one of the added values. These two studies have been combined to show the connection between CREM and the maximisation of wealth for the shareholders. This results in the model found in Figure 14. Demand preferences can be linked to these strategies and can provide a framework for demand identification.

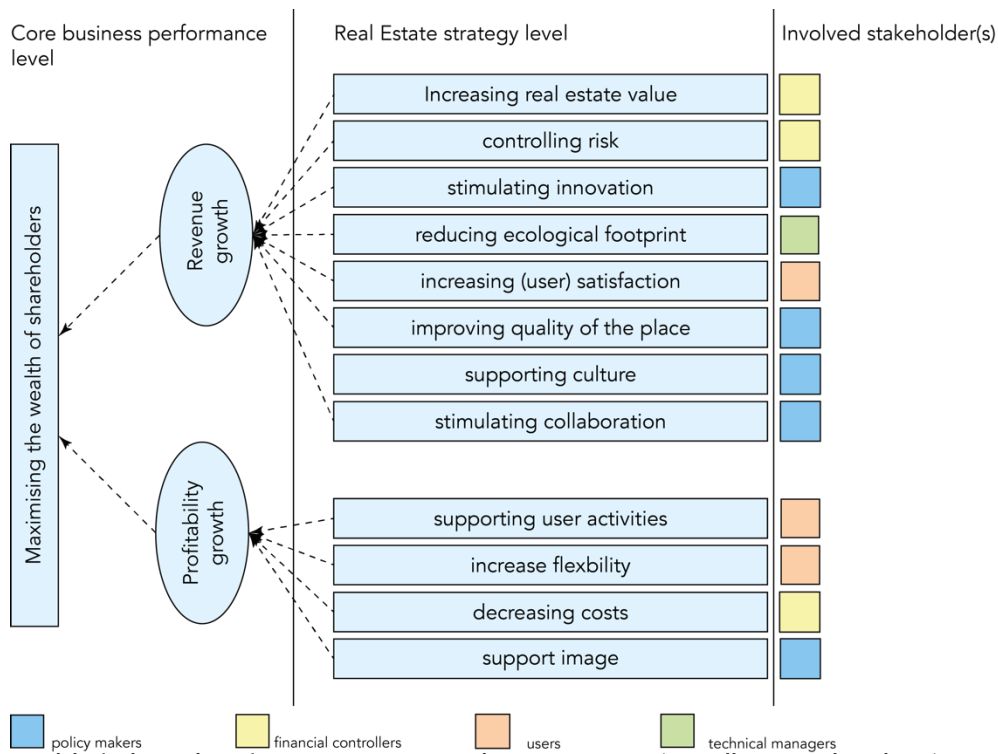


Figure 14: Model of relationship of CRE strategies to core business strategy (own illustration based on (Den Heijer, 2011; Gibler & Lindholm, 2012))

As stated earlier, preferences are per definition subjective (Barzilai, 2010, p. 59). Therefore, it is impossible to list all demands of a company in advance. However, a number of aspects are generic, although with varying values. These aspects are often closely related to the 12 real estate strategies found in Figure 14. An overview of these preference on the topic of location decisions are described in 4.3 and can be found in Appendix A: List of key performance indicators.

5.6 Conclusions

This chapter answers the sub-question: "How can preferences be quantified and modelled?" Preferences show the desire a company has for certain factors. Answering to these preferences can be seen as aligning to the company strategy and therefore as an added value.

Preferences are per definition subjective. The term preference refers to the liking of a person, and can be seen as prioritised needs and requirements. Measuring preferences is therefore an identification process of the needs and requirements, including a prioritisation of these values. Measuring preferences enables one to apply mathematical analysis and calculations to the subject matter.

Preference measurement involves the translation from an empirical system to a mathematical model. Preference is translated into a numerical value, or a scale, which can in turn be fed into a mathematical model.

Preferences are mapped, and a mathematical model is constructed using three objects or points. This follows from the formula used to generate a preference curve, namely $\frac{A-B}{C-D} = k$. 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).

Using these three reference points, one can construct the preference curve, that correctly corresponds to the empirical system. The curve is constructed using a Lagrange curve, which interpolates between a given number of polynomials. The curve can be calculated using:

$$P(x) = \left(\frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} \right) * y_0 + \left(\frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} \right) * y_1 + \left(\frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} \right) * y_2$$

It should be noted that there is a differentiation between stated and revealed preferences. A stated preference is the identification of a stakeholder what he/she would like, whereas a revealed preference is the observation of an action, from which a preference can be distinguished. These preferences could differ, and in this thesis, stated preferences predominate.

6. Multi-criteria decision-making and PAS

This chapter focusses on decision-making tools and answers the sub-question: *What are the state of the art developments in real estate decision-making processes?* For this, first the field of multi-criteria decision analysis is explained. Multi-Criteria Decision Analysis is used when multiple objectives, which are often conflicting, have influence on a decision-making process. For MCDA to be used, preferences should be measured. Using the preference-function modelling methodology of Barzilai (1997), scales can be made that allow for mathematical operations. The Preference-based Accommodation Strategy, developed by Arkesteijn (2015), based on the Preference-based design procedure of Binnekamp (2010), does this, and provides a solid basis for further development.

6.1 Theory of multi-criteria decision analysis

Multi-Criteria Decision Analysis (MCDA), according to Belton and Stewart (2002, p. 2), 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”. MCDA can be applied when decisions have to be made, which involve a number of criteria which have influence on the outcome. It is especially often used when conflicting objectives occur, either from one stakeholder, or from various stakeholders. An easy example is finding a dwelling to live in. Although for example one wants to live in the city centre, this objective can conflict with the maximum price one is willing to pay, forcing him/her to find a compromise. The process of MCDA can be described as an iterative process following three main phases. Figure 15 gives an overview of these phases.

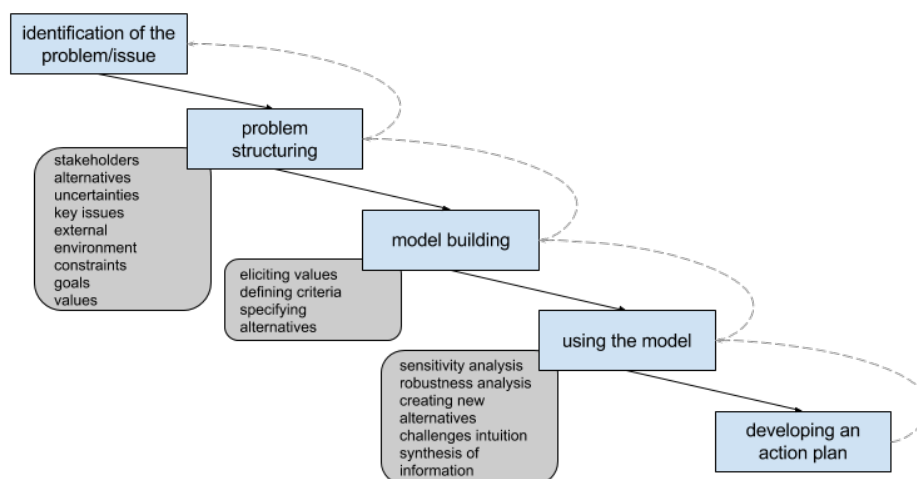


Figure 15: MCDA process (own illustration based on (Belton & Stewart, 2002))

First, the problem needs to be identified and structured, as to provide a common understanding of the problem amongst all stakeholders. The phase focusses on structuring the problem in terms of involved stakeholders, the values of the variables, the constraints and uncertainties. In the second phase a model is constructed, which is a mathematical model of the problem. This model is then used to develop a number of alternatives. These alternatives are also analysed for comparison, based on the previously defined criteria of the stakeholders. The last phase consists of the development of an action plan, as the decision can be taken using the information from the analysis (Belton & Stewart, 2002, pp. 6-7). The process MCDA can lead to a decision, which is called MCDM (Multi-criteria decision making).

The MCDM process essentially develops a number of alternatives, which are then assessed, choosing the best alternative. This decision is based on which alternative is preferred over the other alternatives by the stakeholders. This is done by stating several preferences and their relative importance or weights (Binnekamp, 2010, p. 31).

6.2 MCDM models in real estate management

Within real estate, several MCDM models exist as real estate decision making often involves multiple (conflicting) criteria. Arkesteijn and Binnekamp (2014) evaluated a number of CREM and Public Real Estate Management (PREM) models based on the two main criteria of good models: (1) the use of mathematical operations and (2) the type of scales used in relation to preference measurement, as explained in section 5.3. Table 5 provides an overview of this assessment, in which it can be found that at that time, no model existed which made use of mathematical operations whilst making use of strong scales.

Table 5: Evaluation of CREM and PREM models (Arkesteijn & Binnekamp, 2014)

Domain	Authors	Use of mathematical operations	Scales used
CREM	Nourse and Roulac (1993)	Yes	Not indicated
CREM	Edwards and Ellison (2003)	No	N.A.
CREM	Osgood (2004)	No	N.A.
CREM	Scheffer et al. (2006)	Yes	Weak ¹
PREM	Brackertz and Kenly (2002)	Yes	Weak
PREM	Wilson et al. (2003)	No	N.A.
PREM	Van der Schaaf (2002)	Yes	Weak

Therefore, the Preference-based accommodation strategy (PAS) design approach was developed (Arkesteijn et al., 2015). PAS is developed as a tool to operationalise the DAS-framework (Designing an accommodation strategy) in order to reach better alignment between demand and supply. The DAS framework involves a number of steps to be taken determining the current state of alignment of the real estate portfolio (supply) and the corporate strategy (demand). This is followed by an iterative process, to design a real estate strategy for future alignment. This design involves a selection of interventions in the buildings in the portfolio, based on a stakeholder analysis and translation of the corporate mission into real estate related objects. The corporate strategy is translated into a real estate strategy, whilst taking into account long-term uncertainties in the business.

However, the DAS framework and other tools used in real estate management have two main difficulties. Firstly, the procedure is ill defined as to how an overall portfolio preference rating is generated. This implies that the model designer is needed for application of the framework (Arkesteijn et al., 2015, pp. 101, 103). The second issue in alignment tools is the measurement of preferences. Arkesteijn (2015, p. 103) and Arkesteijn and Binnekamp (2014, p. 89) found that the models used in real estate management make use of preference scales that do not allow mathematical operations of calculus and linear algebra. These issues resulted in the necessity to develop a well-defined, operationalised procedure: the preference-based accommodation strategy (PAS).

Prior to the development of the PAS, Binnekamp (2010) developed the Preference-based design procedure which made it possible to design alternatives based on strong scales, following the comprehensive work on preference measurement and preference functioning modelling of Barzilai (2006). The Preference-based design procedure allows stakeholders to determine decision variables, which are rated on preference. As this procedure only focussed on a building level, it was further developed into the preference-based portfolio design (PBPD) procedure. The PBPD procedure allows designing alternatives for an entire portfolio, and is designed such that the preference functioning modelling algorithm (PFM) developed by Barzilai (2006) can be used for evaluation of the generated portfolio alternatives (Arkesteijn & Binnekamp, 2014, p. 97). In later publications, the PBPD procedure is referred to as the PAS procedure (Arkesteijn et al., 2015, p. 103).

The PAS procedure consists out of six steps (Arkesteijn et al., 2015, pp. 103-104):

Step 1: Specify the decision variable(s) the decision-maker is interested in.

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 (x_0, y_0).
 - 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 (x_1, y_1).
- 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 (x_2, y_2).

Step 3: To each decision variable, assign decision-maker's weight.

Step 4: Determine the design constraints

Step 5: Generate all design alternatives (using the number of buildings and allowed interventions). Then use the design constraints to test their feasibility.

Step 6: Use the PFM algorithm to yield an overall preference scale of all feasible alternatives.

In the first step of the procedure, the decision variables are defined by the decision-maker. These are the only variables that are used in the procedure. Step two consist of establishing preference ratings. The PAS procedure utilises Lagrange curves for the development of the ratings. The Lagrange curve is a curve which is fitted through a top and bottom reference alternative, which goes through a third alternative, determining the shape of the curve (see for example Figure 16). The shape of the curve can be mathematically calculated by solving for:

$$P(x) = \left(\frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} \right) * y_0 + \left(\frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} \right) * y_1 + \left(\frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} \right) * y_2$$

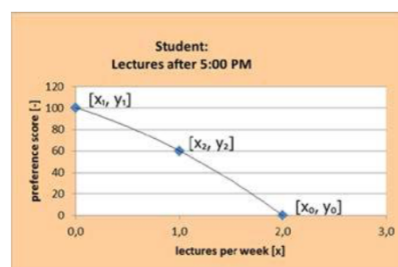


Figure 16: Example of a Lagrange curve (Arkesteijn et al., 2015, p. 104)

After the generation of the preference curves, the decision maker should decide on the weights assigned to each decision variable, which is the third step of the procedure. The weights represent the relative importance assigned to each variable. However, when multiple stakeholders are involved in the process, assigning weights also implicitly incorporates the power of the decision makers (Arkesteijn et al., 2015, p. 105). This would require a negotiation between the decision makers, often resulting in the actor with the most power realising higher weight(s) for his/her variable(s). As the intention of the procedure is to provide transparency in the real estate decision making process, this implicit incorporation of multiple stakeholders was contradicting to the goal of the procedure. Therefore, a next version of the PAS procedure was developed, which is presented in section 6.3.

The fourth step determines the design constraints, as to test in the next step whether the generated alternatives are feasible. These constraints are to be defined by the decision-

makers themselves. The penultimate step of the procedure is the generation of all portfolio alternatives. These alternatives are based on the allowed interventions defined by the stakeholders, and the number of buildings in the portfolio. Next, all alternatives are checked on the constraints put forward in step 4, as to see whether the alternative is feasible.

Step 6 assesses each alternative generated in step 5 on the preference scales and weights developed in step 1-4, using the PFM algorithm. This results in a ranking of all alternatives based on the preference rating. The alternative with the highest rating aligns best with the demands set forward by the stakeholders. Moreover, the added value of the new real estate strategy can be expressed explicitly, as the difference between the rating of the new portfolio and the current portfolio. The difference expresses how much more the new portfolio aligns with the corporate demand.

6.3 Application of the PAS procedure

During the first tests with the PAS procedure, a number of issues arose. Firstly, a technical issue arose with the generation of the alternatives. The number of possible alternatives is equal to the number of allowed interventions to the power of the number of buildings. This results in very large number of possible portfolios to be generated already in simple cases. For example, in the simple theoretical case by Arkesteijn and Binnekamp, three interventions were used on 15 buildings, resulting in $3^{15}=14.348.907$ possible portfolios (Arkesteijn & Binnekamp, 2014, p. 98). Therefore, it was recommended that a search algorithm was to be developed, which finds the most preferred alternative in more complex cases.

In the first practical pilot study of the PAS procedure, a case was used which was more complex, rendering it impossible to generate all alternative portfolios as a search algorithm was not available yet. Therefore, the procedure was altered, also taking into account the explicit incorporation of multiple decision makers. Step 5 and 6 were altered significantly, as to bypass the need for a search algorithm by manually designing portfolio alternatives. Step 3 was altered as well, incorporating assigning weights to each decision-maker by the subject owner. The procedure that followed these alterations is the following (Arkesteijn et al., 2015, pp. 105-106):

- Step 1: Each decision-maker specifies the decision variable(s) that he/she is interested in.
- Step 2: Each decision-maker rates his/her 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 (x_0, y_0).
 - 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 (x_1, y_1).
 - 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 (x_2, y_2).
- Step 3: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.
- Step 4: Each decision-maker determines the design constraints he/she is interested in.
- 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 portfolio.
- Step 6: The decision-makers select the design alternative with the highest overall preference score from the set of generated design alternatives.

This pilot showed that when using the procedure, a new portfolio can be developed which yields a higher preference rating. In the pilot, the decision-makers followed the procedure iteratively. First, the decision-makers designed portfolio alternatives themselves as to optimise the overall preference rating. This process enables the decision-makers to gain insights in the effects of the preferences and interventions. These insights were then used to alter their preferences, following the PAS procedure once more. Following the process in an iterative manner, helped to increase the quality of the results according to the pilot study. The overall preference rating was increased due to the iterative process, and the decision-maker's preferences were better represented in the model (Arkesteijn et al., 2015, pp. 117-118).

A limitation on the new PAS procedure developed is that it is uncertain whether the alternative portfolio designed by the decision-makers has the highest possible rating. Assessing this would require to generate all possible alternatives, which poses the problem of the large number of alternatives to be generated, as described previously in this chapter. Therefore, the development of a search algorithm was still recommended. However, Arkesteijn et al. (2015, pp. 117-118) do recommend that the self-design element of the portfolio alternatives is not completely substituted by a search algorithm, due to the insights gained in the design iterations. Moreover, a self-design element could increase the decision-maker's acceptance of the results following the procedure (Arkesteijn et al., 2015, pp. 117-118). In his graduation research, de Visser bypassed the absence of a search algorithm by a brute force calculation, which also found the alternative with the highest possible rating (de Visser, 2016).

6.4 Conclusions

This chapter answers the research question: what are the recent trends and developments in real estate decision-making processes?

Corporate Real Estate decision-making processes involve multiple objectives, which are often also found to be conflicting. Therefore, use is often made of MCDA tools, which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton & Stewart, 2002). In essence, in a multi-criteria decision-making process a number of alternatives are developed, which are assessed against the criteria set, and the best alternative is chosen.

In real estate management, several MCDM models exist. In an assessment of various models, it was found that a large number of models do not allow for mathematical operations, which therefore cannot make proper use of preference measurement. As to tackle this issue, the Preference-based Accommodation Strategy (PAS) design approach was developed (Arkesteijn et al., 2016).

The PAS design approach, in its definitive form, consists out of three elements: steps (procedural rationality), activities (structural rationality) and a mathematical model (substantive rationality). The design approach identifies the preferences of a company and finds the optimal portfolio that aligns best to these preferences.

7. Risk measurement and management

Risk can be defined as the probability of an event occurring times the magnitude of loss or gain. Risk should first be identified, for which several techniques are available, following an analysis of the risk based on the probability and magnitude of loss. As a result of the analysis, measures can be taken as to control the risk, following monitoring and evaluation. This chapter therefore answers the sub-question: "How can risk be assessed, managed and quantified?"

7.1 Risk theory

According to the Oxford dictionary, risk can be defined as 'a situation involving exposure to danger' (Oxford University Press, 2013). Risk in this sense can be split into two components; a value component and a probability component (Koele & van der Pligt, 1993). The value component is the effect or consequence of the event expressed as the deviation from the desired outcome.

In literature, often only the negative consequences are considered (e.g. (Byrne, 1995; Cooper & Chapman, 1993; Stichting Bouw Research, 2000; Wang & Roush, 2000)). However, Raftery notes that a positive deviation can also be seen as a risk, as this is still a deviation from the expected outcome (Raftery, 1994). The second component of risk is the probability of occurrence. This results in the following definition of risk:

$$\text{Risk} = \text{Probability of event} \times \text{magnitude of loss/gain} \text{ (Raftery, 1994)}$$

Risk and uncertainty are closely linked and are often mixed, but a significant distinction can be made. According to Sloman (1995), Risk is when an outcome may or may not occur, but its probability of occurring is known whereas uncertainty is when an outcome may or may not occur, but its probability of occurring is not known. This results in uncertainty not being quantified, but risk can be quantified and therefore modelled if statistical material is available (Gehner, 2006). However, uncertainty still plays a major role in risk assessment, as it is the origin of risk.

7.2 Views on probability

In literature, two main views on probability exist; the frequentist view and the personalist or Bayesian view (Morgan et al., 1992). The frequentist view defines probability as "the frequency with which an event occurs in a long sequence of trials" (Morgan et al., 1992, p. 48). Trials are in this view expected to be exchangeable with others in the sequence (Morgan et al., 1992). Difficulty with this is that one should be able to identify the relevant population of trials of similar events. In the case of for example a dice this is evident, however, in many events this provides a difficulty.

Therefore, a second view on probability was developed; the Bayesian view. From this perspective, probability is defined as "the degree of belief that a person has that it will occur, given all the relevant information currently known to that person" (Morgan et al., 1992, p. 49). This definition implies that the assigned probability is a function of both the uncertain event and the person's state of information, providing the possibility to assign a probability to events that have not taken place yet. However, this assignment can only be meaningful if the event is well-specified. A well-specified event is an event that given complete information, people would agree on whether the event had occurred or not (Morgan et al., 1992). This requires a degree of precision in the definition of the event so that it is measurable in one single value which can be measured empirically (Morgan et al., 1992).

7.3 Uncertainty in risk analysis

Risk occurs when something changes and there is uncertainty in the change. If future events would be certain, a company knows how to respond to it, and no risk is involved.

The world itself is constantly changing, and everyone faces uncertainty. Modelling the future by using existing data on the occurrence of events, taking a frequentist approach, allows for measuring the probability of the occurrence, allowing for risk analysis. However, risk analysis itself also holds a number of uncertainties.

Uncertainty in quantitative risk analysis can have several sources. According to Parry (1998), three major classes of uncertainty exist: (1) parameter uncertainty, (2) model uncertainty, and (3) completeness uncertainty. Parameter uncertainty implies that the values of the parameters in a model are not known accurately (Abrahamsson, 2002). Moreover, parameters can be subject to natural variability, which makes the precise identification of the value difficult. A common solution to this uncertainty is to assign probability distributions to the parameters (Abrahamsson, 2002). Model uncertainty refers to the fact that any model inevitably is a simplification of the reality, resulting in approximation uncertainties (Abrahamsson, 2002). Completeness uncertainty embodies the impossibility to account for every contribution to risk in a model.

In the parameter uncertainty, using the Bayesian view on probability, two main sources of uncertainty are recognised, although with many different names. The first type of uncertainty is that of aleatory uncertainty, or variability, randomness, stochastic uncertainty or irreducible uncertainty (Abrahamsson, 2002; Morgan et al., 1992). Aleatory uncertainty represents randomness in nature and unknowns that differ each time an experiment is run.

The second type of parameter uncertainty is dubbed epistemic uncertainty, but is also referred to as ambiguity, ignorance, knowledge based, reducible or subjective uncertainty. This type of uncertainty refers to a lack of knowledge regarding a fundamental problem. Epistemic uncertainty is considered to be reducible to virtually non-existent through creating an understanding of the problem by means of for example expert opinions. Obtaining a probability curve for the aleatory uncertainty can be done using several techniques, which are explained in section 7.8.4.5.

7.4 Risk management

Risk management can be seen as acknowledging and controlling risks and uncertainties during the realisation of a project with the goal of increasing the chance of a successful result (Stichting Bouw Research, 2000). Managing risks is therefore the identification of risks and acting on this identification process through activities and measures aimed at controlling the risks. The process of risk management can roughly be divided in three parts (Gehner, 2008): risk analysis, risk response and risk control. An overview can be found in Figure 17.

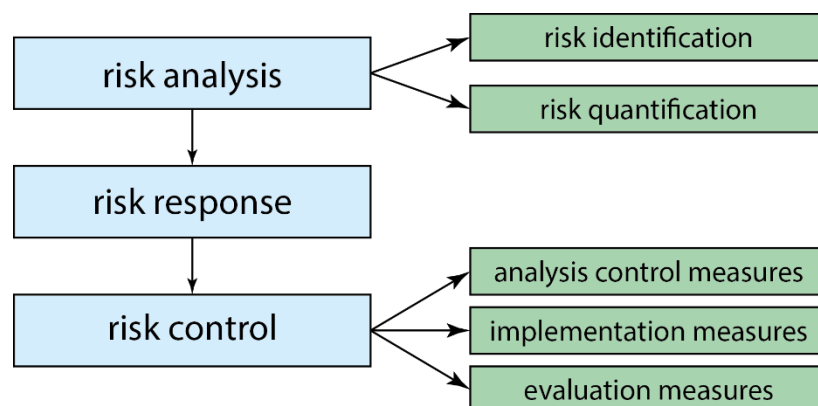


Figure 17: Risk management cycle (Gehner, 2008)

Merna and Al-Thani have a similar approach, but make a clear distinction in the analysis of risks (Merna & Al-Thani, 2010) and broaden the process of risk management. A simplified version of their corporate risk management process can be found in Figure 18.

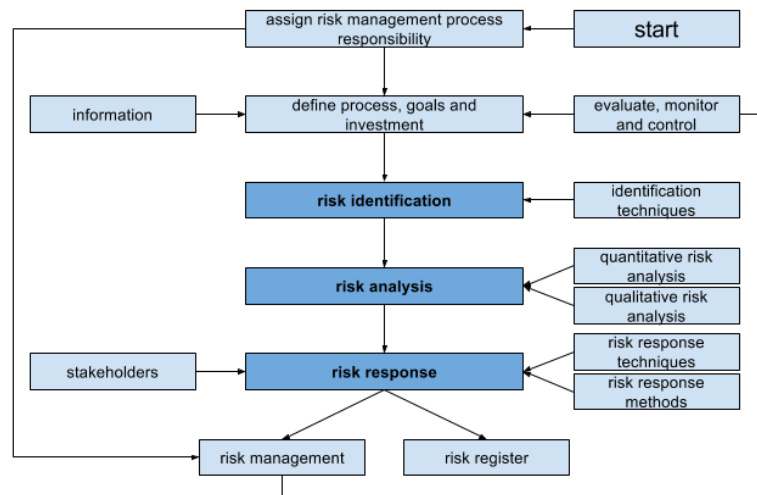


Figure 18: simplified version of the corporate risk management process (adaptation from (Merna & Al-Thani, 2010))

The process depicted in Figure 18 shows that first, the process and goals have to be defined before risks can be assessed. This is done as to define the desired outcome and starting point of the risk management process. Next, risks can be identified, followed by an analysis of the risks. The analysis of risks can be approached from two perspectives; either quantitative or qualitative. After the risks have been analysed, a response can be developed in dialogue with the involved stakeholders, in which either the risk can be registered, not following any response or risk is managed, following a re-evaluation of the risks.

An overlap can be seen with the risk process of Gehner. Where Gehner describes risk analysis as the first step, Merna and Al-Thani divide this step into risk identification and risk analysis, similar to the sub-steps of Gehner (Gehner, 2006; Merna & Al-Thani, 2010). The risk response is also similar, whilst the third step of Gehner, risk control is dubbed risk management in the model of Merna and Al-Thani. As the model of Merna and Al-Thani provides a more detailed overview and a clear distinction between risk identification and risk analysis, this model is used as the base of the following sections.

7.5 Risks occurring in the real estate lifecycle

In CREM, controlling risks is considered one of the added values of real estate. However, corporate real estate risk management is only a relatively new aspect in CREM. First publications on Corporate Real Estate Risk Management (CRERM) originate from 1999 to 2004, in which Simons (1999), Gibson and Louargand (2002) and Huffman (2003, 2004) published articles on the topic of CRERM.

Before the 90's, although the concept of risk was understood by corporate real estate managers, a focus on risks on the portfolio level was lacking (Gibson & Louargand, 2002). However, as corporate risk managers started viewing real estate as an asset and considered the large investments involved in CREM, the necessity to reduce risks became evident (Gibson & Louargand, 2002).

The goal of CRERM is similar to that of corporate risk management, but focusses on real estate. Rosenbluth (2011) based the goal of CRERM on two principles: (1) Identification and possible mitigation of unacceptable risk to a property's operational availability during a variety of adverse situations. (2) Establishment of plans, procedures and protocols to ensure the continued operational availability of the property and in worst case scenario bring the property back to operational status as soon as possible.

In a review of literature and a survey by Bartelink et al. (2015), six main risk categories were identified which can influence the shareholder value of an organisation. In total, 43 risks were divided over these categories, which can be found in Figure 19.

Development risks	Financial policy risks	Operational & business policy risks	Location risks	Appearance risks	External & regulation risks
Zoning plan risk Ground acquisition risk Tender risk Financing risk Temporary housing risk Nuisance risk Planning risk Workspace design risk Development budget risk Social unethical development risk	Liquidity risk Solvability risk Cost of capital risk CRE budget risk Budget cut risk Book value risk Real estate investment risk	Maintenance risk Facility management risk Malfunctioning installation risk Health and safety risk Real estate flexibility risk Occupancy rate risk Office layout risk Relocation risk Expansion profile risk	Preferred location risk Uptime of production facility risk Stakeholder risk Accessibility risk Supplier risk	Design risk Maintenance risk	Natural disaster risk Terrorism risk Political and social unrest Economy risk Exchange rate risk Property market risk Contracts risk Regulation risk Real estate data availability Technology advancement

Figure 19: Risks as identified in literature (own illustration based on (Bartelink et al., 2015))

These risks refer to many sub risks and can be interrelated. For example, in the column operational and business policy risks, the occupancy rate risk, office layout risk, real estate flexibility risk and expansion profile risk are all interrelated on the variable size. When a certain type of office layout is used, the required size could be decreased, but could also increase the occupancy rate of the office when desks are shared. However, when the office size is decreased to just fit the current number of employees, one could face flexibility risks and expansions risks, as in the event of an increase in number of employees, shortages of space arise. Therefore, although the literature provides an extensive list of risks which cover most risks, they are by no means the only risks arising in real estate, and are often umbrella terms of various risks.

7.6 A way of dealing with risks: flexibility

Next to mapping risks more thoroughly and adjusting a strategy to the new information, CRE managers can also take a different approach to deal with risk; by means of flexibility. Where the procedure developed here can be seen as creating robustness, building flexibility allows for creating a resilient strategy. A strategy can be seen as resilient when it can adapt to internal and external challenges by changing the method of operations whilst continuing to function (Lindgren & Bandhold, 2009). The strategy adapts to the new environment.

Flexibility can be seen as a means to deal with risks. Van Reedt Dortland (2013) researched the use of real options as a tool to make users aware of the flexibility potential and to build flexibility proactively. A real option is the right, but not an obligation to exercise an option. The options are created in advance and involve some investment. The option underwritten in such real option can for example be the option to defer, to grow or scale down. Van Reedt Dortland developed a tool for decision making on real estate by means of the logic of real options thinking (van Reedt Dortland, 2013, p. 220). In the tool, scenario planning is used as to provide an idea of the potential need for flexibility. This is then translated into real options that can be used as to create flexibility.

Although creating flexibility is a generally acknowledged and an often-used way of dealing with risks, a number of issues arise when flexibility or real options are introduced in the field of location decision-making. Although flexibility on a real estate level can be achieved in location decisions through the use of short(er) term contracts or break clauses, allowing for a quick retreat from a location in the event of change, the impact of changing the location has more far reaching consequences. Employees are often reluctant to move to a new location if this location increases their travel time. Moreover, in the event of retreating from a country, all investments in that country prove to be virtually worthless. Therefore, although flexibility should be taken into account and can be supportive in dealing with risks, only building flexibility is inadequate for dealing with the uncertainties a company faces in location decision making.

7.7 The first step of risk management: risk identification

The first stage in risk management is the determination of the risks which are likely to affect the performance of a strategy. Risk identification consists of systematically mapping the risks in a project, in which a distinction should be made between the source, the event and the effect (Nederlands Normalisatie Instituut, 2009). Several underlying factors (sources) can trigger an event, causing a (negative) effect on the expected outcome of the project. For identification and quantification of risk, several techniques are available. Raz & Hillson (2005) reviewed 9 standards for risk management including both national and international standards and professional standards, and drafted a list of tools and techniques for risk identification. These techniques can be categorised in 5 categories, which can be found in Figure 20.

Stakeholder help	Previous experience	Diagramming techniques	Testing and modelling	Other
Delphi technique	Documentation reviews	Cause and effect diagrams	Prototyping	Assumptions analysis
Expert opinion	Evaluation of other projects	Root cause analysis	Testing and modelling	Benchmarking
Interviewing	Experience in similar organisations	Event tree analysis	Scenario analysis	Prompt lists
Nominal group technique	Experience in the organisation	Fault tree analysis		Technology readiness level
Peer review	Historical data	Flow charts		Project monitoring
Questionnaires	Incident investigation	Constraints analysis		Examination of vulnerabilities and weaknesses
Structured interviews	Lessons learned	Influence diagrams		SWOT analysis
Risk assessment workshops	Personal observation	Taxonomies		
Brainstorming	Checklists	Systems analysis		
Stakeholder analysis		Hazard and operability studies		

Figure 20: tools for risk identification (own illustration based on list by (Raz & Hillson, 2005)).

The category *stakeholder help* holds a number of tools which make use of other stakeholders or experts on the matter. By making use of interviewing techniques or workshops, a list of risks can be identified based on experiences of the stakeholders and their opinions.

Tools in the category *previous experience* apply previous experience for identification of risks in the current project. By learning from previous experiences, the risk manager is able to identify probable risks in advance. The manager can also make use of experiences of other people, in the form of e.g. checklists. Diagramming techniques are tools that map the process, and identify causes of risks on the nodes mapped. Each event in the process is identified and assessed on possible risks.

In the *testing and modelling* category, tools are available that try to mimic reality in the form of models, which are tested to identify the risks involved. Examples are scenario analysis, in which the future is modelled to assess the risks of a certain process when a scenario unfolds or prototyping, in which in early concepts or models of the process are tested as to identify potential risks. Next to these four main categories, several *other* tools are available for risk identification.

For risk identification, a combination of tools is often used, combining stakeholder help with previous experience, as these are most easy to retrieve. For this research, interviewing (in the category *stakeholder help*) is used as the main tool for identifying the risks, combined with input from experts, as to verify the interviewing results, and to extend the identification process.

7.8 The second step in risk management: Risk analysis

7.8.1 Two types of analysis

Once the risks have been identified, they can be analysed on the two main components of risk: probability of event and magnitude of gain/loss. The main goal of risk analysis is to determine which risk events warrant a response (Bartelink, 2015). Two approaches exist for analysing risks: the qualitative approach and the quantitative approach.

The qualitative approach uses relative values for the value of potential loss, and describe the nature of the risk as a way of getting a better understanding of the risk. The approach

is easy to use, as no calculations are needed and nothing needs to be quantified, but it still covers the most important areas of risk and evaluates these (Ramona, 2011). However, major disadvantages persist, with the results being subjective and dependent on the quality of the risk assessment team. There is insufficient differentiation between major risks and the performance of risk management is difficult to assess due to the subjectivity of the analysis (Ramona, 2011).

Quantitative risk analysis analyses the risk numerically and results in a quantitative value for risk. The objective of quantitative risk analysis is to provide a method for assessing the risk based on scientifically obtained data and measurements (Rider et al., 2000). Statistical data is often used, assigning the potential likelihood of an event and a value to the risks (Bartelink, 2015). Although the calculations can be complex in nature and can take a long time to develop, the results enable one to sort the risks by their impact and risk management performance can be observed closely (Ramona, 2011).

The objective of risk analysis is to provide an estimate of the expected outcome and its volatility or possible deviation from the expected mean, as this can be converted into a probability of event and the magnitude of gain/loss. As the probability curve of an event that takes place in the future needs to be assessed, use can also be made of forecasting techniques as to provide the expected mean of the variables, and potentially a probability curve, from which the probability and magnitude of gain/loss can be abstracted.

7.8.2 Selecting the forecasting technique

Over the years, several methods have been developed for forecasting, which can be divided in three basic types; qualitative techniques, time series analysis and causal models (Chambers et al., 1971). Qualitative techniques, as the name suggests, make use of qualitative data based on expert opinion and formulate a forecast such as future demand out of this. The techniques are often used when data is scarce and is therefore often used in the early phase of product life-cycles (Chambers et al., 1971). Examples of methods used in this category are the Delphi method, basic market research, panel consensus or visionary forecasting.

Time series analysis methods for forecasting focus on historical data and try to identify patterns and pattern changes and extends this pattern into the future. Therefore, historical data of some significance is necessary and the method is used when relationships and trends are both clear and relatively stable (Chambers et al., 1971). Raw data is stripped of cyclical patterns (such as seasonal effects) and growth rates are subtracted. This method assumes that existing patterns will continue in the future. Although this could be the case in the short term, long-term forecasts are difficult to be made, as the future often holds several turning points, in which the reality deviated from the trend (Chambers et al., 1971). Examples of methods for time series analysis are the Moving Average model, exponential smoothing, Box-Jenkins models and trend projections.

The last category of methods, the causal models, identify the forecast as a system and use information regarding the relationships between elements of the system to construct a future forecast. The models express relevant causal relationships mathematically as to model the reality. The model utilises predictions of related events, which are known or more easy to estimate (Chambers et al., 1971). The models are constantly updated as new information about the system becomes available. Causal models are often useful in predicting turning points and long-range forecasts. Examples of these methods are Regression analysis, Econometric models, Input-output models, Leading indicators, and Life-cycle analysis.

A large number of techniques for risk analysis have been developed, and can be categorised using the division of Chambers et al. Ho and Ho (2006), Bos (2012), and Chambers, Mullick & Smith (1971) describe a number of techniques, which are outlined in sections 7.8.2.1, 7.8.2.2, and 7.8.2.3

7.8.2.1 Qualitative techniques

Delphi method

The Delphi Method was developed by RAND in the 50s as a technique to forecast the impact of technology on warfare ("Delphi Method | RAND," 2016). The method was developed as the researchers found that forecasting at that time often consisted out of round-table discussions, resulting in influence by psychological factors such as specious persuasion. In order to eliminate this, the Delphi method was developed with the aim of eliciting opinions with the object of obtaining a group response of a panel of experts (Brown, 1968).

First, a group of experts is selected to whom a questionnaire is send, in which an estimation of a certain variable is asked (e.g. the population in the year 2100). Next to the estimate, a relative rating to the estimate should be given, as a form of self-appraisal. These results are fed back to the expert panel, with the provision of a median and interquartile range. After this, a second round of questionnaires is held, in which the respondents are able to revise their estimate if desired. Next to this possible revision, the experts are asked to describe the reasons for their estimate in terms of factors considered. Before a third round of questionnaires, the results of the second round are fed back to the expert panel, and members are asked to provide critique on the reasons provided by their peers in the second round. A final round gives the last opportunity to revise the estimates of the expert panel. The median of this final response is taken as representation of the group response to the question (Brown, 1968). However, their estimates can also be used as distribution of the probability. Main disadvantage of the method is the use of experts, which could fail in predicting the future due to ignorance or misinformation.

Panel consensus

Panel consensus techniques make use, in contrast to the Delphi method, of round-table discussions amongst a group of experts. Multiple experts are invited to share their vision on future developments and communication is encouraged. The assumption that several experts can arrive at a better forecast than one is hampered by the possibility of psychological factors such as specious persuasion influencing the forecast. The technique makes use of the same input as the Delphi method, namely a group of experts, and often results in rather poor accuracy in forecasts (Chambers et al., 1971).

Scenario planning

The future demand in previous research in real estate is often explored using scenario planning. Examples can be found in for example research by van der Schaaf (2002), Den Heijer (2011, pp. 153-171), Krumm et al. (2000), and Valks (2013). The goal of scenario planning is to identify how current trends evolve in the future (Lindgren & Bandhold, 2009). The tool acknowledges the inherent uncertainty that the future holds, and identifies several possible futures. Lindgren and Bandhold define five steps of scenario planning; Tracking, Analysing, Imaging, Deciding and Acting. In the first step, trends are identified, using various methods such as simple internet search or expert panels and the Delphi method. In the second step, the trends are brought into relation with each other, clustering them and linking them, resulting in the identification of which trends are more certain and which can vary a lot. Eventually, four scenarios are identified resulting from the trends which have the largest impact on the real estate portfolio, and where the company does not have influence upon. Next, desired actions based on these four scenarios are made resulting in four strategies. These strategies are assessed on their performance in each of the four scenarios, and the best one is chosen (Lindgren & Bandhold, 2009). In Den Heijer (2011), the identification of the trends was operationalised by identifying the trends and developments affecting four stakeholder perspectives: organisational, financial, user and technical (Den Heijer, 2011, p. 153). Main downside to a scenario planning approach is the lack of quantitative (ranges of) consequences, forcing managers to often return to more simplistic approaches such as extrapolation of data (Den Heijer, 2011, p. 170). Den Heijer identifies the need for additional information regarding the future demand and the effects on the variables used by managers (Den Heijer, 2011, p. 171).

The Analytic Hierarchy Process (AHP)

The AHP is a methodology based on multi-criteria decision making models and allows both subjective as objective factors in the process. The tool starts with a description of the goal, followed by several criteria the decision needs to comply with in order to reach the goal. Next, several alternatives are developed, which are assessed on compliance with the criteria (Saaty, 1980). The framework offers a systematic thinking environment and provides a basis that is rational for making the decision (Mustafa & Al-Bahar, 1991). In risk assessment, the criteria are substituted by identified risks and all alternatives are assessed based on their ability to mitigate the risks (Mustafa & Al-Bahar, 1991). Main disadvantages lie in the need for judgements to derive relative priorities. Measurement tools are not included in the AHP, which makes it difficult to form scales on which the risks can be assessed.

Game theory

Game theory “provides a language for the description of conscious, goal oriented decision-making processes involving more than one individual. [...] It is a branch of mathematics which can be studied as such with no need to relate it to behavioural problems, to applications, or to games.” (Shubik, 1971, p. 3). The theory is often brought into practice by gaming, in which a number of actors make simulated decisions. These decisions are assessed afterwards on their impact, assessing the threat of risks (Cox, 2009). Game theory does not take into account the concept of probability and is dependent on the rules implied in the game, limiting the results for risk analysis (Horowitz, Just, & Netanyahu, 1996).

Utility theory

The utility theory quantifies the risk consequences based on a loss function. The probability of the worst possible risk outcome is taken as the value representing the risk consequences (Ben-Asher, 2008; Bos, 2012). The model calculates the risk based on the utility of having the opposite result (Rabin, 2000). It implies that if the risk of a loss of a certain value is rejected (the risk is not accepted), the risk of a higher loss is rejected as well, holding the same probability, regardless of the possible gain (Rabin, 2000). This results in a utility function, wherein the risk consequences are mapped. Limitations to the theory is that the hypothesis of expected-utility should hold. This hypothesis states that people are expected-utility maximisers. However, the procedure only works when people are expected to be risk averse. This holds a fundamental contradiction, as many theorists believe risk taking has been fundamental to human development (Rabin, 2000).

7.8.2.2 Time series analysis

Moving average

The moving average technique makes use of time series, in which the data points are analysed by creating averages over subsets of the dataset. This provides a range of averages, resulting in the moving average (Wei, 1994). Various more complex techniques based on the moving average exist, but the simple moving average consists out of the following steps:

- Calculate the unweighted mean of the $[0,n]$ points in the data set.
- Calculate the unweighted mean of the $[0+1,n+1]$ points in the data set.
- Continue until the last point has been reached
- Draw a line through all calculated points, this is the moving average.

n should be calculated as such, that the range surpasses seasonal effects or other irregularities, as to eliminate these effects. The moving average process makes use of historical data, which makes an short term forecast quite accurate (Chambers et al., 1971; Wei, 1994), however, the technique fails to predict turning points and is therefore inaccurate in forecasting on the medium to long term.

Box-Jenkins

In the Box-Jenkins technique, Autoregressive moving average (ARMA) or autoregressive integrated moving average models (ARIMA) are used to find which model fits best to the known data (Wei, 1994). ARMA and ARIMA models are extensions of the moving average model. The autoregressive part uses regression of the variable on the own past (or 'lagged') values, whereas the moving average part models the error on the moving average mentioned in the previous section. The model is better at modelling the process in terms of peaks in the data, compared to the good modelling of the valleys of the moving average process, which is also included in the Box-Jenkins technique (Wei, 1994). Although the model provides very good to excellent results in the short term and good results in the medium term, it lacks accuracy in the very long term (over 10 years) (Chambers et al., 1971). This can partly be explained by the use of historical data.

Trend projections

In trend projections, a mathematical equation is fitted to the available time series and is projected into the future as forecast. The trend projection can be straight-line, but can also be a polynomial, logarithm or other types of equations. The accuracy can be very good in the short term, and often provides fairly good estimations for the medium term (Chambers et al., 1971).

Monte Carlo simulation

Monte Carlo simulation makes use of a random number generator, which takes a random sample out of a predefined distribution by defining the mean and standard deviation of the variable. Underlying variables are used to model the probability curve of the risk (Higham, 2004). The tool is particularly useful when there are many variables with significant uncertainties (Ho & Ho, 2006). Limitation to the Monte Carlo method is that a large number of simulations are necessary before reaching significant probability levels (Huntington & Lyrantzis, 1998). However, with modern computer power, this limitation has been mitigated to a minor inconvenience. A more substantial limitation in the Monte Carlo method is that the simulation is not dynamic, and does not allow for risk mitigation of one of the variables during the simulation. However, adjusting the simulation has become possible as an extension of the method (Araki, Muramatsu, Hoki, & Takahashi, 2014).

7.8.2.3 Causal Methods

Regression models

In regression modelling, one relates a variable to other, for example economic variables and models the relationship between the two variables. The model is fitted using the least squares criterion, which states that the solution must give the smallest possible sum of squared deviations of the observed variable from the true means (Rawlings, Pantula, & Dickey, 1998). The modelled line summarises the relationship between the two variables. Using forecasts of the second variable (e.g. the economic variable), the first variable can be forecasted as well. Regression models are very accurate in the short term and medium term, but often perform poor in long term forecasts.

Econometric models

Econometric models make use of the regression technique mentioned in the previous subparagraph, combining several equations into one coherent system of equations. It makes use of multiple equations, expressing causalities more precise in regard to regression models and is therefore better in predicting turning points (Chambers et al., 1971). Creating such models is an iterative process, in which the final preferred model often differs significantly from the initial model. Moreover, the result does not need to be unique, implying that a different researcher using the same initial data and theory could arrive at a different model (Brooks, 2014). Econometric models prove to be very accurate in the medium to short term, and even perform well in the long term, due to their ability to predict turning points well.

Input-Output models

The purpose of input-output models is to analyse the interdependence of industries in the economy (Miller & Blair, 2009). In the most basic form, the model consists of a system of linear equations, each describing a distribution of an industry's product in the economy. It is often used to describe sectoral behaviour in the economy, and does not express detailed information regarding specific variables. The models are good at providing a long-term forecast, and is to some extent able to identify turning points.

Life-cycle analysis

The life cycle analysis, also known as the technology life cycle, describes the gain of a product throughout its life cycle, from research and design up till maturity and decline (Day, 1981). The model helps to identify the stages through which a product will go during its life. The model is based on a S-curve, in which first investment is necessary, before yielding any profit. The end of the S-curve is the declining period, when the product reaches the end of its life cycle. Forecasting is often troublesome, as a large number of assumptions need to be made to find the right curve. This results in often poor accuracy.

Fuzzy-set theory

The fuzzy-set theory builds on the idea that there are sets whose elements have degrees of membership, which enables an element to partly be in a set. This allows vague concepts to be defined mathematically (Quelch & Cameron, 1994). This allows for a distribution of the risks on involvement, but lacks the probability distribution. A fuzzy-set logic system can help to model the cause and effect relationships without the need for quantitative probability distributions (Shang & Hossen, 2013). However, due to the lack of probability inclusion, it is difficult to validate the results.

Systems thinking

The core assumption in systems thinking is that "a whole entity [...] can adapt and survive, within limits, in a changing environment" (Checkland, 1999, p. 49). It is a complicated way of thinking, showing that interrelationships between events are present and that improvements in one area can adversely affect another (Bos, 2012). The method is often used for testing new ideas regarding social systems and mainly focusses on how systems interact instead of analysing individual elements (Checkland, 1999). The limitation of this method is the difficulty of the method and the building of such a system. Moreover, it is more suited to the development of innovative solutions than as a tool for risk assessment (Bos, 2012).

7.8.3 Overview of techniques

When comparing the techniques, some general remarks can be made. First of all, for all techniques, the input (either data or experts) is of importance. Here, the concept of 'garbage in, garbage out' (GI-GO) applies. If non-accurate data is used, or people are questioned who do not have clear knowledge on the subject, the results can never be reliable. From this concept, it also follows that techniques cannot be assessed precisely on how well they perform on certain elements, as they are so heavily reliant on proper input.

Selection of the best technique for this research can be done using a number of selection methods (Armstrong, 2001). For example, the researcher can use what he/she is used to. A more well founded choice is to consider the market popularity and preference, or by making use of structured judgement.

Considering market popularity, it can be observed that expert opinion is most commonly used as a forecasting method (Armstrong, 2001, p. 3). Use of this method also agrees with experts' preferences, who (logically) also prefer expert opinion as the main method of forecasting (Armstrong, 2001, p. 3). Main advantages of using expert opinions, is that they are relatively inexpensive and do not require complex models or calculations.

When using structured judgement of the best method, one has to consider the most important criteria and evaluate each method on these criteria. Yokuma and Armstrong (Yokuma & Armstrong, 1995) reviewed the importance of criteria in selecting a forecasting technique, rating them on a scale from 1 (being "unimportant") to 7 ("important") amongst a number of stakeholders. The results are displayed in Table 6.

Table 6: importance of criteria in selecting a forecasting technique (Yokuma & Armstrong, 1995, p. 2)

Question	Mean agreement rating				
	Avg.	Decision maker (DM)	Practitioner (PR)	Educator (ED)	Researcher (RS)
Accuracy	6.20	6.20	6.10	6.09	6.39* ^{DM, PR, ED}
Timeliness in providing forecasts	5.89	5.97	5.92	5.82	5.87
Cost savings resulting from improved decisions	5.75	5.97	5.62	5.66	5.89
Ease of interpretation	5.69	5.82	5.67	5.89	5.54
Flexibility	5.58	5.85* ^{PR, ED, RS}	5.63	5.35	5.54
Ease in using available data	5.54	5.79	5.44	5.52	5.59
Ease of use	5.54	5.84* ^{PR, RS}	5.39	5.77* ^{PR, RS}	5.47
Ease of implementation	5.41	5.80* ^{PR, ED, RS}	5.36	5.55	5.24
Incorporating judgmental input	5.11	5.15	5.19	5.12	4.98
Reliability of confidence int.	4.90	5.05	4.81	4.70	5.09
Development cost (computer, human resources)	4.86	5.10	4.83	5.02	4.70
Maintenance cost (data storage, modifications)	4.73	4.72	4.73	4.75	4.71
Theoretical relevance	4.40	3.72	4.43* ^{DM}	4.20* ^{DM}	4.81* ^{DM}

* denotes significantly higher ratings ($p < 0.05$) for column group versus group/s listed in superscript.

For obvious reasons, accuracy is considered the most important criterion in selecting a forecasting technique. However, beyond this, the ease of use in several forms also score highly on importance (ease of interpretation, ease in using available data, ease of use, ease of implementation). Table 6 forms the basis for evaluating the forecasting techniques. However, some criteria are not important in this specific research. Development costs and maintenance costs are not considered, as the pilot study is a one-off proof of concept, not requiring these types of costs.

Next to this, the research specifically focusses on risks in the future, making the reliability of the confidence interval not an important factor, as this is taken into account in the model. The criterion ease of implementation is also not considered, as the procedure is newly developed, and allows for implementation of every type of forecasting technique. Moreover, cost savings resulting from improved decision is omitted as well as a criterion, as this is highly dependent on the current way of working, which can be different in each company. This leaves the following criteria to be considered: (1) accuracy: is the method normally accurate? (2) timeliness in providing forecasts: does the forecast provide long term forecasts? (3) flexibility: is the user able to change input easily? (4) ease of use: is the tool understandable, also for less experienced people? (5) incorporating judgemental input: can the input be judgementally adjusted? Table 7 presents the results of the evaluation of the forecasting techniques. As the GI-GO concept mentioned earlier applies, rating is only done qualitatively and in comparison with the other techniques, yet using literature available.

Table 7: Overview of forecasting techniques (own illustration based on (Armstrong, 2001; Chambers et al., 1971))

Category	Qualitative techniques				Time series analysis				Causal methods		
	Delphi method	Basic market research	Panel consensus	Scenario planning	Moving average	Box-Jenkins	Trend projections	Regression models	Econometric models	Input-output models	Life-cycle analysis
accuracy	Good	Fair	Good	Fair	Poor	Very good	Good	Very good	Excellent	Not applicable	Poor
timeliness in providing forecasts	Very good	Fair	Good	Good	Poor	Very good	Good	Good	Excellent	Very good	Fair
flexibility	Depends on accessibility experts	High	Depends on accessibility experts	High	High	High	High	Low	High	Low	Medium
ease of use	High	High	High	High	Medium	Medium	Medium	Low	Low	Low	Medium
incorporating judgemental input	Yes	Yes	Yes	Yes	Only as an extra step	Only as an extra step	Only as an extra step	Only as an extra step	Yes	Yes	Yes

For the criterion accuracy, Chambers et al. (1971) have assessed the forecasting methods on the short term, medium term and long term. These are averaged into one overall accuracy criterion. As the assessment of Chambers et al. was done qualitatively, using the scale poor to excellent. The same rating was applied here where the scores one to five were assigned to each qualitative value, and then averaged to come to the new value. The timeliness in providing forecasts is also assessed by Chambers et al. and is directly represented in Table 7.

Flexibility is assessed on whether it is easy to retrieve new data and use this data. For example the use of public historical data for a time series model is easily retrievable, whereas interviews with experts highly depends on how well the experts are accessible. Ease of use is determined based on the category of forecasting methods. Time series analysis is often more difficult, as it requires some mathematical operations compared to a simpler questionnaire for experts. Causal models however, are even more difficult to apply, as interrelationships have to be researched as well. Judgemental input is almost always possible with the exception of pure time series methods. Here, the results are only based on the quantitative data provided, and do not allow for changes by the user. However, it is possible to alter the input after the time series models are made and the forecast is provided.

When considering this table, it follows that an econometric model is the best method for forecasting. The model provides excellent accuracy and performs excellent in the timeliness in providing forecasts, the two most important factors in forecasting with the only negative downside of it being difficult to use. However, econometric models require extensive modelling of a large number of variables which are interrelated. For the purpose of this research, this can be heavy-handed, as it requires identification of a large number of underlying variables and testing. In assessing multiple locations, the method can be too extensive.

A method that is also considered to be a good approach for forecasting, is Box-Jenkins, part of time series analysis. This method has a very good accuracy and timeliness in providing forecasts, and is easier to use. The method allows for making a probability curve, including a projection of what the future values of a variable could be. Each variable can be seen as a scenario, that can be taken into account in the risk analysis. As this method provides good quantitative insights into the risks, time series is used as the main tool for analysing risks.

7.8.4 Using the forecasting technique: time series analysis

A time series is a set of observations x_t , each one being recorded at a specific time t (Brockwell & Davis, 2002). Often, discrete-time time series are used, for example with fixed time interval observations. The purpose of time series analysis is to draw inferences from the recorded time series. This implies that a forecast can be made, and possible futures can be modelled.

For this, a mathematical model is developed that mimics the time series data. This model then forecasts the values of the variable. Accompanied by this is a confidence interval, showing the certainty of the value falling within a certain range. From this, a risk curve can be abstracted.

When observed data is available, in time series analysis, one would like to represent the data as a realisation of the process

$$X_t = m_t + s_t + Y_t,$$

where m_t is a slowly changing function, known as the trend component. s_t is the seasonal component, with a known period d and Y_t is a residual random noise component that is stationary. Stationarity will be explained in section 7.8.4.1. When all three components are computed, the observed data is translated into a process, which can be forecasted.

In the process described above, the trend component and the seasonal component are constants. What triggers the uncertainty in a time series process is the random noise component Y_t . Therefore, first the trend and seasonal component should be computed, followed by the computation of the random noise component. The following sections are based on Brockwell and Davis (2002), who wrote a detailed book on time series analysis.

7.8.4.1 Computing the trend component and seasonal component

The aim of determining the trend and seasonal component is to have a residual component Y_t that is stationary. Creating stationary residuals is a translation of a time series into a process whose statistical properties do not change over time. This allows a distribution function to be fitted over the data. A process $\{X_t\}$ can be called stationary if (Tsay, 2005):

- (1) $\mathbb{E}[X_t] = \mu$ is independent of t
- (2) $Cov(X_{t+h}, X_t)$ is independent of t for each h

This shows that the expected value of the time series at each moment in time should be equal, and that the covariance of these values does not depend on the moment in time. Each value at time t now represents a possible deviation from the mean value.

Removing the trend and seasonality from the time series can be done through an estimation of the m_t and s_t . This process is explained below.

Suppose one has a set of observations $\{x_1, \dots, x_n\}$. For purpose of the example, use is made of the number of accidental deaths per month in 1973-1978 in the United States of America. The set of observations can be found in Figure 21.

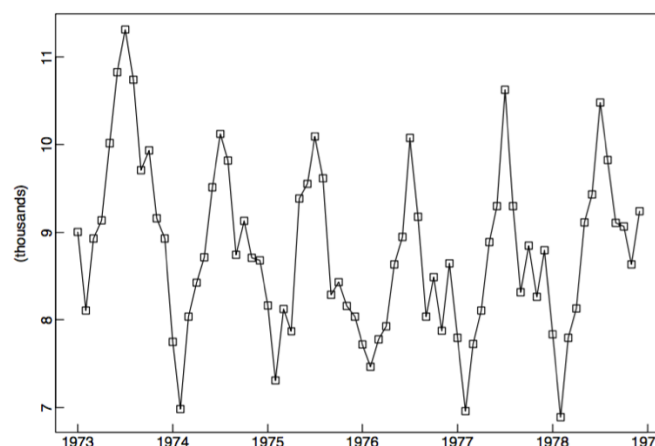


Figure 21: Number of monthly accidental deaths from 1973 to 1978 (Brockwell & Davis, 2002, p. 4)

As can be observed, there is a clear seasonality in this dataset. Eliminating this seasonality is done by first applying a moving average filter which is specially chosen to eliminate the seasonal component. A filter is a function that turns a time series into another time series, emphasising or decreasing certain elements, in this case the seasonality. For this, a value d is to be observed from the graph, which is the length of one seasonal cycle. If the period d is even, then the moving average filter is:

$$\hat{m}_t = \frac{0.5x_{t-q} + x_{t-q+1} + \dots + x_{t+q-1} + 0.5x_{t+q}}{d}, \quad q < t \leq n - q$$

where q is a nonnegative integer. If the period d is uneven, a simple moving average can be used, which is:

$$\hat{m}_t = (2q + 1)^{-1} \sum_{j=-q}^q X_{t-j}, \quad q + 1 \leq t \leq n - q$$

Now, the seasonal component can be estimated. For each $k=1, \dots, d$, an average of deviations is calculated. This average ω_k of the deviations equals:

$$\omega_k = \{(x_{k+jd} - \hat{m}_{k+jd}), \quad q < k + jd \leq n - q\}$$

This formula computes each deviation of the time series $\{X_t\}$ from the moving average previously calculated. The average deviations are combined into the estimated seasonal component as:

$$\hat{s}_k = \omega_k - d^{-1} \sum_{i=1}^d \omega_i, \quad k = 1, \dots, d. \text{ and } \hat{s}_k = \hat{s}_{k-d}, k > d$$

\hat{s}_k now reflects the seasonal component of each point within one seasonal cycle. Now the seasonality can be eliminated from the time series, creating a deseasonalised data set d_t as follows:

$$d_t = x_t - \hat{s}_t, \quad t = 1, \dots, n$$

Now, the trend can be re-estimated by smoothing once again with a moving average filter, and subtracting the moving average from the time series. The residual is stationary according the definition stated earlier in this paragraph. For the example of monthly accidental deaths, the result can be observed in Figure 22.

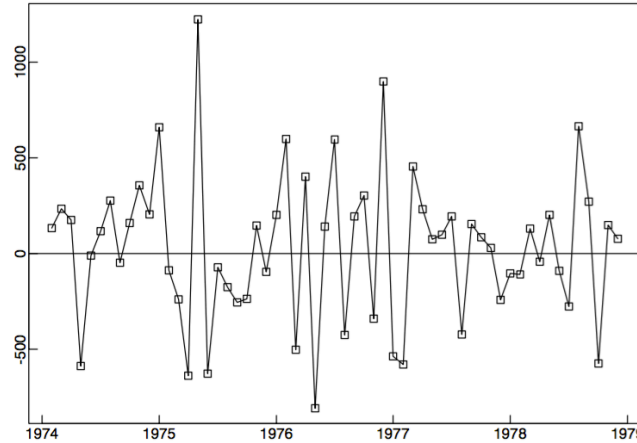


Figure 22: data series when trend and seasonality are eliminated (Brockwell & Davis, 2002, p. 34)

7.8.4.2 Identification

Next step in time series forecasting is to check the hypothesis that the residuals are independent and identically distributed random variables. This makes sure that the data is not dependent on previous values any more. For this, a number of tests can be done, which imply whether a forecasting model should be added to come to independent and identically distributed random variables (i.i.d.). A sequence is i.i.d. if each random variable has the same probability distribution as the other variables and they are all mutually independent.

The first important statistical function is the *autocovariance function* (ACVF). This function is defined as (Brockwell & Davis, 2002, p. 16):

$$\gamma_x(h) = Cov(X_{t+h}, X_t)$$

where $\{X_t\}$ is a stationary time series. The h value determines the lag of the autocovariance function. A covariance function shows the linear relationship of two variables. In the case of the autocovariance function, this relationship refers to the linear relationship of two variables from the same time series. The lag h determines how far the variables are apart in the time series. If the ACVF is positive, then the greater values of the one variable mainly correspond to greater values of the other variable. This is similar to the correlation of a function. However, the correlation is a scaled version of the covariance, as the range falls between -1 and +1 (with 0 being uncorrelated).

From the autocovariance function, the *autocorrelation function* (ACF) can be calculated. The ACF of a stationary time series $\{X_t\}$ at lag h is (Brockwell & Davis, 2002, p. 16):

$$\rho_x(h) \equiv \frac{\gamma_x(h)}{\gamma_x(0)} = Cor(X_{t+h}, X_t)$$

Using this formula the autocorrelation function for a time series model can be calculated. However, when using observed data, a model is not yet available. Therefore, to assess the degree of dependence in the data, and therefore to select a model that best fits the observed time series, a *sample autocorrelation function* (sample ACF) can be computed.

The sample ACF is, if the values of the observed data are considered a stationary time series (as can be done by the steps explained in section 7.8.4.1), an estimate of the ACF of time series $\{X_t\}$. The result of a sample ACF is the autocorrelation of the data for each lag h . This can be used to distinguish how the values of the time series are related. The following definition can be used for calculating the sample mean, the sample

autocovariance function and the autocorrelation function of a time series (Brockwell & Davis, 2002, p. 19):

Let x_1, \dots, x_n be observations of a time series. The sample mean of x_1, \dots, x_n is

$$\bar{x} = \frac{1}{n} \sum_{t=1}^n x_t$$

The sample autocovariance function is:

$$\hat{\gamma}(h) := n^{-1} \sum_{t=1}^{n-|h|} (x_{t+|h|} - \bar{x})(x_t - \bar{x}), \quad -n < h < n.$$

The sample autocorrelation function is:

$$\hat{\rho}(h) = \frac{\hat{\gamma}(h)}{\hat{\gamma}(0)}, \quad -n < h < n.$$

This sample ACF can be used to check with the hypothesis that the residuals are i.i.d. For large n , the sample autocorrelation function of a i.i.d. sequence Y_1, \dots, Y_n approximates a normal distribution $N(0, 1/n)$. This implies that about 95% of the sample ACF's should fall between two standard deviations of the mean (between the bounds $\pm 1.96/\sqrt{n}$). If the sample ACF of the residuals falls out of these bounds at a certain lag, the hypothesis that the residuals are i.i.d. is rejected. An example of an ACF can be found in Figure 23.

In Figure 23, the two horizontal dotted lines represent the bounds of a normal distribution ($\pm 1.96/\sqrt{n}$). What can be observed is that first at lag 0, the line is out of these bounds, and equals 1. This is always the case, as a number is always fully correlated with itself. However, at lag 1, the ACF is also out of bounds. This is an indication that the process is not i.i.d., but has a correlation with the former value.

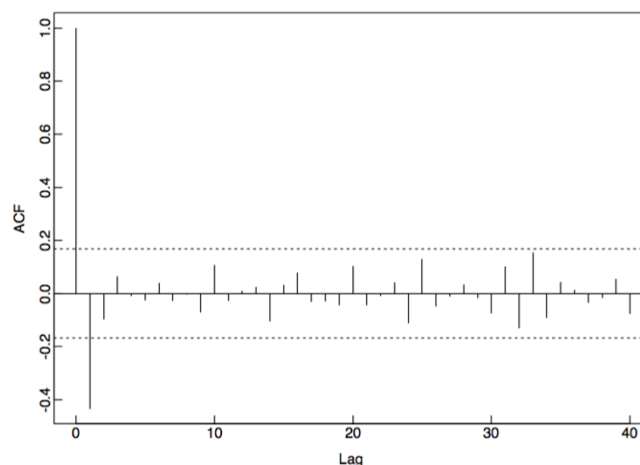


Figure 23: ACF of a simulated process (Brockwell & Davis, 2002, p. 62)

The dependency on a previous variable shown in Figure 23 indicates that a model can be fitted to the residual data set, which is not yet i.i.d. The type of models that can be used are explained in the next section.

Another statistical tool important in time series forecasting is similar to the ACF, and is the partial autocorrelation function (PACF). The PACF is noted as $\alpha(k)$, and is the

autocorrelation between value x_t of a time series and x_{t+k} , that is not accounted for by lags 1 to $k-1$. The PACF can be calculated as:

$$\alpha(1) = \text{Cor}(x_{t+1}, x_t) \text{ for } k = 1$$

$$\alpha(k) = \text{Cor}(z_{t+k} - P_{t,k}(z_{t+k}), z_t - P_{t,k}(z_t)), \text{ for } k \geq 2$$

where $P_{t,k}(x)$ is the correlation of the intermediate values between t and $t+k$. The result of this calculation is a figure similar to Figure 23.

7.8.4.3 Estimating

Using the ACF and the PACF, one can see which model should be fitted to the residuals, such that only i.i.d. variables remain. The appropriate model is chosen with the help of the following matrix (see Table 8).

Table 8: Choosing the appropriate forecasting model based on the ACF and PACF (own illustration)

Model	ACF	PACF
AR(p)	A spike occurs and decays towards 0 as the lag increases.	A spike occurs and is cut off to 0 directly.
MA(q)	A spike occurs and is cut off to 0 directly.	A spike occurs and decays towards 0 as the lag increases.
ARMA(p,q)	A spike occurs and decays towards 0 as the lag increases.	A spike occurs and decays towards 0 as the lag increases.

The different models are explained below.

Autoregressive (AR(p)) models

An autoregressive model is one in which the value X_t only depends linearly on its own past values X_{t-i} . The model is defined as:

$$X_t = c + \sum_{i=1}^p \varphi_i X_{t-i} + \varepsilon_t$$

where $\varphi_1, \dots, \varphi_p$ are the parameters of the model, c is a constant value and ε_t is white noise. White noise is similar to i.i.d. residuals, but is not necessarily independent.

Moving Average (MA(q)) models

A moving average model is one in which the value X_t only depends linearly on the current and various past values. The model is defined as:

$$X_t = \mu + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \dots + \theta_q \varepsilon_{t-q}$$

where μ is the mean of the time series, $\theta_1, \dots, \theta_q$ are the parameters of the model and $\varepsilon_t, \varepsilon_{t-1}, \dots, \varepsilon_{t-q}$ are white noise terms.

Autoregressive moving average (ARMA(p,q)) models

An autoregressive moving average model is one in which the AR and MA models are combined into one model. The ARMA model therefore is defined as:

$$X_t = c + \varepsilon_t + \sum_{i=1}^p \varphi_i X_{t-i} + \sum_{i=1}^q \theta_i \varepsilon_{t-i}$$

where c is a constant value, ε_t is white noise and φ_i and θ_i are the parameters of the model. These parameters show the relative influence of that part of the equation. φ_i indicates how much the value X at time t is influenced by the value X at time $t-i$, which is the autoregressive element of the equation. θ_i on the other hand is the parameter on the moving average part of the model, and indicates how much the value X at time t is influenced by the white noise at time $t-i$.

Autoregressive integrated moving average (ARIMA(p,D,q)) models

The integrated component of the model shows the order of differencing. As previously stated, for a time series model to work, one requires a stationary time series. The same applies when an AR, MA or ARMA model is fitted to the time series. Differencing has the goal of making the time series stationary.

Differencing is the computation of the differences between consecutive observations. It helps stabilising the mean of a time series by removing changes in the level of a time series, thus eliminating trend and seasonality. A differences series is the change between consecutive observations in the original series. Differencing can be done on a number of levels, although the concept remains the same.

In first-order differencing, the change between the observations of t and $t-1$ are considered. This calculation can be written as:

$$y'_t = y_t - y_{t-1}$$

When the resulting time series y'_t does not appear to be stationary, the data can be differenced once again in order to obtain a stationary time series:

$$\begin{aligned} y''_t &= y'_t - y'_{t-1} \\ &= (y_t - y_{t-1}) - (y_{t-1} - y_{t-2}) \\ &= y_t - 2y_{t-1} + y_{t-2} \end{aligned}$$

This process can be followed again and again to obtain higher order differenced time series. However, in practice it is almost never necessary to test higher order differencing. Differencing can also be done on a seasonal level, where the difference between an observation and the corresponding observation from the previous year is considered:

$$y'_t = y_t - y_{t-m} \quad \text{where } m = \text{number of seasons}$$

Test for need of differencing

The need for differencing can normally be observed from the data, as to see whether the is stationary or not. However, this process can also be automated in an objective test called a unit root test. Unit root tests are statistical hypothesis tests of stationarity. One of the most common tests is the *Augmented Dickey-Fuller (ADF) test*. This test has a null-hypothesis that the data is non-stationary, and tests this with the time series data. If the p-value of the test is therefore high, it indicates that the time series is non-stationary. Normally, a 5% threshold on the p-value is applied, indicating that differencing is required if the p-value is greater than 0.05.

The following regression model is estimated in a ADF test:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \dots + \delta_{p-1} \Delta y_{t-p+1} + \varepsilon_t$$

Where α is a constant, the β the coefficient on a time trend and p the lag order of the autoregressive process. The test then calculates the value γ by solving for the equation. If a time series is stationary, γ should equal 0. If this is not the case, differencing should be applied.

Advantages ARIMA model

The advantages of an ARIMA model compared to an AR, MA or ARMA model are evident. First of all, when an ARIMA(p,D,q) is fitted to a time series, one doesn't need to make the time series stationary first, as this part is integrated in the ARIMA model. Moreover, all AR, MA and ARMA models are considered when fitting an ARIMA model, as the p and q values can also take a value of 0.

Fitting the model

Fitting the right model is not an exact science. Each type of model has its own specific ACF and PACF graphs. Selection of the right parameters (p and q) is often done by testing the different combinations of the ARMA model, as to find which combination of p and q results in residuals that are i.i.d. The AR and MA models are automatically included in testing ARMA models, if the p or q value is set at 0.

The parameters φ_i and θ_i are most often found through the maximum likelihood estimation (MLE) method. The maximum likelihood estimation method estimates a preselected number of alternatives, and test how well it fits to the existing time series.

Combining the previous steps

All steps mentioned in this paragraph can be combined when an ARIMA model is applied. An ARIMA model is an autoregressive integrated moving average model. This model first makes the time series stationary by removing the trend and seasonality through differencing, and fits an ARMA(p,q) model to the residuals.

7.8.4.4 Check

The next step in time series analysis is to check the model that was made. A basic check can be done by plotting the actual time series and the modelled time series over the historical data. This is again done by making use of the maximum likelihood estimation described previously.

7.8.4.5 Making the forecast

In making time series forecasts, often a point forecast is given. A point forecast is a single value forecast of the time series. However, as Gardner (1988, p. 541) states: "almost all point forecasts are wrong". This is because an estimation is made for the likely value in the future, which is inherently uncertain. As to provide insight in the precision of a forecast, a prediction interval is needed.

A prediction interval indicates what percentage of future realisations will fall within a prediction interval with a prescribed probability. A prediction interval therefore gives insights in the range of expected values of a time series. This can be seen as a risk assessment, as upper and lower boundaries are presented given a prescribed probability.

Prediction intervals are traditionally computed using a theoretical approach, which makes two critical assumptions: (1) that the applied forecasting model specifies the underlying stochastic process correctly and (2) the forecast errors follow a specific distribution (Chatfield, 2001). Often, it is assumed that the error distribution is Gaussian (normally distributed), as to derive theoretical formulae to calculate the prediction interval. However, the conditional distribution of forecast errors may not be normally distributed, even for a Gaussian data-generating process (Y. S. Lee & Scholtes, 2014, p. 219). Therefore, a number of empirical methods for computing prediction intervals have been developed (see for

example Chatfield (2001), Gardner (1988), Lee & Scholtes (2014), Makridakis & Winkler (1989), and Williams & Goodman (1971)).

A prediction interval is computed using a forecasting model. Considering a stochastic process, X_t , the forecasting model, at a τ -step ahead point forecast is defined by:

$$\hat{Y}_{t,\tau} = g(Z_t, Z_{t-1}, \dots, Z_{t-\omega+1})$$

At time t (Y. S. Lee & Scholtes, 2014). Here, g is the forecasting model chosen, whereas ω is the window size, or size of a sub-sample used to make point forecasts. This definition makes it possible to make use of various different point forecasting models, such as an ARIMA, AR, or MA model. Making such model is explained in the previous sections of this chapter.

The prediction interval is computed by using the forecast errors $E_{t,\tau}$, which have an (unknown) cumulative distribution function. A $100\alpha\%$ prediction interval, with α being the interval (e.g. 0.8 for an 80% prediction interval), is calculated around the point forecast $\hat{Y}_{t,\tau}$. This is done by calculating the lower and upper bound of the interval, providing the range of values (Y. S. Lee & Scholtes, 2014, p. 219). These bounds for $Y_{t,\tau}$ are:

$$[L_{t,\tau}, U_{t,\tau}] = \left[\hat{Y}_{t,\tau} + Q_t \left(\frac{1 - \alpha}{2} \right), \hat{Y}_{t,\tau} + Q_t \left(\frac{1 + \alpha}{2} \right) \right]$$

Where $L_{t,\tau}$ is the lower bound and $U_{t,\tau}$ is the upper bound. The value Q_t is the forecast error quantile. These values are unknown, and must be estimated in order to calculate the upper and lower bounds.

A different approach - applying a Monte Carlo simulation

A different approach to gain insight in the uncertainty of the forecast is by the use of a Monte Carlo simulation to the model. The Monte Carlo methods are a class of algorithms that rely on repeated random sampling. Central to this idea is that some problems can be solved by taking a large number of random drawings from a probability distribution (Rubinstein & Kroese, 2017).

In a Monte Carlo simulation, the residual random noise component Y_t is simulated a large number of times, making use of the probability distribution identified from historical data from the same variable. The Monte Carlo simulation draws a random number from this probability distribution and applies this to the time series model. This process is repeated a large number of times, for example 10.000 times. These 10.000 simulations represent 10.000 scenarios that could unfold.

Each scenario is a representation of a possible future. As a random number is drawn from the probability distribution of the specific variable, also a probability distribution function can be made from the results. This can be done by making a histogram of the results, binning the values, as shown in Figure 24. This figure shows the probability that a certain value will be the actual value in the future.

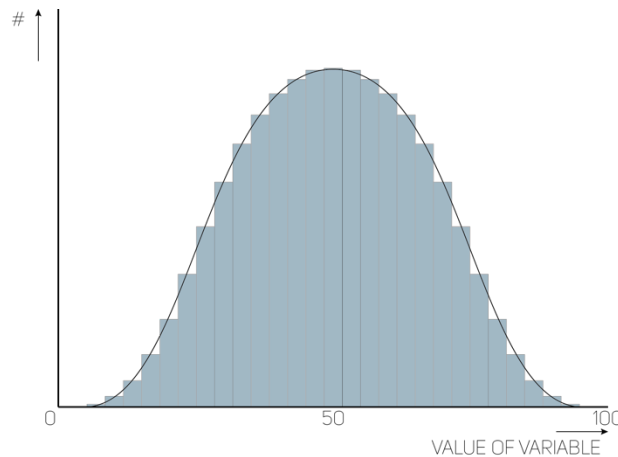


Figure 24: probability distribution function of an example variable, resulting from the Monte Carlo Simulation (own illustration)

7.9 The third step in risk management: risk response

How to respond to a risk depends on the size of the risk and the risk attitude of the decision maker (Gehner, 2006). In general, four types of control measures are possible, with decreasing effectiveness: avoid, reduce, transfer and accept.

Avoid

The most effective means to deal with a risk is avoidance. Avoidance is the prevention of the probability that the risk event occurs. The most extreme example of avoidance is termination of the project.

Reduce

If a risk cannot be avoided, measures can be taken to reduce the impact of the risk as much as possible. This is only possible if the decision maker or the company has direct influence on the risk. An example specific to corporate real estate management is the incorporation of flexibility in the portfolio. This way the building is adaptable to continuously align the supply with changing demand (van der Zwart & van der Voordt, 2013). Flexibility was identified as one of the seven added values for real estate by De Jonge (1996). In the field of real estate, four types of flexibility can be identified (De Jonge & Den Heijer, 2014, pp. 76-77); spatial flexibility, technical flexibility, juridical-financial flexibility and organisational flexibility. Main disadvantage of flexibility are the costs involved.

Transfer

Transfer of risk is the placing of risk under the authority of another party who is best able to carry the effect of the risk in the event of occurrence. Often, costs are involved in the transfer of risks. The most common way of risk transfer is by insuring for certain events. When an event occurs, which has negative effects, the company is compensated for the loss through a third party.

Accept

Risks with a low effect or low probability can be accepted. The size of risks to be accepted is dependent on the risk preferences of the decision maker.

A tool for deciding which type of control measure is best is the probability/impact matrix (Winch, 2010). In this matrix, the risks are mapped using the probability and impact defined and assessed in the previous step, and are spread through four quadrants, depending on the risk preferences of the involved stakeholders. The matrix can be found in Figure 25.

	High	Insure / mitigate	Mitigate / cancel
Impact	Rare catastrophe		Probable disaster
	Bad luck		Management challenge
	Low	Accept	Externalise
		Low	High
		Probability	

Figure 25: probability/impact matrix (Winch, 2010)

7.10 Conclusions

In this chapter, the sub-question “How can risk be assessed, managed and quantified” is answered.

Risk can be defined as the probability of an event occurring times the magnitude of loss or gain. A significant distinction can be made between risks and uncertainty. Risks is when an outcome may or may not occur, but its probability of occurring is known, whereas uncertainty is when an outcome may or may not occur, but its probability of occurring is not known.

Risks are managed by first conducting a risk analysis, identifying the risk and assessing it. Then, the respective manager is able to respond to the risk and control the risks. Managing risks can in general be done by taking one of four control measures: avoiding the risk, reducing the risk, transferring the risk or accepting the risk. This is dependent on the probability of an event occurring, and the impact it can have.

The first step of risk management is the identification of the risks. For this, a large number of tools are available, but it is found that often ‘stakeholder help’ and ‘previous experience’ are used as a basis for risk identification. This is mainly due to the ease of access of these resources. In this research, interviewing (stakeholder help) and an expert panel is used.

Risk analysis can be done in two ways: quantitatively or qualitatively. The advantage over a quantitative analysis compared to a qualitative analysis is that a quantitative analysis is more objective, and enables one to create a probability curve of an event. This way, more detailed knowledge is gained on the probability of an event occurring, enabling the manager to better respond to the risk.

For the research, use is made of Box-Jenkins time series analysis as this method scores high on accuracy and allows for making a probability curve. A time series is a set of observations x_t , each one being recorded at a specific time t . Making use of historical data, a prediction is made of future developments of the variable. The available observed historical data is first represented as a realisation of the process

$$X_t = m_t + s_t + Y_t,$$

where m_t is a slowly changing function, known as the trend component. s_t is the seasonal component, with a known period d and Y_t is a residual random noise component that is stationary. A process can be called stationary if:

- (1) $\mathbb{E}[X_t] = \mu$ is independent of t
- (2) $Cov(X_{t+h}, X_t)$ is independent of t for each h

Through a large series of statistical tests (ACVF, ACF, PACF, ADF, BIC, see Section 7.8 and Appendix B for a detailed description) and simulations, an autoregressive integrated moving average (ARIMA(p,D,q)) process is fitted to the historical data, as to closely reflect the historical process. The resulting model is a mathematical process, that can be written in the form

$$X_t = c + \varepsilon_t + \sum_{i=1}^p \varphi_i X_{t-i} + \sum_{i=1}^q \theta_i \varepsilon_{t-i}$$

Where c is a constant value, ε_t is white noise, p is the autoregressive order, q the moving average order and φ_i and θ_i are the parameters of the model.

The mathematical process can be used to define the future value of the variable. However, a point forecast, which is often given, does not give the required insights for a risk analysis, as it does not provide a probability curve for the risk occurring. As a solution to this, a Monte Carlo simulation can be applied to the model. In the Monte Carlo simulation, the residual white noise component is simulated a large number of times, making use of the probability distribution function identified from the historical data from the same variable. The Monte Carlo simulation draws a random number from this probability distribution and applies this to the time series model. This process is repeated for a large number of times, creating various scenarios. By means of a histogram, a probability curve can be abstracted from these values.

PART III: DEVELOPING A FRAMEWORK

8. Effective decision support systems

Before a decision support system is developed, first it is important to distinguish what the characteristics of an effective decision support system are. Therefore, this chapter answers the research question: "How can decision-making tools be evaluated?". This chapter describes the purpose of decision support systems, followed by a description of the important factors for effective systems. The chapter builds on prior research (Arkesteijn et al., 2015; de Visser, 2016) on this topic. However, the original sources were consulted as to validate this research.

8.1 Definition of decision support systems

As decision-making processes are becoming increasingly complex, with an increasing number of criteria, systems are being developed that support this process. A decision support system (DSS) can be defined as a system that aids a decision-maker in making a decision, by utilising data through models to solve semi-structured and unstructured problems (Razmak & Aouni, 2015, p. 101; Riedel et al., 2010, p. 232; Zhou, Huang, & Chan, 2004).

DSSs are developed to assist in making decisions and often come in the form of formal steps for solving a problem, integrating preferences of multiple stakeholders. DSSs are applied for example strategic planning or development processes, where human information processing is required (Razmak & Aouni, 2015, p. 102).

Riedel et al. (2010) classified DSSs in four types: model-oriented, data-oriented, decision-oriented, and general. The first type of DSSs aim to aid in decision making in a specific problem domain and focus on optimisation routines. Data-oriented models focus on providing information and facilities for data storage. Decision-oriented models are applied to a specific decision process, and aid to help in making the decision. Lastly, general DSSs support multiple decision areas or domains.

The LDM framework, which is described in the following chapters, when the above definition is applied, can be seen as a decision support system. This is because it makes use of a formal set of steps, where preferences are integrated in the decision-making process, which results in generating and selecting relevant options in a multi-criteria decision making environment. As the LDM focusses on one decision process, namely the location decision for the real estate portfolio, it can be classified as a decision-oriented model.

The advantages of using DSSs are threefold, as stated by Carlson & Turban (as cited in Riedel et al., 2010, p. 234). DSSs improve the efficiency of decision-making, it supports in making sound decisions and it allows for interactive problem solving.

8.2 Developing a decision support system

Over the time, DSS literature scarcely considered anything but the technical perspective in decision making processes (Courtney, 2001, p. 30). However, in order to develop a decision support system that is accepted by the stakeholders, more perspectives are to be taken into account. Therefore, Courtney (2001) developed a new DSS paradigm, which can be found in Figure 26.

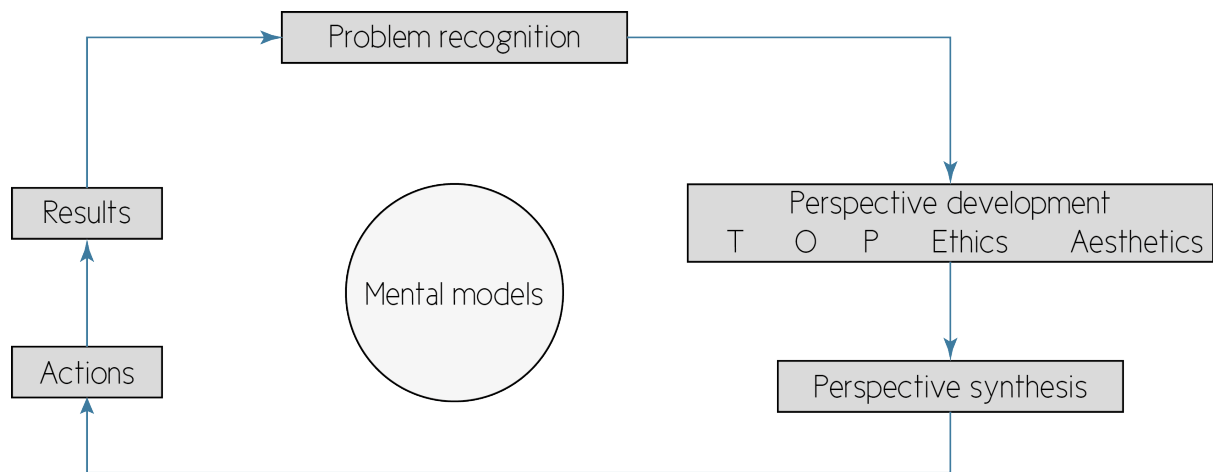


Figure 26: DSS paradigm model (own illustration based on (Courtney, 2001, p. 31)

A decision process starts with the recognition that a problem exists. This implies that a decision should be made on how to deal with the problem. The next step is to determine the perspective of the stakeholder(s) to the problem. The T, O and P stand for respectively technical, organisational and personal perspectives. The model shows what information and perspectives stakeholders take into account regarding the problem at hand. This comes forward through the mental models the stakeholders have on all of these topics. The development of this perspective is crucial in making a decision support system, as the system should reflect these perspectives. If a DSS does not take this into account, it could lead to rejection of the system. Developing the model iteratively can ensure the perspectives are taken into account, as the model is tested and feedback on the model can be used to improve the support system (Riedel et al., 2010, pp. 236, 239-240).

8.3 Effective decision support systems: creating acceptance and satisfaction

Creating an effective decision support system requires an interaction between human (the user) and the model. DSSs leverage the human abilities in complex decision-making, and thus do not fully take over the entire decision-making process (Riedel et al., 2010, p. 242). Therefore, the interaction needs to be optimal in order to have an effective decision support system. Riedel et al. (2010) researched the factors that influence this interaction. He based his model on four main perspectives that are important for the use and acceptance of a DSS.

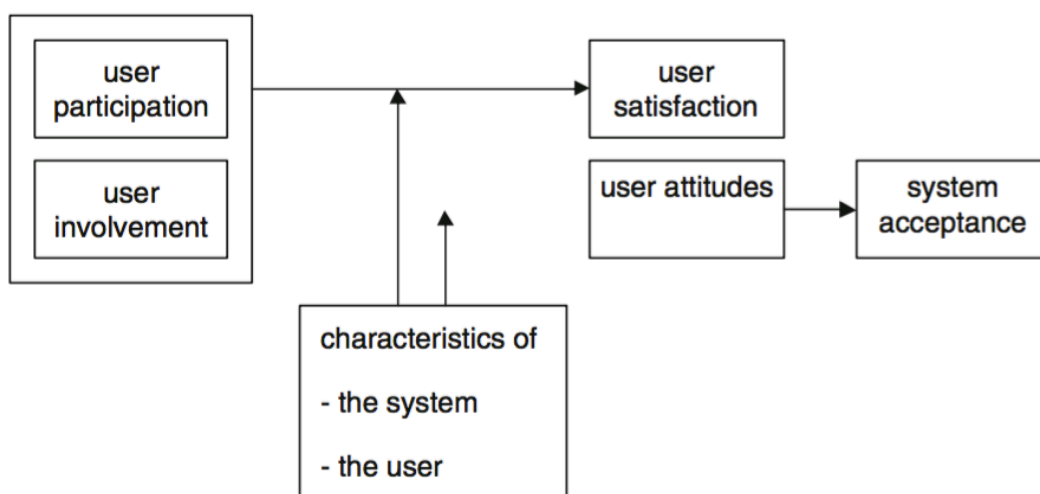


Figure 27: User participation and user involvement technology acceptance (Riedel et al., 2010, p. 249)

As can be seen, system acceptance is based on two variables: user attitudes and user satisfaction. The attitude of the user is partly predefined, due to the openness of the user in applying models as a tool. However, both variables are influenced by the characteristics of the model and by two other important factors: user participation in the process and user involvement. Participation is defined by Riedel as observable behaviour, whereas involvement is a "subjective psychological state of the actors, regarding the importance of the system" (Riedel et al., 2010, pp. 246-247).

The model indicates that whilst developing the model, it is important that the user is involved in the process, and an iterative design process between this user and the system engineer takes place. Both factors have a positive influence on the user satisfaction and the attitude towards the system and therefore contributes significantly to the system acceptance.

The need for user participation and involvement is also reflected in Riedel et al.'s conceptual model of determinants in DSS modelling, as seen in Figure 28.

The participation and involvement help in achieving a higher level of perceived control, which in turn raises both perceived usefulness and behavioural intention. Perceived usefulness is also influenced another way by participation and involvement. Involvement of the stakeholders in the decision-making process helps the stakeholders to improve their input in the model, which is the representation of their perceptions in the characteristics of the model. This can translate to higher levels of system complexity, as the mathematical calculations can become more complex and reflect the preferences of the stakeholders closer. This also improves the perceived usefulness of the model.

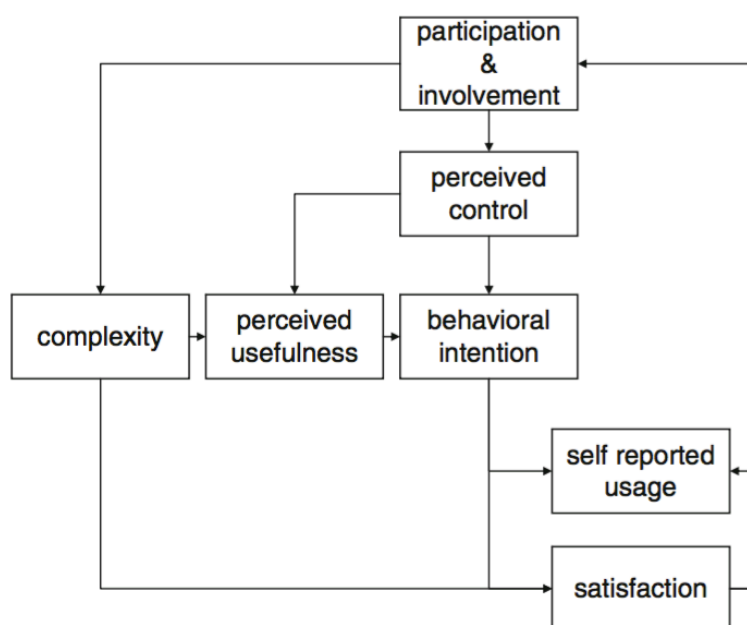


Figure 28: conceptual model of determinants in DSS modelling (Riedel et al., 2010, p. 258)

In several case studies, the relationships laid out in the model of Figure 28 were tested in practice (Riedel et al., 2010, p. 259). These case studies showed mixed results. It was shown that user participation lead to increased perceived usefulness through an increased complexity of the system. However, it was also found that a too complex system decreases the user satisfaction. This implies that the model should still be understandable for the users, as it can decrease their perceived control and perceived usefulness if the user is incapable of grasping how the model works. The study however did find a positive relationship

between user participation on the acceptance of a system, through the perceived control of the users (Riedel et al., 2010, pp. 266-267).

It can be concluded that user participation and involvement play a crucial role in increasing user satisfaction and user acceptance of the decision support system. User participation can increase the complexity of the model, which up to a certain level increases the perceived usefulness of the model. However, there is a limit to this positive effect, as a too complex system decreases the perceived control and user satisfaction of the system.

8.4 Effective decision support systems: gaining trust

As described before, an effective decision support system requires an interaction between human and the model. It is of importance that the model supports the user in making the decision. The users have certain expectations of what the system does and what the results of these steps are. These expectations have to be met in order to create an effective decision support system, and the user needs to trust the system that his/her expectations are actually met. Therefore, trust is an important concept to take into account in the human-computer interaction.

Trust can be defined as *"the attitude that an agent (the DSS) will help to achieve an individual's goal in a situation characterised by uncertainty and vulnerability"* (Riedel et al., 2010, p. 268). In other terms, the 'individual' or user needs to get the feeling that the system actually helps in achieving the goal in a way that the user couldn't do him- or herself. This requires a voluntary interaction of the user with the system, as the user should only use the system when the user trusts this system (Riedel et al., 2010, p. 270).

Trust in automation and decision support systems is influenced by three main elements: performance, process and purpose (J. Lee & Moray, 1993). The performance of the system is rated in terms of the ability of the system to achieve the user's goals. Here, one of the core determinants is reliability. If the system is reliable, this has a positive effect on the trust in the system (Wiegmann et al. as cited in Riedel et al., 2010, p. 273). The second element, process, refers to the ability of the system's algorithms to align with the user's goals. This is closely linked with the complexity element described in the previous section. If the user is able to understand how the model works and believes the algorithm is capable of performing the task, users will put more trust in the system (Miller & Larson as cited in Riedel et al., 2010, pp. 272-273). The last element that influences trust is the purpose. This indicates that a user has more trust in the system if the system is used for its intended use.

Usage of a system is directly influenced by the user's trust in a system. If users do not trust the system, it will not be used, as the outcomes would not be accepted as a valid result (Riedel et al., 2010, p. 277). In an online survey, Riedel et al. found that the system performance indeed has a positive influence on the trust of the system (2010). Opposed to this is a negative influence when the system shows performance variability.

Next to the system characteristics, some user characteristics also play a role in trusting the model. This is also related to the user characteristics influencing the user satisfaction with the model as shown in Figure 27. Prior experience with DSSs helps in gaining a positive attitude towards such systems. Moreover, the abilities of the user also positively influence trust (Riedel et al., 2010, pp. 282-286). This can be explained by the fact that complexity of the model can negatively influence the trust in the model, as the user cannot comprehend the way the model comes to a solution. Therefore, user characteristics also play a significant role in trusting the system.

As shown in this section, trust is an important factor in creating system acceptance. If the system is not trusted, this can lead to overall rejection of the results of the system, and therefore to not applying the system at all. For trust to be gained by the system, the system should be able to achieve the user's goals, align the algorithms to these goals and should be used for its designated function. However, some user characteristics play a role in gaining

trust in the model as well. Prior experience and the abilities of the user to understand how the model works play a significant role in creating trust.

8.5 Evaluating a decision support system

When testing the decision support system in a pilot study it becomes possible to evaluate the system. It can be tested whether the system actually created acceptance, satisfaction and trust. Next to this the impact of the system on the problem can be measured. Joldersma and Roelofs (2004) researched empirical studies on the different types of measurement that are used, and found four main types:

1. Experiences with the method
2. Attractiveness of the method
3. Participant's perceptions of effectiveness of the method
4. Observer's perceptions of the effectiveness of the method

The first type of method refers to how the system is perceived by the user in terms of their own use of the system. This closely refers to the participation and involvement of the users as described in Section 8.3. In this this category the moments of interaction between the user and the system are evaluated.

The attractiveness of the model involves inquiring whether people like the method that is used and whether they feel comfortable using it. This category is closely linked to the perceived control described by Riedel et al. (2010). It is also related to acceptance of the results (Joldersma & Roelofs, 2004, p. 698). Trust is closely related to the attractiveness of the model, because a trustworthy system increases the chance of using the model again and increases the attractiveness of the model. Therefore, performance, process and purpose play an important role here.

Attractiveness of the model is closely related to the third type of measurement: participant's perception of effectiveness of the method. Evaluating this perception involves surveying the participants about their views on the contribution of the method to the outcomes (Joldersma & Roelofs, 2004, p. 698). However, in research it is found that this category is often more closely allied to attractiveness of the method than to the quality of the results (Joldersma & Roelofs, 2004, p. 698)

The last category is the observer's perception and measurements of effectiveness of the method. This usually refers to criteria such as the quantity and quality of results produced within a particular length of time, changes in participant's attitude and improved likelihood of acceptance of the results (Volkema, 1983 as cited in Joldersma & Roelofs, 2004, p. 698). The observer's perception adds an extra layer on the measurement of effectiveness, and helps in determining this effectiveness.

8.6 Conclusions

Decision support systems are systems that aid a decision maker in making a decision, by utilising data through models to solve semi-structured and unstructured problems (Razmak & Aouni, 2015, p. 101; Riedel et al., 2010, p. 232; Zhou et al., 2004). A DSS therefore helps the user in solving complex problems that are difficult to impossible to solve without the system.

Using a DSS requires a human-computer interaction, which requires a certain level of system acceptance, trust and satisfaction before the results from the DSS are accepted, and the system will actually be used. User participation and involvement is crucial in gaining such acceptance, and plays a significant role in creating trust. User participation can increase the complexity of the model, which up to a certain level increases the perceived usefulness of the model. However, there is a limit to this positive effect, as a too complex system decreases the perceived control and user satisfaction of the system.

Trust plays a significant role in system usage, and is influenced both by the model as by the user's characteristics. The performance of the model in terms of achieving the user's goals, and alignment of the algorithms to the user's goals are important from a system perspective. Moreover, using the model for its designated use helps in gaining trust in the system. From a user perspective, the experience that the user already has with the system itself or with similar systems increases the trust in the system. Furthermore, the abilities of the user can influence the trust in the system, as the ability to comprehend how the model works plays a major role.

Evaluating the effectiveness of a system can be done by evaluating on four categories: (1) experiences with the method, (2) attractiveness of the method, (3) participant's perceptions of effectiveness of the method, and (4) observer's perceptions of the effectiveness of the method. These four elements closely relate to the trust and acceptance of the model. Table 9 links these two elements together, and can be used as the elements on which the model can be evaluated.

Table 9: Evaluation checklist for decision support systems and its development process, based on (de Visser, 2016; Joldersma & Roelofs, 2004; Riedel et al., 2010)

Characteristic	Evaluation category (Joldersma & Roelofs, 2004)	Resulting effect (Riedel et al., 2010)
Participation and involvement (Riedel et al., 2010)	Experience	System acceptance
Perceived control (Riedel et al., 2010)	Attractiveness	System acceptance
Perceived usefulness (Riedel et al., 2010)	Attractiveness	System acceptance
Satisfaction with the system (Riedel et al., 2010)	Attractiveness	System acceptance
Performance of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Performance reliability of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Purpose of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Perceived ease of use (Riedel et al., 2010)	Attractiveness	System acceptance
Complexity (Riedel et al., 2010)	Attractiveness	System acceptance
Familiarisation with algorithms of the model (Riedel et al., 2010)	Experience	Trust in the system

9. Developing the location decision-making framework

The Location Decision-Making framework can be seen as an adaptation of the PAS design approach of Arkesteijn (2015), incorporating risk analysis in this approach. This chapter describes the model in detail, and answers the research question: "How can risk be incorporated in a preference-based location decision-making process?"

9.1 Three levels of rationality in decision-making

Answering the question of where to locate your buildings portfolio is a complex question, which cannot be answered directly. The question arises how a process can be organised such that an answer to this main question can be given. Arkesteijn et al. (2017) use the concept of rationality to answer this question and organise their process accordingly.

Rationality is described by Kickert (1980, p. 60) as: "Rationality in decision-making behaviour is a concept that deals with behaviour. As behaviour is generally considered to be a choice made between alternatives, rationality is therefore a concept that deals with the way one chooses between alternatives." Rationality therefore, can be seen as a way to describe the process how one reaches a certain goal, namely the best alternative. In choosing the location(s) of the building portfolio, the goal is to find the best selection of locations, that best suits the companies' preferences. The process as to come to this solution can be described using rationality.

De Leeuw describes three levels of rationality on which the decision-making process can be structured (De Leeuw, 1992): the substantive rationality, the procedural rationality and the structural rationality. The three rationalities combined provide a solid basis for a decision-making framework. They are explained below.

Substantive rationality - the model

The substantive rationality describes the strategy and process for finding an answer. The main research question is unravelled into smaller and smaller elements, until a set of questions that are easily answerable remain. This way, a methodological approach is developed of what elements should be answered, and the question is modelled into a more manageable structure.

Procedural rationality - the procedure

The procedural rationality is the determination of the best procedure of decision-making. In the substantive rationality, the main question is divided into smaller "bite-size chunks", whereas the procedural rationality focusses on which "chunk" should be handled first. This ensures that no question is answered without knowing the results from a prerequisite question.

Structural rationality - the activities

The last level of rationality describes the stakeholders that are involved and what they should do in order to come to a decision. This element is often forgotten, but is crucial in coming to an end result. If the same method is applied, but with different stakeholders, the chance that a different end result is reached is significant. Structural rationality therefore describes in each step of the procedural rationality how responsibilities and actions are divided amongst the stakeholders involved, and who should undertake which activity.

9.2 Developing the location decision-making framework

The development of the LDM framework, is based on the PAS design approach developed by Arkesteijn (Arkesteijn & Binnekamp, 2014; Arkesteijn et al., 2015). This approach is described in detail in sections 6.2 and 6.3. All three rationality levels of De Leeuw are reflected in this approach. The LDM framework can be seen as a further development of PAS, where it is adjusted and extended where needed, as to incorporate risk in the procedure.

Firstly, the substantive rationality is represented by the mathematical model, which provides a methodological approach for answering the main question. This model can be seen as the supporting tool of the procedure, in which the entire process is modelled. The procedural rationality is reflected in the procedure, where the steps that need to be taken are explained. Lastly, the structural rationality is described in the activities, which describe which stakeholders should do what in which form. The three elements combined provide a basis for the framework used in this research, and are illustrated in Figure 29.

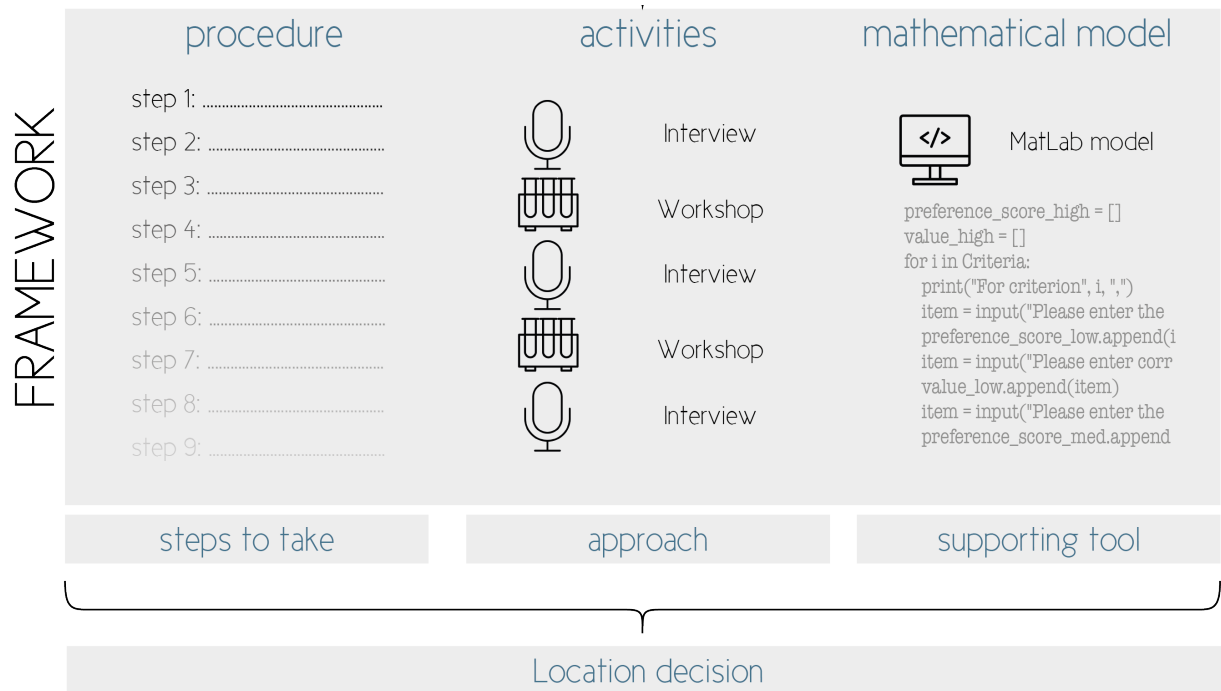


Figure 29: Framework for location decisions (own illustration)

This framework is adapted to incorporate risk management in the decision-making process. In the following sections, each of the three elements is explained in detail.

9.3 The location decision-making procedure

The procedure of the LDM framework is a list of the steps to be taken in order to come to a location decision. The procedure explicitly states how all relevant variables and stakeholders are introduced in the decision-making process using a step-by-step plan. The procedure can be used by the subject owner and other relevant stakeholders, and therefore only explicitly mention the steps they need to take. The following steps present the procedure that was developed for the pilot study.

- Step 1: Each decision-maker specifies the decision variable(s) that he/she is interested in.
- Step 2: Each decision-maker rates his/her 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).

Step 3: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.

Step 4: Each decision-maker/expert indicates for each decision variable whether there is a risk that the value of the decision variable will change over time.

Step 5: Each decision-maker determines the design constraints he/she is interested in.

Step 6: The decision-makers define the locations in consideration other than the current locations in the real estate portfolio.

Step 7: The decision-makers jointly decide on an acceptable risk, formulated as a probability level between 0 and 1, that the alternative will not take a value lower than the corresponding preference score.

Step 8: The decision-makers jointly assign a weight to the current and future overall preference score of the portfolio.

Step 9: 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.

Step 10: Use an algorithm to yield an overall current and future preference score and one overall preference score.

Step 11: The decision-makers decide group wise based on the overall preference score of the alternative portfolios and insights in the risks of these portfolios.

What can be seen is that the procedure has significant similarities with the PAS procedure as described in section 6.2. Previous pilot studies with this method yielded positive results (see Arkesteijn et al. (2015), Arkesteijn et al. (2016) and de Visser (2016)). As PAS makes use of strong scales (for which the reference points are determined in step 2 of the procedure) and allows for determining the relative importance of the criteria (by assigning weights to each criterion in step 3 of the procedure), it is an extremely useful basis for a preference-based location decision-making model.

Compared to the PAS procedure, the LDM procedure has a number of extra steps that need to be taken. These alterations are described below.

Step 4

First of all, in step 4 the decision-maker or (external) experts indicate for each decision variable whether there is a risk that the value of the decision variable will change over time. This step refers to the first step of risk management, risk identification, as described in section 7.7. The step is necessary as the system engineer requires knowledge from the company's perspective on what variables actually hold risk. If the system engineer would determine these risks the engineer influences the outcomes of the system and could potentially miss some risks. The possibility that some risks are not identified by the decision-makers using the LDM-framework is compensated by allowing risk experts to give their vision on which variables hold any risk. Although it is possible to assess every decision variable on risk, this step reduces the amount of time required to research and develop future scenarios. A decision variable such as size obviously holds no risks in a regular contract, as this supply characteristic will not change over time. Here, it should be noted that the model now only considers changes in supply characteristics, and not changes in demand preferences.

Step 6

Step 6 of the LDM-framework is an addition to the PAS procedure in order to clarify the flexibility of the framework. Although in the PAS method it is possible to add new locations to the set of alternative locations, it is not unequivocally mentioned in the process. The addition of the sixth step in the LDM-framework does mention this extra step, which significantly enlarges the applicability of the framework.

Step 7

The LDM-framework considers two time periods. First the current moment in time, t , for which an overall preference score is calculated. Secondly, a future time period, $t+n$, is

introduced, which expresses the risks of changes in the location characteristics. The preference score for the future time period $t+n$ is calculated by means of a time series forecast, applying a Monte Carlo simulation, as explained in more detail in section 9.5. The forecast results in an inverse cumulative distribution function, showing the probability that the alternative will take a value higher than or equal to a given preference score. The stakeholders should indicate the risk level they are willing to accept, as then it can be calculated what the lowest possible preference score is relating to this risk level. The risk level is expressed in the form of a probability level, ranging between 0 and 1.

Step 8

Due to the incorporation of risks in the framework, the decision-makers need to determine a weight between the current situation and the future situation in Step 8 of the procedure. As is described in detail in section 9.5, the model calculates both a current overall preference score, and a large number of overall preference scores, based on the various scenarios developed from a time series model. From the scenarios, the most common value is determined, which is seen as the future overall preference score. The decision-makers jointly make a decision on how important the future overall preference score is compared to the current overall preference score. This step is mainly meant for the model to mathematically calculate the best overall portfolio alternative. However, in the model itself, the decision-makers are able to see the full overall preference score overview in terms of a histogram as shown in Figure 31.

Step 11

In Step 11 of the procedure, a slight alteration to the last step of the PAS procedure is made, by including the need to take into account the insights of the risks of the portfolios into the decision.

9.4 The location decision-making activities

Applying the steps described in section 9.3 requires a number of activities with the involved stakeholders. The activities comprise of three interviews and two workshops, that alternate in the pattern I-W-I-W-I, which is equal to the PAS activities (Arkesteijn et al., 2015). Each interview and workshop is explained below, preceded by the introductory steps:

Introduction

The first step in the framework is to define the case and the involved stakeholders. One stakeholder is identified as the subject owner. This stakeholder selects the other stakeholders which should be involved in the decision-making process. All stakeholders should be present in the following steps. Ideally, at least one stakeholder of each perspective (strategic, financial, functional, physical) as described in Section 3.2 should be involved. Next to the stakeholder identification, the exact case should be determined in advance. This can be in the form of selecting a portfolio of current locations, a geographical area, or in any other way the boundaries of the case are defined. Finally, the time horizon considered in the model should be determined in advance. This is the time period over which the risks are assessed. When deciding on this time horizon, one should keep in mind that the longer the time horizon, the more inaccurate the data will become.

Interview 1

The interviews are held individually per stakeholder. In the first interview, the first six steps of the procedure are followed. The interviews are semi-structured, where the system engineer explains the input that is required from the stakeholder. The systems engineer also gives a brief explanation of the framework, such that every stakeholder knows what the procedure is. Goal of the first interview is that the first six steps of the procedure are completed the first time.

Workshop 1

Before the first workshop is held, the system engineer processes the input of the first interview. The workshop is meant to show the results of the these steps. A short

recapitulation of the interviews is given, and the results of the input of every stakeholder is presented to all stakeholders simultaneously. Next, the model is used by the stakeholders to generate alternatives. The stakeholders are able to turn locations on and off, and try to come to a portfolio with a higher overall preference score. Moreover, the stakeholders jointly take step 7 and 8 of the procedure, determining the probability level for future preference scores and the importance of the future values compared to the current values. The goal of the workshop is to provide insight in how the model works for the stakeholders.

Interview 2

In the second interview, the stakeholders are able to change their input if required. The interview is similar to the first interview, following each of the six steps. In the pilot study, the second interview also serves as a moment of reflection, where the stakeholders can provide their initial feedback on the process and on the model itself.

Workshop 2

Before the second workshop, the systems engineer has processed all adaptations that came forward in the second interview. During the workshop, the stakeholders are able to once again design alternatives they think will better match the preferences. At the end of the workshop, the mathematical model will calculate the best alternative. This alternative is fed back to all stakeholders.

Interview 3

In the third interview, each stakeholder individually confirms that the alternative that is calculated as the best alternative, is indeed the accepted alternative. If this is not the case, the stakeholders are able to adapt their input once again, in a similar way as in the first two interviews, and a new workshop is to be held.

In this research, the third interview is also used as a moment of reflection on the process. Here, each stakeholder involved is interviewed on how the process went, and if they view the model as having added value over their own process. Moreover, the model itself is reflected upon, based on Riedel et al. (2010).

9.5 The location decision-making mathematical model

In order to support the stakeholders in applying this framework, a mathematical model is developed. The model is a computer programme, written in the programming language Matlab. This makes it possible for the stakeholders to autonomously follow (part of) the procedure. In this section, the requirements of the model are presented, as to distinguish which elements are crucial in the model. Secondly, the structure of the model itself is explained.

9.5.1 Model requirements

The development and use of the mathematical model serve the purpose of determining the preference rating per criterion for a set of potential future portfolio alternatives. Also, the model should be able to provide a weighted overall preference rating for each possible future portfolio. Not only should these be given for the current moment, but also for a to be determined future moment in time, in the form of scenarios. All these results should be presented in an understandable manner, such that the user is able to visually compare the alternatives to each other and to the current supply rating.

9.5.2 Model structure

The data generated from following the first seven steps of the procedure serve as input for the model. Therefore, the available data is used as a starting point for development of the model. A flowchart of the model can be found in Figure 30.

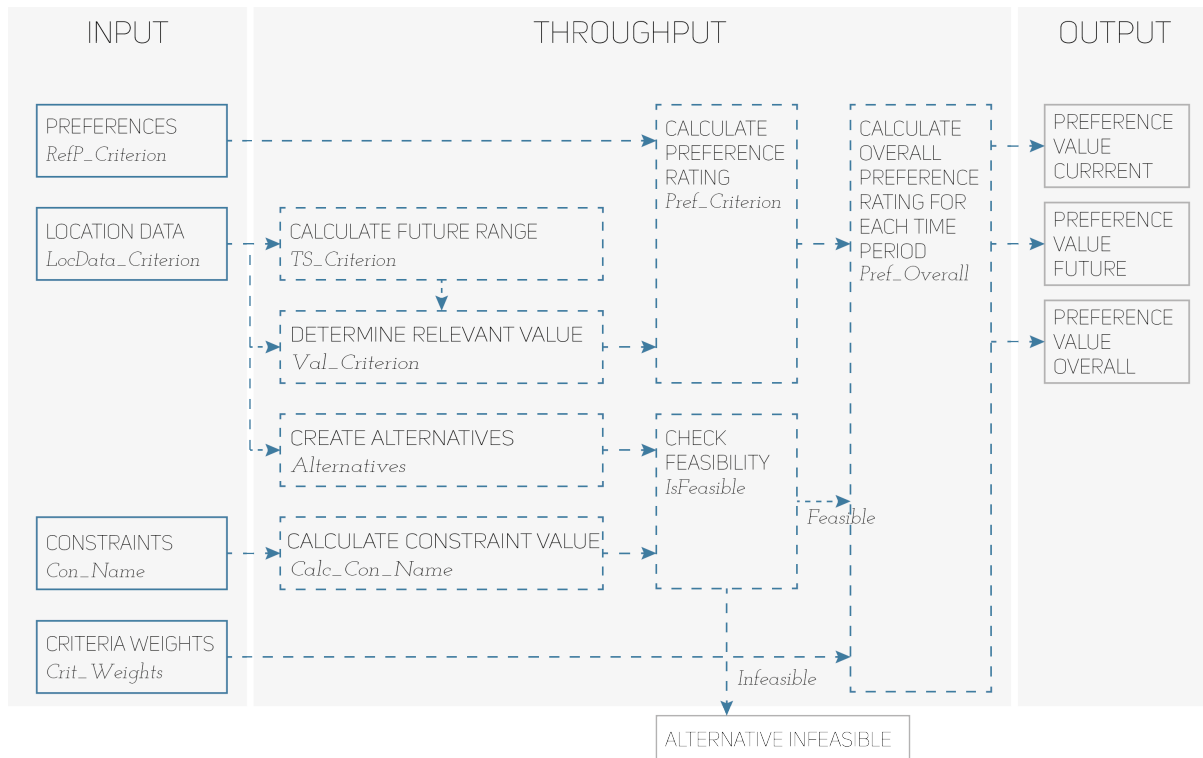


Figure 30: principal structure of the model (own illustration)

On the left, at input, one can see the input that is distilled from the interviews. The preferences are put in the model by providing the three reference points from step 2 of the procedure for each decision variable.

Secondly, the location data is fed into the model. This data is gathered by the system engineer. For each relevant location (the current locations and the locations determined in step 6 of the procedure), information is gathered on each of the decision variables. This information is used to first calculate a future range of the location data. The procedure for this is explained in chapter 7: using a time series model. Using such time series model, that is fitted to historical data for each criterion, 10.000 values are calculated. These values represent 10.000 possible scenarios that could unfold over a time horizon t . If the future value is not susceptible for changes in the future (for example the size of office space in m^2 , determined in step 4 of the procedure), then the future value will be equal to the current location data value.

Next, both the current location data values and the future location data values are fed into a function that calculates the relevant value. This is done as each criterion can have a different way of calculating the value. For example, the average travel distance for employees to the new locations will be based on the minimum travel distance to one of the locations. This requires a different calculation than the total size of all locations in the alternative combined.

The input from the relevant value function and the reference points are used to calculate the preference rating for each location, for the current dataset and the scenarios.

The Location data is also used to determine all possible combinations of portfolios. This is done by taking all locations, and making combinations of these locations, by turning a location on (1), or off (0). Each alternative is one combination of locations. If for example there are 7 alternatives, an alternative portfolio could be 0 1 0 1 1 0 1, where location 2, 4, 5 and 7 are selected. In total 2^n alternative portfolios are generated, where n is the number of locations. In the example of 7 locations, there are 128 different portfolio alternatives.

Each of the alternatives generated is checked against the constraints determined in step 3 of the procedure. Using the location data, the value of the alternative is checked with the constraint value, to determine whether the alternative is feasible or not. If the alternative is infeasible, it is rejected, and not considered any more. If the alternative complies with the constraints, it is used to calculate the preference rating.

The next step of the model is a function that calculates the overall preference rating of each feasible alternative. For this, the feasible alternatives are fed into the function, combined with the preference ratings for each of the locations. The result of this is an output consisting of multiple values: the overall preference rating of the current data, and the overall preference rating for each of the scenarios.

The output generated in the previous step of the model consists of 10,001 overall preference ratings per feasible alternative. From this, a histogram as shown in Figure 31 can be abstracted.

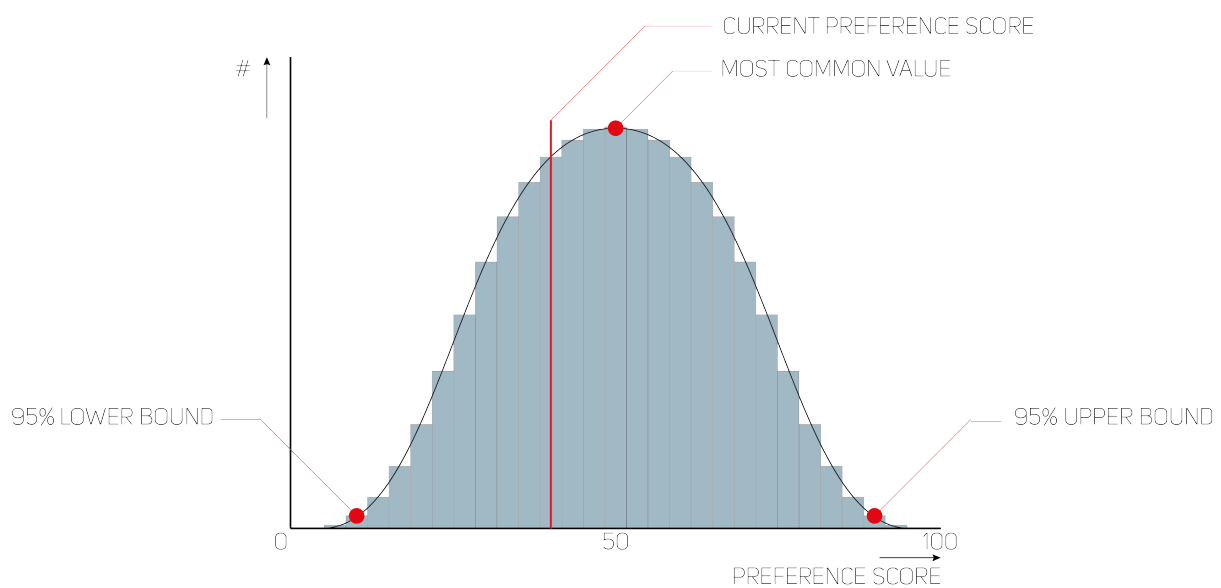


Figure 31: histogram of overall preference score for each scenario (own illustration)

The figure above shows a histogram of the overall preference scores for all scenarios. Each individual scenario has its own overall preference score. These are binned, and counted, resulting in the histogram. In this example, one can see that the preference score for a location is expected to increase over time.

In this histogram, four points are relevant. First of all, the upper and lower bounds. These values reflect the range of preference scores the alternative will lie in between. In the example of Figure 31, the overall preference score for this alternative will lie between approximately 12 and 85. This implies that one can say with 95% certainty, that at time horizon t the locations have such characteristics, that the alternative will have an overall preference score that is between 12 and 85. Although this range is very wide, it is expected that in the pilot studies this range will be significantly smaller. Moreover, it should be noted that the histogram of the overall preference scores does not necessarily has to be normally distributed. This is dependent on the historical location data. If this data has a different distribution, then the curve can be different.

The third relevant value is the most common value. This value represents the preference score that is most expected for the alternative at time horizon t . The last relevant value is the current preference score. This line shows the current preference score, and can be used to discern whether it is expected the overall preference score will increase or decrease over time until time horizon t . In the example of Figure 31, it is clear that the overall preference

score is expected to be higher at time horizon t . The current preference score is also used in the selection of the best alternative.

Choosing the best alternative

The data presented in Figure 31 can also be visualised differently. The histogram shows how often a certain value will appear. By plotting this information in an inverse cumulative distribution function one can determine the probability that the preference score will take a value higher than or equal to a certain value. By setting the probability level at a value x , one can determine which alternative has the highest overall preference score. This process is visualised in Figure 32.

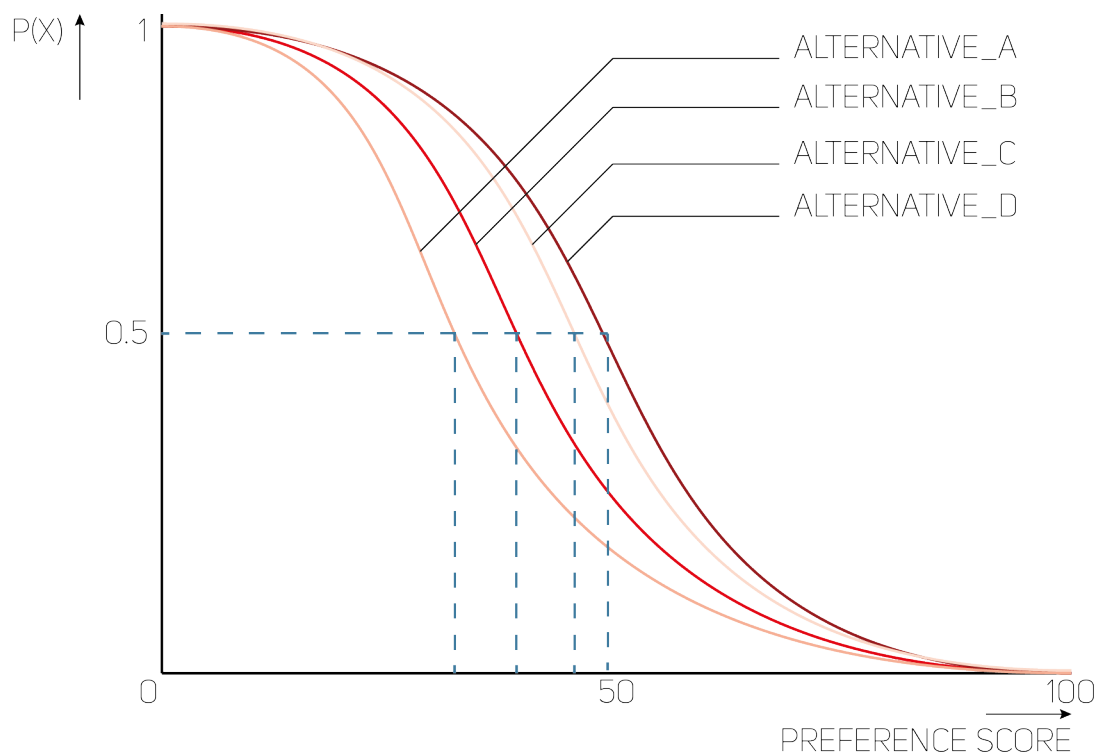


Figure 32: inverse cumulative distribution function, with an assessment of alternatives based on a probability level of 50% (own illustration)

The relevant probability level on which this assessment is made, is determined in step 7 of the procedure. The model considers each alternative, and calculates the overall preference score that corresponds to the probability level. The alternative with the highest overall preference score proves to be the most robust in maintaining a high preference rating over time. In Figure 32, this is Alternative_D.

Important to note is the degree in which the stakeholders can influence the shape of the functions shown in Figure 32. The functions are partly determined by both the decision variables that are defined by the stakeholders and the corresponding preference reference points. Changes in for example the preferences for a decision variable, have direct influence on the shape of the probability curve as a decision variable value will then have a different preference score. Not only the place of the curve on the x-axis but also the shape of the curve can be influenced by the preferences of the stakeholders. This can be derived from the x-axis of the inverse cumulative distribution function being the same scale as the y-axis of the preference curves.

The second factor influencing the shape of the curves shown in Figure 32 is the changing characteristics of a location, which cannot be influenced by the stakeholders involved. These are external factors, which are calculated through the time series analysis and Monte Carlo simulation.

The connection between the preference curve, the Monte Carlo Simulation and the inverse cumulative distribution function are visualised for one variable in Figure 33. Here, the Monte Carlo simulation results are plotted on the right x-axis. Using the preference curve, the corresponding preference score can be calculated. By calculating the probability of occurring, the inverse cumulative distribution function can be plotted, on the left side of the figure. The figure shows the direct relationship of the preference curve and the corresponding inverse cumulative distribution function.

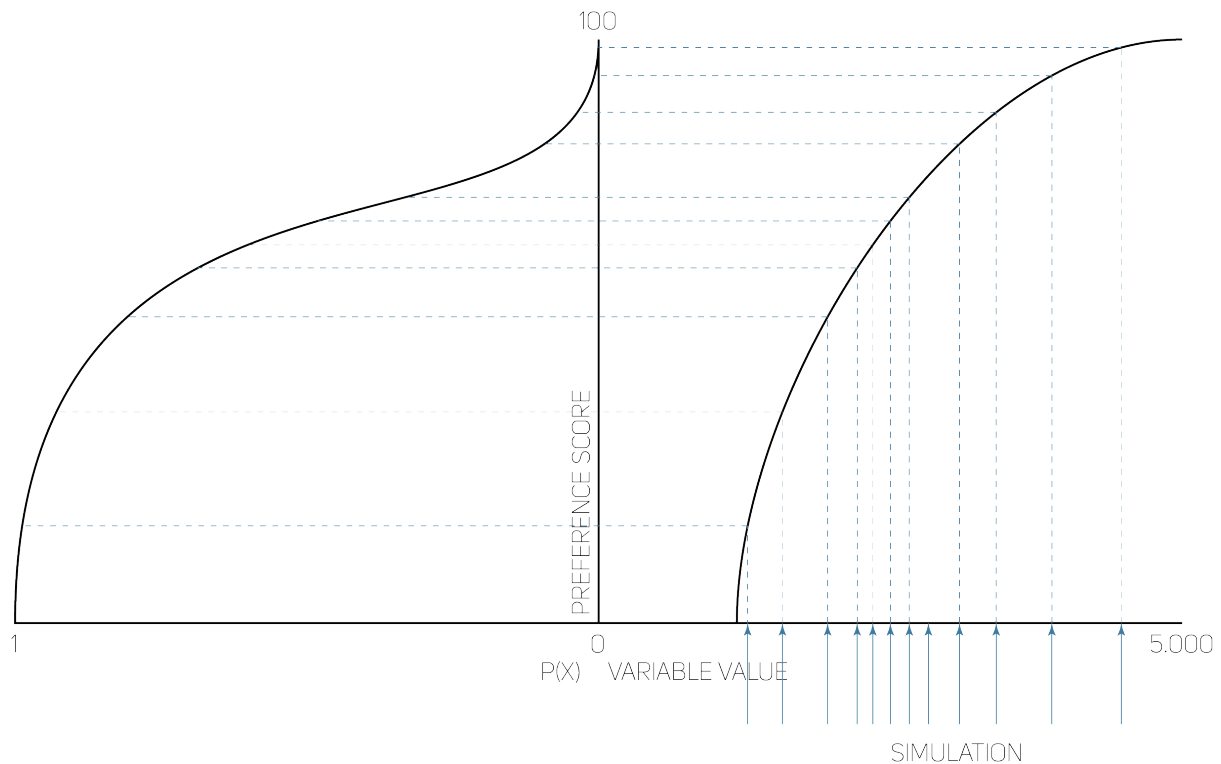


Figure 33: relationship between the inverse cumulative distribution function, the preference curve and the Monte Carlo simulation (own illustration)

The last step of the model is to calculate the average overall preference score of each alternative, based on the current overall preference score, the future preference score based on the given probability level and the weights determined in step 8 of the procedure. The alternative that has the highest average overall preference score, is selected as the best portfolio.

A detailed description of the model can be found in Appendix B, where the generation of scenarios is described in detail as well.

9.5.3 A note on correlation between variables

When determining the future range of values using a time series model, part of the future values is calculated by drawing a random number, based on the probability distribution deducted from the historical data. It is important to note that some variables could show significant correlation over time. Correlation is a statistical relationship between two datasets. A positive correlation indicates that if *Variable A* is increasing, *Variable B* is likely to increase as well. Although this does by no means implies that the relationship is causal, it should be taken into account in the model that a certain level of correlation is present between certain variables.

The first step is to determine whether two variables are correlated or not. This can be done by the following formula:

$$\rho_{X,Y} = \text{corr}(X,Y) = \frac{\text{Cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{\mathbb{E}[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y}$$

For this pilot study, if values have a correlation above 0.5, then the variables are assumed to be positively correlated, and the random values are the same in both variables. If the correlation is below -0.5, then the variables are assumed to be negatively correlated, and the random values of Variable B are calculated as: 1-Random Value_{Variable A}.

9.6 The use of the LDM-framework explained through an example

Use of the LDM-framework, besides a theoretical explanation, can be best explained through the use of an example, in which the process of the framework is described. This paragraph therefore describes the application of the LDM-framework in a fictitious example, in which a supermarket concern ("SuperM") would like to open their first store in the Netherlands. The LDM-framework can be used to determine where this first store should be opened.

The subject owner of SuperM identified two stakeholders are important, himself (SubjectOwner) and one other stakeholder (Stakeholder1), which both have a weight of 0.5. Together, in an interview, they give answer to the first six steps of the procedure. This input is shown in Table 10, Table 11, and Table 12.

Table 10: Fictitious input of step 1 to 4 of the LDM procedure

Decision variable	Weight	Value 1	Value 2	Value 3	Risk variable?
SubjectOwner: Households with an income per year over €75.000 within 20km	0.6	(20.000, 0)	(35.000, 50)	(60.000, 100)	Yes
Stakeholder1: Yearly rent per square meter (€/m ² /year)	0.4	(200,0)	(135,50)	(100,100)	Yes

Table 11: Fictitious input of step 5 of the LDM procedure

Design constraint	Value
The location should be accessible by the distribution center located in Hoofddorp within 45 minutes	Travel time <45 min to DC in Hoofddorp

Table 12: Fictitious input of step 6 of the LDM procedure

Location alternative	Value variable 1	Value variable 2	Comply with constraints?
Amsterdam	60.000	195	Yes
Leiden	25.000	135	Yes
Haarlem	35.000	155	Yes
Utrecht	55.000	185	No

The input received from the stakeholder is fed into the mathematical model. The values from Table 9 show the current values of the locations. However, it was indicated by the stakeholders that both decision variables had a risk of change. Therefore, first the future values of these variables should be determined for each location alternative. For this, a time series model of each variable for each location is made, and a forecast is made on possible future values. This is visualised for Decision variable 1 for Amsterdam in Figure 34.

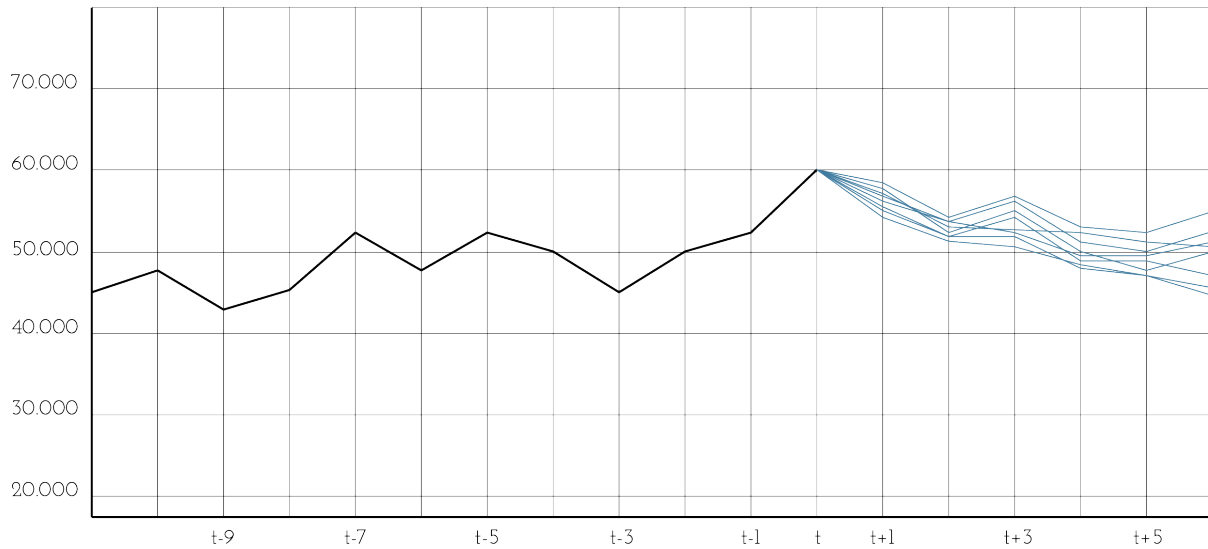


Figure 34: Fictitious example of change of decision variable 1 (own illustration)

This figure shows that although the value for decision variable 1 has increased over time to 60.000, it is expected to decrease in the future. The values from the risk analysis shown in Figure 34 can be translated into a cumulative distribution function. The stakeholders, following step 7 of the procedure, indicated that they are willing to accept a risk level of 0.6, meaning that the stakeholders want to have 40% certainty that the value in the model will be at minimum the actual value. From this, a future expected value can be abstracted, as shown in Figure 35 (left), which in this example is 48.000.

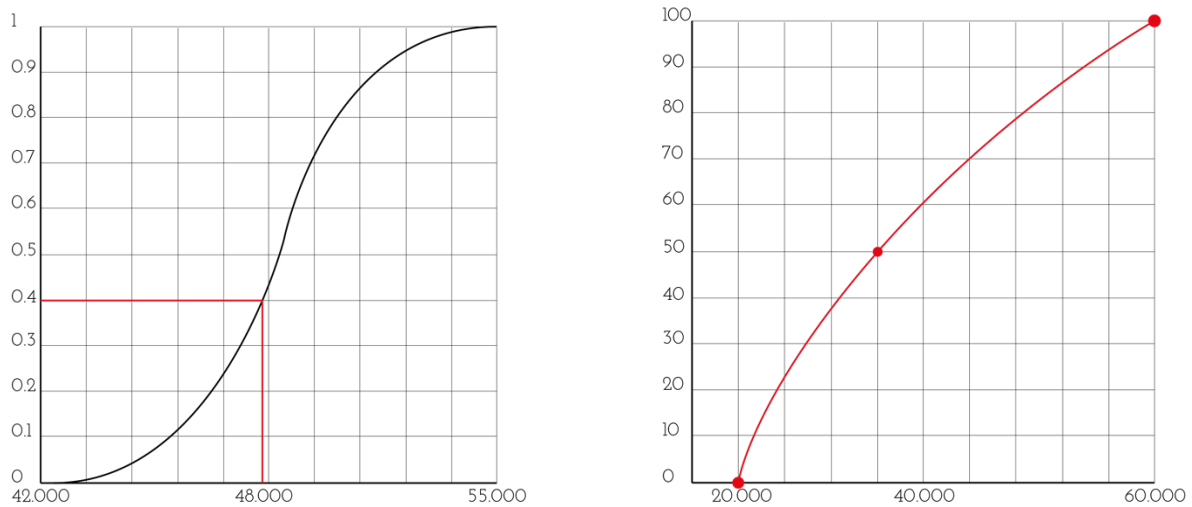


Figure 35: Left: fictitious cumulative distribution function and risk level (x-axis). Right: preference curve for decision variable 1. (own illustration)

This process is repeated for each decision variable that has a risk. From this, the following table can be made (Utrecht is omitted as it does not comply with the constraints):

Table 13: Overview of values per decision variable, now and in the future (own illustration)

Decision variable	Amsterdam		Leiden		Haarlem	
	Current	Future	Current	Future	Current	Future
Variable 1	60.000	48.000	25.000	29.000	35.000	42.000
Variable 2	195	200	135	130	155	145

These values can be translated into preference scores, using the three reference points that were provided by the stakeholders and the preference curve that can be constructed from these points. This is visualised in Figure 35 (right). For example, for Variable 1 in

Amsterdam, the current preference score equals 100, and the future preference score equals 76.

With this information, and the weights, two preference scores for each location can be calculated: the current overall preference score and the future overall preference score. For example for Amsterdam, this is calculated as follows:

$$\begin{aligned}
 PrefScore_{current} &= Prefscore_{decision\ variable\ 1} * weight_{decision\ variable\ 1} \\
 &+ Prefscore_{decision\ variable\ 2} * weight_{decision\ variable\ 2} \\
 &= 100 * 0.6 + 13 * 0.4 = 65.2
 \end{aligned}$$

$$\begin{aligned}
 PrefScore_{future} &= Prefscore_{decision\ variable\ 1} * weight_{decision\ variable\ 1} \\
 &+ Prefscore_{decision\ variable\ 2} * weight_{decision\ variable\ 2} \\
 &= 76 * 0.6 + 0 * 0.4 = 45.6
 \end{aligned}$$

These values can be combined into one overall preference score, using the weights determined in step 8 of the LDM procedure. In this example, the weights are divided equal meaning that the future preference score is equally as important as the current preference score. This results in the Overall preference score for the location Amsterdam to be $65.2 * 0.5 + 45.6 * 0.5 = 55.4$. This can be done for every alternative:

Table 14: Preference scores per alternative (own illustration)

Alternative	Prefscore current	Prefscore future	Overall pref score
Amsterdam	65.2	45.6	55.4
Leiden	33.2	42	37.6
Haarlem	46.3	51.4	48.9

This shows that that Amsterdam has the highest overall preference score of the three alternatives. This implies that the location in Amsterdam aligns best with the preferences stated by the stakeholders. Therefore, Amsterdam should be the choice of the stakeholders as their future location for SuperM.

9.7 Conclusions

This chapter answers the research question: how can risk be incorporated in a preference-based location decision-making process?

The Location Decision-Making Framework (LDM-framework) is an adaptation of the Preference-based Accommodation Strategy design approach developed by Arksteijn (2015). Equal to the PAS design approach, the LDM-framework is based on the three rationality levels of De Leeuw (1992), describing the process which should be followed to come to a solution. The model consists out of three parts, the model (substantive rationality) the procedure (procedural rationality) and the activities (structural rationality), which closely interact with each other and cannot be used independently from each other. The entire process results in a decision for which real estate portfolio matches best with the preferences stated by the stakeholders. The process is visualised in a flowchart, which can be found in Figure 36. On the top, the steps of the procedure can be found, whereas on the left the activities are listed, including the stakeholders that are involved. On the far right, the model building activities can be found.

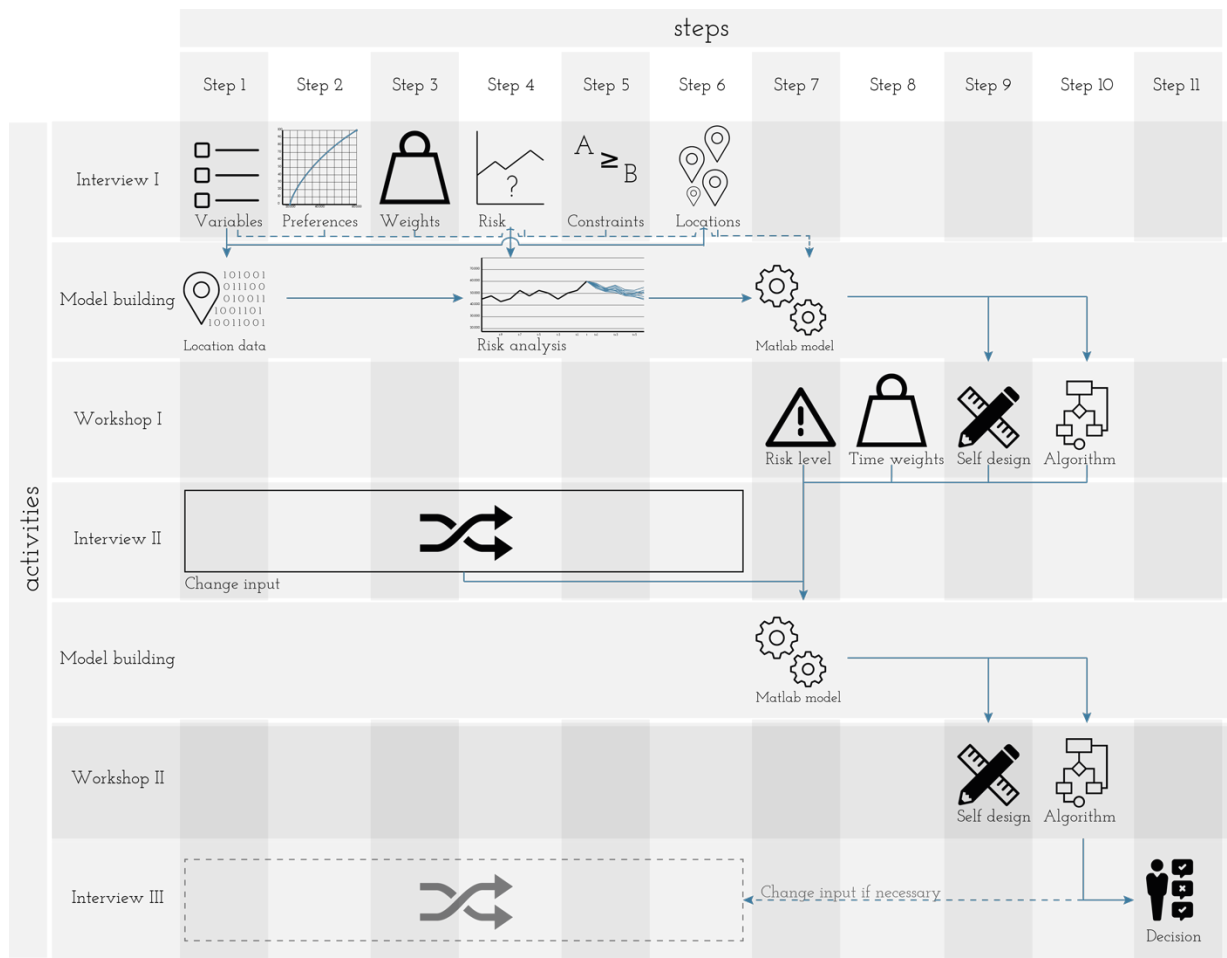


Figure 36: Flowchart of the framework (adaptation from (Arkesteijn, to be published))

PART IV: TESTING THE LDM-FRAMEWORK

10. Current decision-making process in the pilot organisation

The LDM-framework developed is tested by means of a pilot study, at an existing case. In this chapter a company profile is given combined with a description of the current real estate decision-making process. Lastly, the case on which the model is applied is explained.

10.1 Company profile

Engie services is part of the listed Engie group, an international energy and technical installations company, employing nearly 155.000 people and with an annual turnover of nearly €70 billion. Engie Services is the largest technical service provider in the Netherlands and focusses on the industrial, infrastructural and utility markets. Next to consultancy services, Engie Services engineers, manufactures, installs and monitors technical building installations.

In order to function optimally, Engie Services has a real estate portfolio consisting of offices, warehouses and industrial sites. In total, 56 locations, spread across the Netherlands are leased by Engie Services (see Figure 36). The real estate portfolio consists of 131.126m², of which 76.888m² is office space and 54.238m² is industrial space. Next to Engie Services, the company also has a branch called Engie Refrigeration, which is part of the case. Engie Refrigeration focusses on cooling solutions for large corporate clients. Both companies are part of the Engie conglomerate, but function independently.



Figure 37: Locations of Engie Services (own illustration)

10.2 The current decision-making process

Currently, real estate decisions are mainly cost driven. A few years ago, the Engie Services real estate portfolio counted over 90 buildings, spread across the country. After setting up a real estate department, consolidation opportunities were identified and the total occupied space decreased. Real estate decisions are often made ad-hoc, making business cases each time a lease is expiring. In such a business case a range of options are explored. First of all, consolidation opportunities are sought, trying to further decrease the number of locations, and preventing unnecessary vacancy. Secondly, a negotiation with the current building owner is started, too see whether it is possible to decrease the current real estate costs. Also, a market scan is held, considering the possibility to move to a new location. All three possibilities are checked against each other in terms of financial impact, and a decision is made.

Considering the competency model of Joroff et al. as seen in section 3.1, the Engie real estate department is in the transition between the second level (minimising building costs) and third level (standardising building usage), whereas the framework that is applied in the pilot study can be seen as a tool serving the fifth level (business strategist - convening the workforce).

10.3 The case

In the south of the Netherlands, Engie Services and Engie Refrigeration lease seven locations, which are currently under review. The lease terms have been synchronised, and due to efficiency and vacancy, the opportunity arises to consolidate these locations. The current locations of Engie that are taken into account in the pilot study are presented in Figure 38.

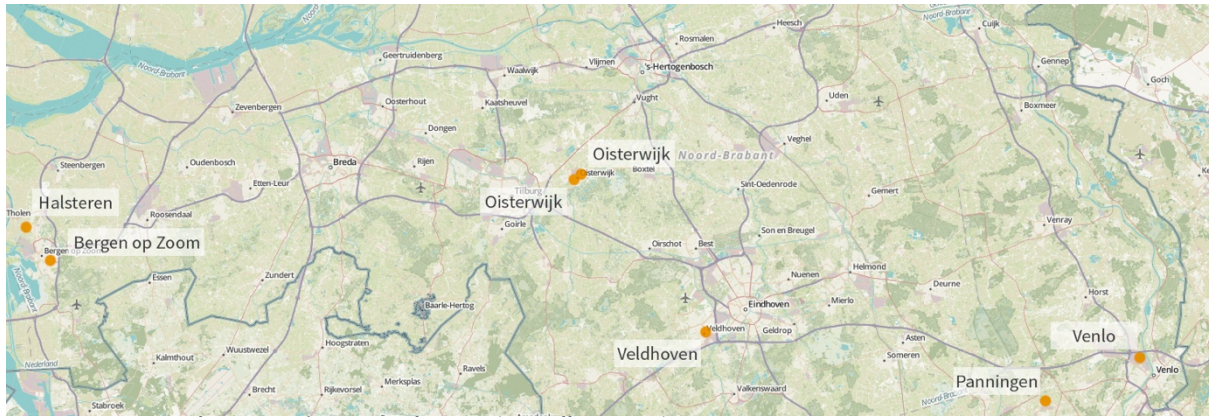


Figure 38: Current locations of Engie in the case (own illustration)

The goal of the real estate department of Engie is to significantly reduce the size and number of locations in their real estate portfolio, and as a result, reduce the overall costs. However, it was also indicated that this should not hamper the productivity of the employees or burden the business. It is the view of the real estate department that real estate should be facilitating to the business, and therefore it should optimally support the business operations.

The case consists of 8 current locations and 22 alternative locations. The subject owner selected 7 main stakeholders including himself, which combined make up for all relevant perspectives identified by Den Heijer: policy makers (2), financial controllers (1), users (3), and technical managers (1) (2011), where stakeholder_1 functions both as a policy maker and a technical manager. From these seven stakeholders, 2 indicated that they wanted to act as one joint stakeholder, which resulted in 6 stakeholders for the decision making process. Every stakeholder follows LDM framework, and the data is fed into one model.

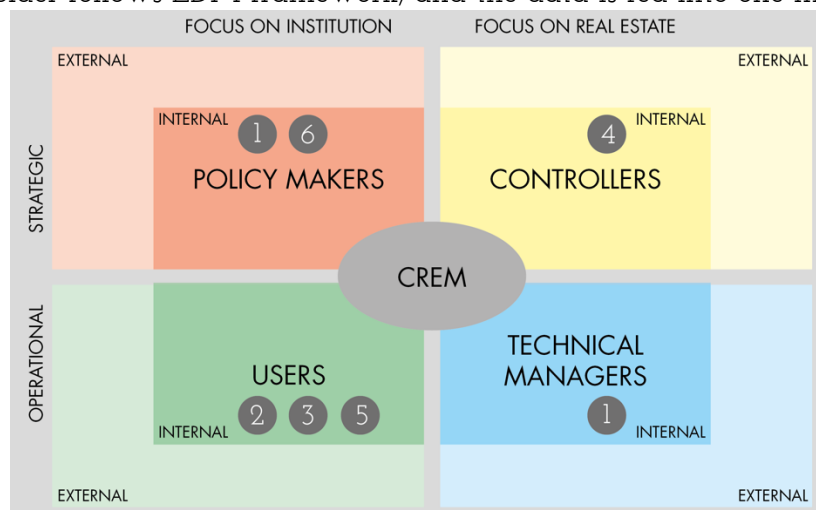


Figure 39: Stakeholders involved in the LDM framework (own illustration based on (Den Heijer, 2011))

Figure 39 shows the stakeholders within the stakeholder framework. The numbers indicated refer to the specific stakeholders, which in the rest of this thesis are indicated as Stakeholder_n, where n is the respective number of the stakeholder.

Although the real estate department already has a conceptual strategy in place for consolidation opportunities, the pilot study is a second opinion, in which a more detailed analysis of all options is considered, and more focus is put on the business preferences in location selection.

10.4 Conclusions

When considering the current decision-making process, real estate decisions are mainly made on micro-level and are mainly focussed on cost reduction. The case in question is one of the first attempts to strategically decide on the real estate locations in a large region. It considers 7 current locations that are in the portfolio. As stakeholders, seven people were identified, which comprise of every significant perspective in such decision-making process.

In the research, all physical data on the current buildings was made available, including the lease contracts. Also access to employee data and other relevant information sources was made available where necessary, as to facilitate the research as much as possible.

11. Testing the LDM-framework in practice

This chapter describes the pilot study. For this, use is made of the process flowchart depicted in Figure 36. The pilot study is used to test the LDM-framework in practice, allowing to change the framework if necessary and to be able to consider whether the LDM-framework proves to be effective in incorporating risk in a preference-based location decision-making model.

11.1 Interview I

The first interviews are meant to compile the first client statement, and are used to go through the first six steps of the LDM procedure. All interviews started with a brief explanation of the goal of the process and the interview, and the goal of this research. Next, using a short, written introduction the process of the entire model was explained, focussing on how the preference curves are used by the model. As to not overload the stakeholders with information, the risk component of the model was not fully explained as of yet, but only touched upon during the explanation of the model. The written introduction that was sent in advance (in Dutch) can be found in Appendix C.

Next to this explanation, an Excel template was used, to be filled in accordingly. Here, the criteria can be filled in, with their corresponding values and weight. This was automatically visualised in the Excel file (as seen on the right of Figure 40), where the preference curves are formed.

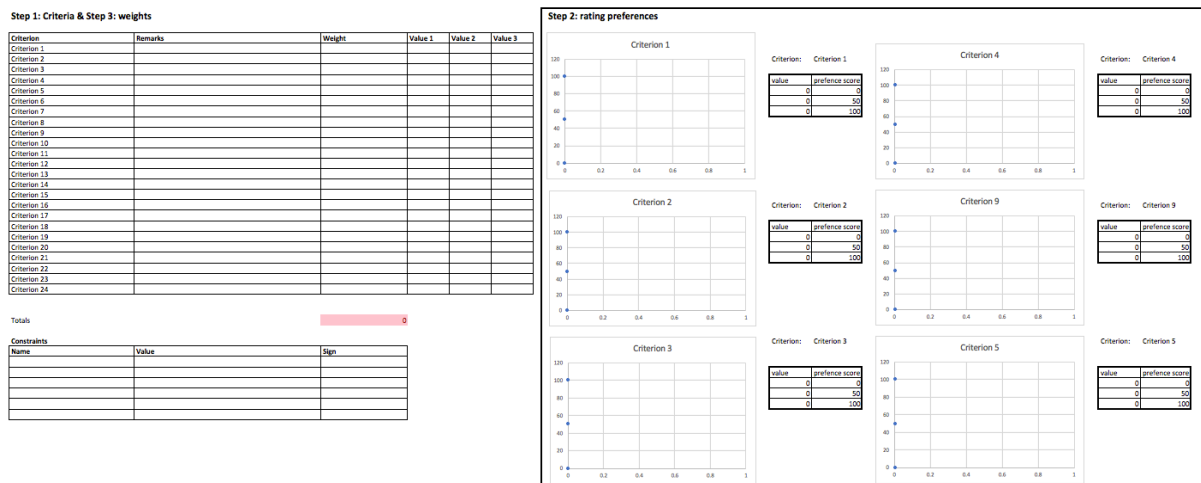


Figure 40: Excel templated used to obtain the preference criteria and constraints in the interviews (own illustration)

In total, 2 face-to-face interviews were held during workshop I, in total accounting for approximately 4 hours. In total, 19 criteria were defined with corresponding preference curves. Also step 3 of the procedure was completed, assigning weights to each of the criteria per stakeholder. In the interview with the subject owner, the weights between the stakeholders were defined. In addition, a total of 9 constraints were identified, completing the first iteration of step 5 of the procedure. These results are presented in Figure 41 and Figure 42.

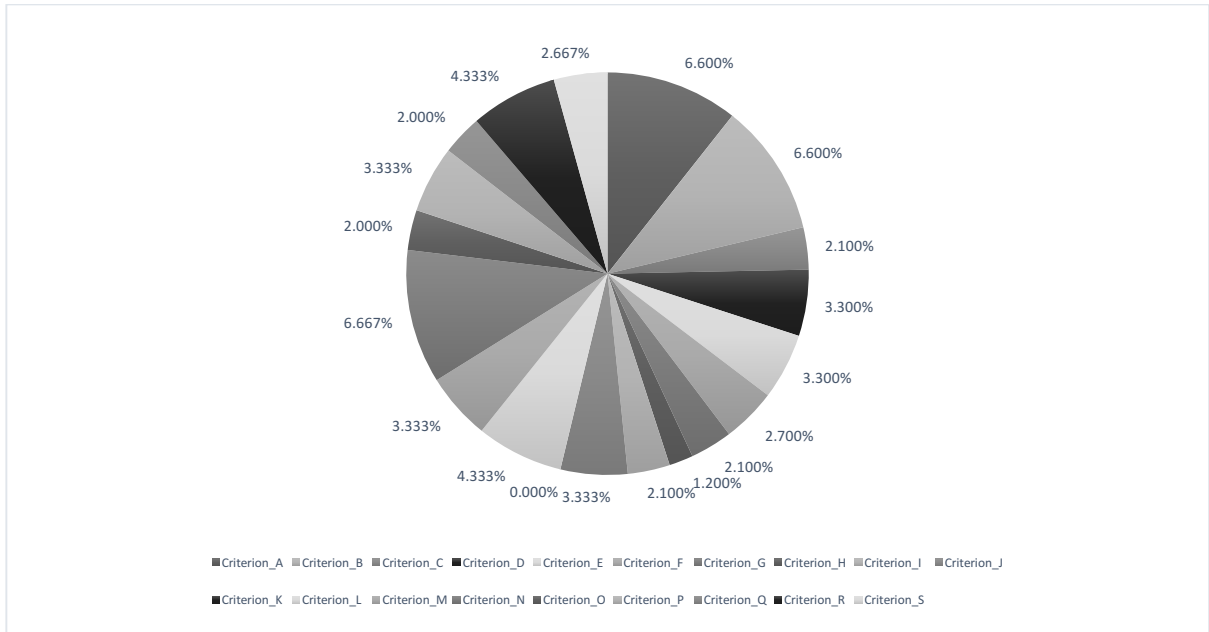


Figure 41: Weights per criterion (own illustration)

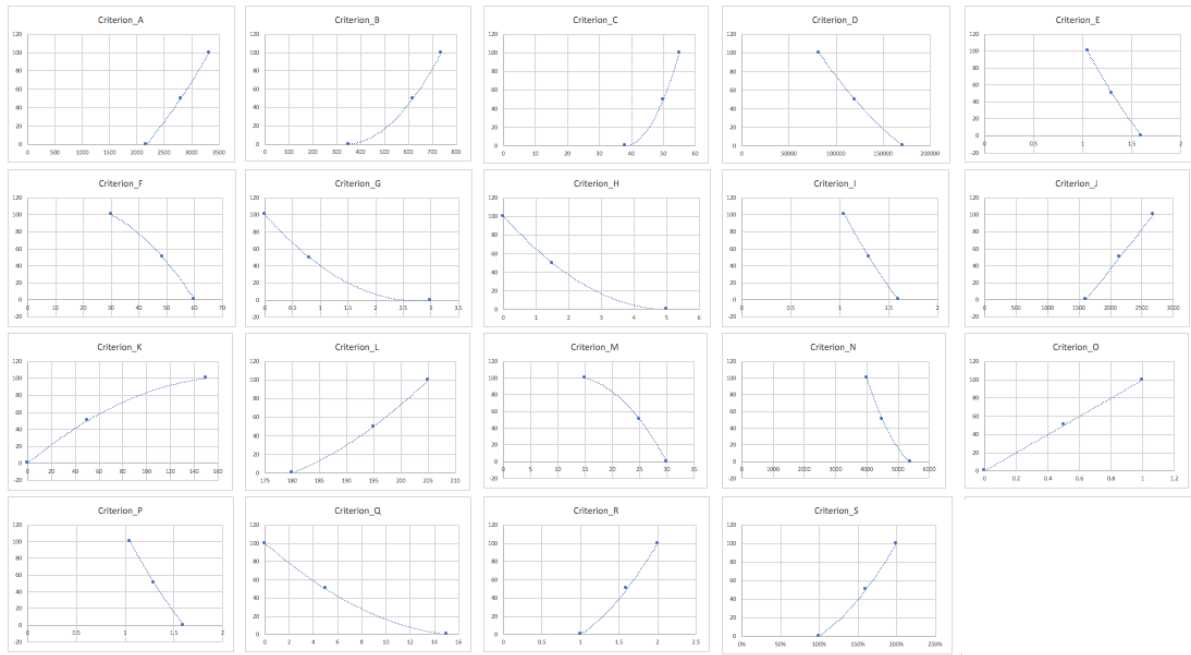


Figure 42: preference curves for each criterion (own illustration)

What came forward during the interviews, is that the fourth step of the procedure (Each decision-maker/expert indicates for each decision variable whether there is a risk that the value of the decision variable will change over time) was difficult to answer for the involved stakeholders. They explained that they could make an educated guess of which aspects are expected to change, but could not fully be sure. As to deal with this issue, use was made of their own insights, and next to this a real estate expert panel from the JLL research team was questioned, which has clear insights in real estate related changes. Moreover, in discussion with the stakeholders, the company related risks were mapped.

Step 6 of the procedure, selecting alternative locations compared to the current locations, was done by asking for regions which the stakeholders would also consider in the decision-making process. Moreover, in dialogue with the subject owner, a number of other locations were selected, as to have an open discussion on the locations and allowing other alternatives to be included as well. From the regions that were identified, actual properties

were selected from Funda in Business, an online platform for brokers to market their available properties.

11.2 Model building

The next step was to build the first iteration of the model, applied to the case. First, all necessary input data needed to be gathered. The preferences, constraints and weights were identified, but the location data was lacking. This data was compiled by making use of several sources. First of all, for the current Engie locations the lease contracts were analysed, from which part of the data could be gathered. Secondly, from Funda in Business data was also gathered for the alternative locations. Next to this, a number of analyses were conducted as to generate location data. This applied to data that was not available, but could be retrieved by gathering and combining information from several sources, both internal and external.

Once all data was gathered, the model structure itself could be determined. Each preference requires a unique method of calculation. This is because some preferences refer to the closest location to a certain point on the map, whereas other preferences refer to an addition of all criterion values of the locations. The necessity to develop a tailored model significantly hampers the ease of the model applicability. A more in-depth description of the structure of the model can be found in Appendix B: Detailed description of the mathematical model.

11.3 Workshop I

The first workshop was held for the two stakeholders involved and the subject owner. During the first workshop, a short review of the work so far was presented, following a detailed explanation of how the model comes to a solution. This helps the stakeholders in understanding how the model determines the overall preference score. Using a presentation, these steps were explained visually, as to achieve maximal understanding. This was perceived by the stakeholders as valuable:

“Going through the model once more, explaining every step and seeing how the steps interrelate makes me understand how we get from preference to best alternative.”

After the explanation of the model, the model was tested by the stakeholders. The model contained all information available at the moment of the workshop (19 criteria), with the exception of the scenarios. It was deliberately chosen to not include the scenarios at this moment in time, to keep the model as simple as possible and understandable for all stakeholders. An example of how the scenarios can be included in the model was given, which will be explained later in this section.

The stakeholders made use of a preliminary Graphical User Interface (GUI), as presented in Figure 43. On the left side, the stakeholders could choose the combination of locations they perceived as the best combination. In the middle of the screen the selected locations are shown. Below these selected locations, the GUI shows whether the selected portfolio meets all constraints, by either turning green or red. On the right of the GUI, the criteria are found, including the preference score corresponding to the criterion and the selected alternative. The physical values are also shown here, indicating the relevant value for the criterion.

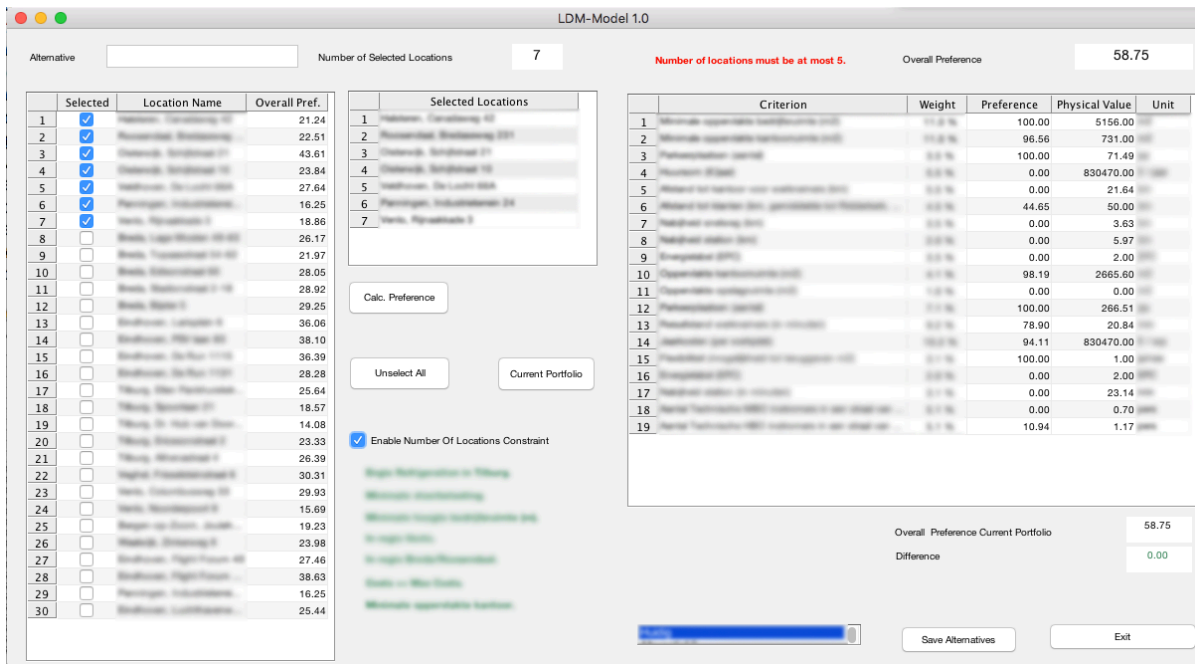


Figure 43: Graphical User Interface used in Workshop I (own illustration)

The stakeholders were able to make combinations of locations, with the objective to create a portfolio that scored higher than the current situation. Each stakeholder had the possibility to fill in their portfolio and see how high this alternative scored. The results of this exercise are shown in Figure 44. This shows that based on the preferences and calculations made at that time, the stakeholders were not able to find an alternative that scored higher than the current portfolio. The model itself, however, using brute force calculation, calculated what the best portfolio is, out of all possible portfolios. This results in an increased overall preference score of 62.69, which is 3.94 points higher than the current portfolio.

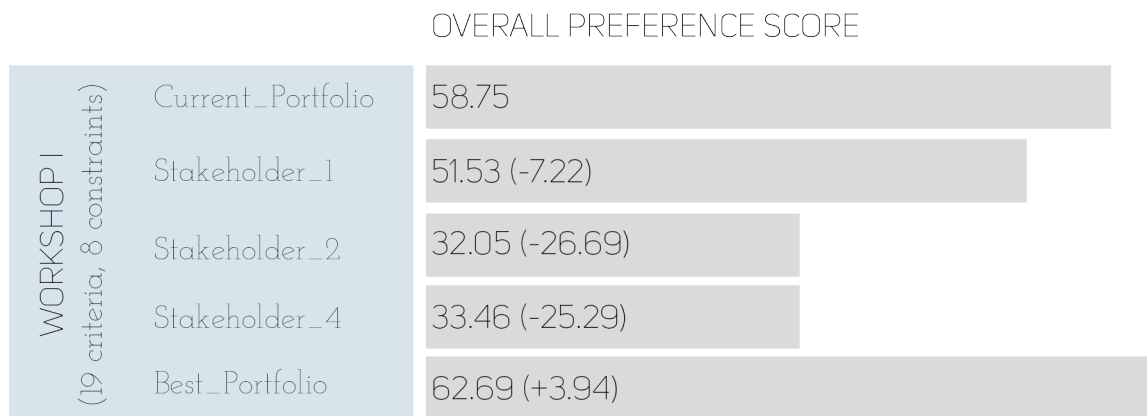


Figure 44: results of the first workshop (own illustration)

The element of self-design in the form of creating your own ideal portfolio, is a form of interaction that helped the stakeholders to gain insights in the preferences they established. One of the results of the first workshop is that all stakeholders wanted to critically evaluate the values linked to each criterion. It appeared to the stakeholders that some of the 'boundaries' (least preferred and most preferred values) were too strict, often resulting in a preference score of either 0 or 100. Therefore, the stakeholders indicated that during the second interview, some adjustments had to be made.

A second added value to the workshop can be found in the way the relevant values are calculated. A discussion with all stakeholders helped in redefining the calculation method, which results in a different overall preference score.

The workshop was concluded by setting out the next steps of the process. Here, the incorporation of scenarios in the next version of the model was explained. The stakeholders were faced with an example of how such calculation takes place, and what the output of the model would be. When asked whether such scenarios would have an added value on the current model one of the stakeholders explained:

“Integrating the future in the model is certainly an added value. It forces us to think better on what we find important in a location, and how we should run our business.”

Moreover, the stakeholders indicated that, even though the contracts have a length of a maximum of 5 years, the lease is often extended, and the business units remain in the same location for a much longer period of time. Therefore, despite the importance of flexibility, the location needs to be suitable for a prolonged period of time.

Contradictory to these positive comments was the remark of one of the stakeholders that the model could become too complex, and difficult to comprehend for the layman user. The combination of the current value and a large number of scenarios can be confusing, and the way the scenarios are determined can provoke distrust in the model.

11.4 Interview II

During the second set of interviews, a number of stakeholders were added to the decision group. Stakeholder_5, Stakeholder_6 and Stakeholder_7 were identified as key decision-makers and were interviewed for the second round of interviews. This resulted in 11 decision variables to be added and one confirmation of a constraint. In total, the model consists out of 30 decision variables, 9 design constraints, and 30 location alternatives.

The interviews all started with a short recapitulation of the previous steps of the progress so far, and had two main objectives: adjusting the input of the stakeholder if necessary (if the stakeholder was involved in the first workshop), and getting feedback on the process so far. This feedback is described in chapter 12.

For the stakeholders that were already involved in the process, an Excel based visual support model was applied, shown in Figure 45. This model shows the preference curve that was originally defined by the stakeholder. Next to this, on the x-axis of every graph, the values of the 30 locations were plotted, as to give an indication of the values that are found in the available supply. This process can be seen as a form of both anchoring and nudging, two psychological terms. Anchoring is a phenomenon that the starting point of an estimate can have influence on the estimate (Tversky & Kahneman, 1974, p. 1128). Showing the preference curve of the previous interview can lead to adjustments that are influenced by the stakeholder's previous input.

Nudging on the other hand also is a form of indirectly influencing the choice (Thaler & Sunstein, 2008). By showing the values of the 30 locations in consideration, the stakeholder is indirectly guided towards a preference indication that covers (almost) all locations. Although both anchoring and nudging can influence the outcome of the research, it was decided to use the graphs such that the stakeholders had all information available.

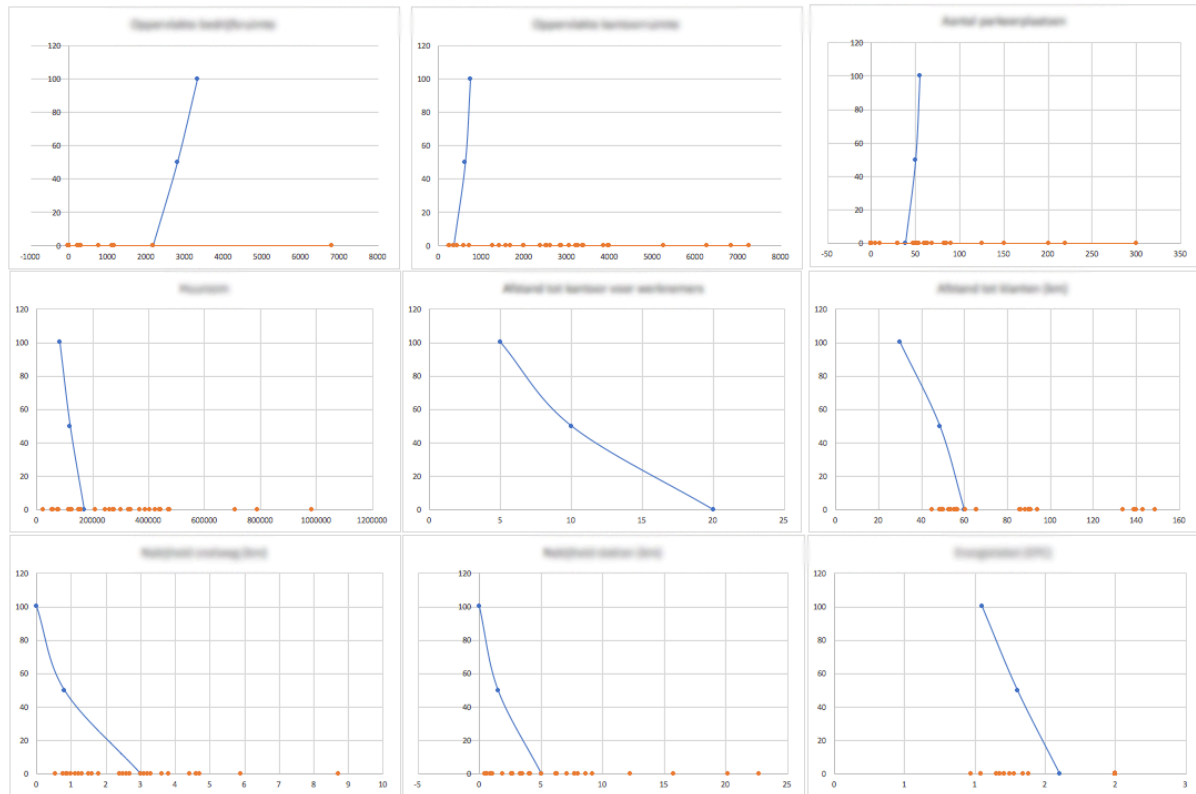


Figure 45: Visual supporting Excel model for interview II (own illustration)

In the second interviews, next to the addition of 19 variables from the new stakeholders, Stakeholder_3 changed one variable and adjusted the preference points of 5 other variables. Furthermore, the weights were redistributed over the variables. Stakeholder_4 only adjusted one variable, whilst keeping the weights intact.

11.5 Model building

In the second model building phase, first the variables that were added and adjusted were processed. Next to this, the scenario calculations were added to the model and the GUI was updated.

The addition of scenarios required some extensive remodelling. First the data had to be gathered on all decision variables that were identified as having a risk. This required a time series analysis, the process of which is described in detail in Appendix B: Detailed description of the mathematical model. Next, the results of step 7 and 8 of the procedure were incorporated in the model. As to visualise the effect of these steps, in the GUI a figure was added, which shows the chosen risk level. This figure is shown in Figure 46. The figure is a cumulative distribution function, that shows the modelled time series in black. This data was matched to a set of theoretical distribution functions, as to give an impression of the type of distribution, and is shown in blue. The red lines represent the risk level that the company is willing to accept. In this example, the risk level was set at 0.5. The model then calculates the corresponding overall future preference score, visualised by the vertical red line, which in this example is approximately 53.

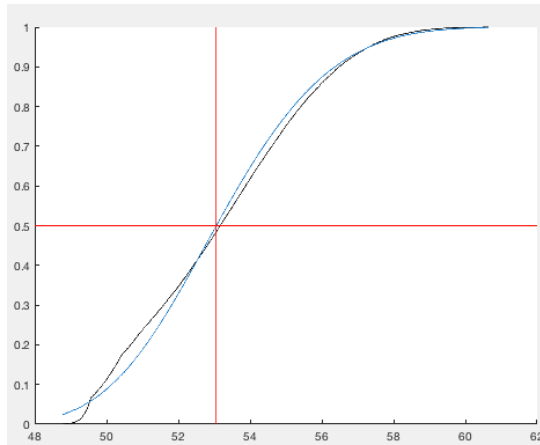


Figure 46: risk profile of the alternative as a cumulative distribution function (own illustration)

The GUI was adjusted to the incorporation of the scenarios as well. Instead of displaying one overall preference score, three scores are shown. The first score shows the preference score at time t , showing how well the chosen alternative matches with the preferences at this moment in time. A second score shows the preference score at time $t+n$, which indicates how well the chosen alternative matches with the preferences at the chosen future moment in time. The last score displays the overall preference score, which is a combination of these two scores and the weights determined in step 8 of the procedure. These scores can be found in the lower right corner of the final graphical user interface shown in Figure 47.

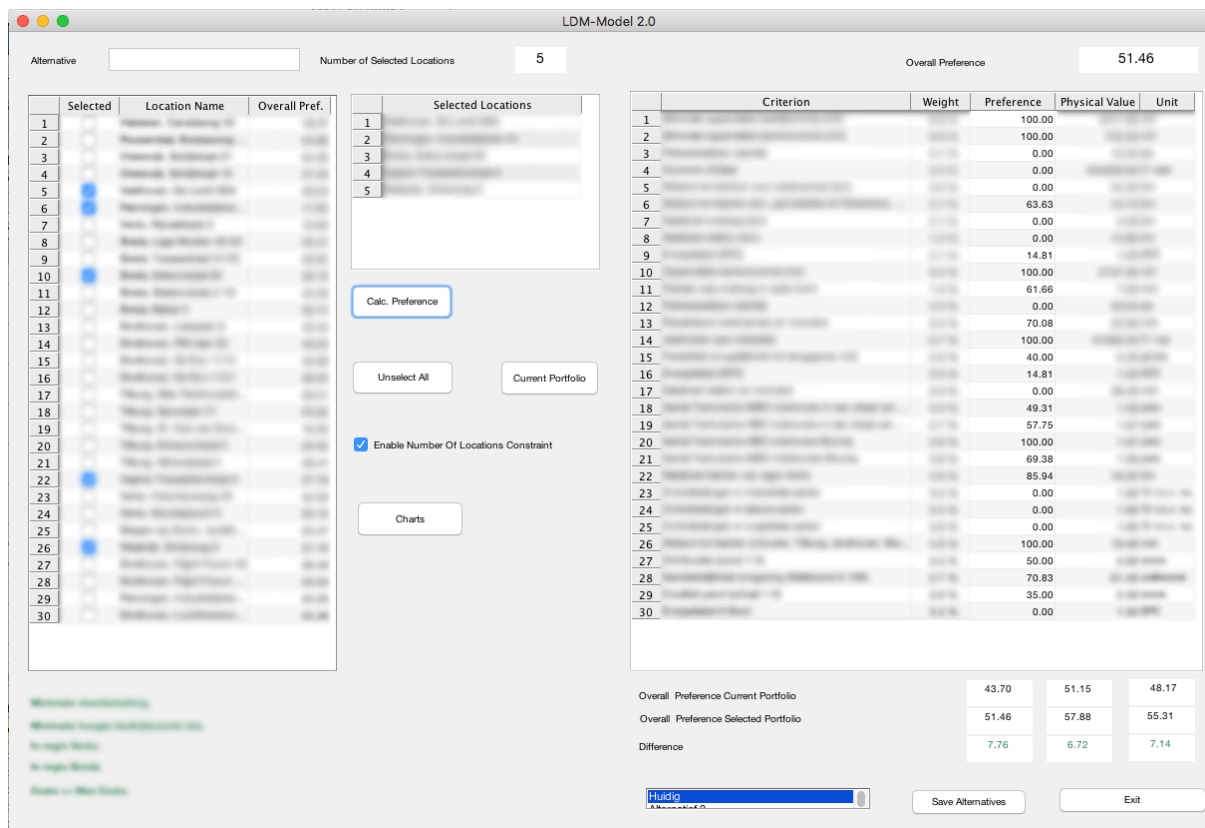


Figure 47: Graphical User Interface as used in workshop II (own illustration)

11.6 Workshop II

The second workshop had once again the purpose of showing the stakeholders all changes in the model, and allowing them to test the model and to self-design alternatives. In the first workshop, the stakeholders were given an Excel sheet, where all relevant data per location was presented, such that the stakeholders could get an idea of what the benefits

of choosing certain locations where. As this was sometimes difficult to understand for the stakeholders, the stakeholders received an interactive map of the locations, enabling them to select each alternative and directly see the corresponding values plotted on the map, a fictitious example of this can be found in Figure 48.



Figure 48: Fictitious example of visual feedback on the relevant values of the location alternatives (own illustration)

The stakeholders indicated that the visual feedback certainly helped them in understanding all relevant data points. The visual feedback alone already helped the stakeholders in gaining insights in the data relevant for their decision. However, as the values were not connected to a preference score and the future values were not included in the visualisations, the feedback as shown in Figure 48 was somewhat limited. This could be improved in further studies.

In the self-design process the stakeholders were able to select the alternative portfolio they expected to best match with their preferences. Also, the model itself, through a brute force calculation, calculated the highest scoring alternative. This is shown in Figure 49. The results show that there is an alternative portfolio that scores significantly higher than the current portfolio.

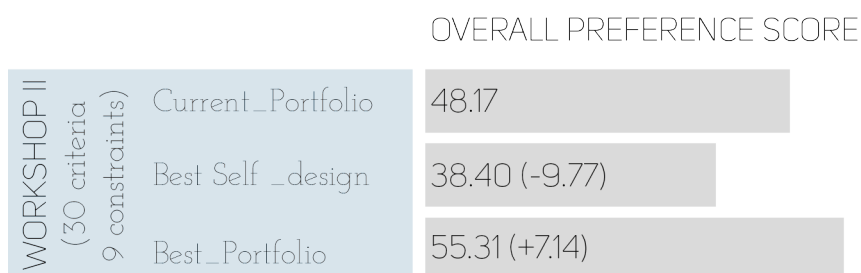


Figure 49: results of the second workshop (own illustration)

As can be seen, in both workshops the stakeholders were unable to design a portfolio alternative themselves that scored higher than the current portfolio. This can be explained in a number of ways.

First of all, the current portfolio has a large number of locations which are dispersed geographically. This increases the preference score of a number of decision variables. However, the current portfolio is infeasible according to the constraints set forward by the stakeholders as the number of locations is higher than 5. With a lower number of locations, it is more difficult to achieve the same result.

Secondly, before making use of the LDM framework, the stakeholders already had an assumption of what the best locations for their new portfolio would be. This assumption was based on gut feeling, and proved to be contradictory to their preferences stated in the LDM-framework. During the workshops, it was found that the stakeholders had difficulty to consider other options other than taking their assumptions as a basis and changing one or two locations at the most. As the highest scoring alternative significantly deviates from the assumed best portfolio, the stakeholders were unable to select the highest scoring alternative.

A third explanation of the inability of the stakeholders to design a better scoring alternative compared to the current portfolio is in the nature of the decision variables stated by the stakeholders. Most of the criteria were calculated on a portfolio level, rather than on a building level. This made it more difficult to comprehend for the stakeholders, as they are more used to think on a building level. This more strategic level increases the complexity of the decision-making process, which proved difficult to grasp for the stakeholders involved. This increased complexity can be dealt with through visual aid that supports the self-design process. Although in this pilot study such visual aid was touched upon by visualising the relevant values as a feedback in the second workshop as found in Figure 48, a more complete visual aid with the specific purpose of aiding in the self-design process can be developed to improve understanding during the self-design process.

11.7 Interview III

The third interview consisted of two parts. First of all, the stakeholders were asked if they accepted the highest scoring portfolio alternative as the best portfolio. The stakeholders indicated that theoretically, the results of the model were accepted as being the alternative that most closely reflects the preferences that were indicated. However, some stakeholders pointed out that they would ideally want to change some of their input, mainly on the weights of criterion_N, and therefore to every other criterion weight as well. As this results in a change in preference scores, this can significantly impact the end results. However, for the purpose of the pilot study, the stakeholders accepted the results as reflecting their input.

In Table 15, the optimum portfolio as calculated by the model is compared to the current portfolio on each of the criteria indicated, at the current moment in time only. The most right column shows if the rating increased or decreased over compared to the current preference rating. What can be seen is that the optimal portfolio does score lower on 4 criteria, whilst an increase can be found on 12 criteria and 14 criteria have an equal preference score. Out of these 14 criteria, 4 have the maximum preference score in both alternatives. Moreover, three criteria are solely focussed on future change and therefore always have a preference score of 0 at the current moment in time.

Table 15: Preference rating per criterion for current state and optimal state of portfolio (own illustration)

Decision maker	Criterion	Preference rating current portfolio	Preference rating optimal portfolio	Difference (%)
Stakeholder_2	Criterion_A	100.00	100.00	0.00
	Criterion_B	100.00	100.00	0.00

	Criterion_C	0.00	0.00	0.00
	Criterion_D	0.00	0.00	0.00
	Criterion_E	0.00	0.00	0.00
	Criterion_F	45.31	63.63	40.43
	Criterion_G	0.00	0.00	0.00
	Criterion_H	0.00	0.00	0.00
	Criterion_I	0.00	14.81	∞
Stakeholder_3	Criterion_J	100.0	100.00	0.00
	Criterion_K	Omitted	Omitted	n/a
	Criterion_L	56.09	61.66	9.93
	Criterion_M	0.00	0.00	0.00
	Criterion_N	78.55	70.08	-10.78
	Criterion_O	100.00	100.00	0.00
	Criterion_P	100.00	40.00	-60.00
	Criterion_Q	0.00	14.81	∞
	Criterion_R	71.77	0.00	-100.00
	Criterion_S	0.00	49.31	∞
Stakeholder_4	Criterion_T	10.94	57.75	427.88
	Criterion_U	42.91	100.00	133.05
	Criterion_V	0.00	69.38	∞
	Criterion_W	100.00	85.94	-14.06
	Criterion_X	0.00	0.00	0.00
	Criterion_Y	0.00	0.00	0.00
Stakeholder_5	Criterion_Z	0.00	0.00	0.00
	Criterion_AA	83.60	100.00	19.62
	Criterion_AB	28.57	50.00	75.01
	Criterion_AC	37.13	70.83	90.76
	Criterion_AD	25.00	35.00	40.00
	Criterion_AE	0.00	0.00	0.00

During the second part of interview III, the stakeholders were interviewed as an evaluation of the pilot study and the LDM-framework based on the evaluation interview protocol as shown in Appendix D: Evaluation interview protocol. The results of this evaluation can be found in Chapter 12.

11.8 Conclusions

This chapter describes the process of the first pilot study with the LDM framework. The pilot study had the purpose of testing the LDM framework on effectiveness. Before starting the activities, the subject owner identified the key stakeholders and the time horizon in question. During the interviews, the input of the preferences was gathered, which is visualised in Figure 50. This was facilitated by visual aids in the form of Excel models.

During the two workshops, the model was tested through a self-design process and a brute force calculation, which selected the alternative with the highest overall preference score. For the purpose of the research, the stakeholders accepted the outcomes of the model. However, some stakeholders requested to increase the weights of some decision variables as defined during the working. This shows that the iterative process is helpful in creating insight in the decision rationale. The evaluation of the pilot study can be found in the next chapter.

		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z	aa	ab	ac	ad	ae	I	II	III	IV	V	VI	VII												
Stakeholder I	Preference																																																		
	Constraint																																																		
Stakeholder II	Preference	■	■	■	■	■	■	■	■	■	■																																								
	Constraint																																																		
Stakeholder III	Preference											X	■	■	■	■	■	■	■	■	■	■																													
	Constraint																																																		
Stakeholder IV	Preference																																																		
	Constraint																																																		
Stakeholder V	Preference																																																		
	Constraint																																																		
Stakeholder VI	Preference																																																		
	Constraint																																																		

input gathered in first interview
 input gathered in second interview
 X Omitted during second interview

Figure 50: Overview of input from stakeholders (own illustration)

12. Pilot study evaluation

This chapter describes the evaluation of the pilot study, to find whether the framework is evaluated positively and whether the model provides an added value to the current real estate decision-making processes. Therefore, this chapter answers the research question: How is the LDM-framework perceived by the stakeholders in practice?

In general, the users evaluated the LDM-framework positively. The users indicated that the framework is a significant improvement over the current real estate decision-making process. The framework was applied to the actual decision-making process and the results are used as input for further steps of the process.

The evaluation of this pilot study is structured according the evaluation checklist developed in Chapter 8, which is again presented below.

Table 16: Evaluation checklist for decision support systems and its development process, based on (de Visser, 2016; Joldersma & Roelofs, 2004; Riedel et al., 2010)

Characteristic	Evaluation (Joldersma & Roelofs, 2004)	Resulting effect (Riedel et al., 2010)
Participation and involvement (Riedel et al., 2010)	Experience	System acceptance
Perceived control (Riedel et al., 2010)	Attractiveness	System acceptance
Perceived usefulness (Riedel et al., 2010)	Attractiveness	System acceptance
Satisfaction with the system (Riedel et al., 2010)	Attractiveness	System acceptance
Performance of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Performance reliability of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Purpose of the system (Riedel et al., 2010)	Effectiveness	Trust in the system
Perceived ease of use (Riedel et al., 2010)	Attractiveness	System acceptance
Complexity (Riedel et al., 2010)	Attractiveness	System acceptance
Familiarisation with algorithms of the model (Riedel et al., 2010)	Experience	Trust in the system

12.1 Evaluating the LDM process and framework

The **participation** of the users in the process is considered a very important element for the users in the acceptance of the model. The interviews with the users helped the users to understand how preference curves are determined, and allowed the users to critically think about the input they are providing. As Stakeholder_1 indicated:

"Asking for three, rather than one value triggers us to look further than the optimal solution, and makes us also consider other options that are workable as well"

In the workshops, the self-design element was extremely helpful in the **perceived control** of the model. In the first workshop, a number of interesting results came forward, and the

users were unable to select a portfolio alternative that yielded higher results than the current portfolio. Although this first led to some suspicion, explaining the results in the workshop, by referring back to the preference score per decision variable and then back to the original input helped the users to understand how the model works. One stakeholder even indicated that:

“Playing with selecting the locations helped me to understand how the model works, and increases my faith in the model in that it calculates everything based on my input. However, the model itself can be too rigid.”

The rigidity of the model refers to the black-and-white nature of mathematical operations. In the first workshop, some input preferences were interpreted wrongly by the system engineer, as the calculation method was not determined precisely enough in the initial interview. When this problem arose in the first workshop, it was considered a solvable problem, and actually helped the users in understanding the necessity to precisely indicate their preferences and how the values should be determined. This is also reflected in the following statement, made by one of the stakeholders:

“Being a mathematical model, the rigidity of the model can be seen as a constraint. However, it forces us to make our preferences very explicit.”

Some users indicated that the **complexity** of the model complicates the system acceptance. The addition of a time element next to the already complex interaction of preferences, constraints, alternatives, weights and scorings is sometimes perceived as daunting. However, one stakeholder indicated that:

“Integrating the future in the model is certainly an added value. It forces us to think better on what we find important in a location, and how we should run our business.”

The issue of complexity was also noticed by the system engineer in advance. This is why in the first workshop, it was decided that step 7 and 8 of the procedure were not taken, and the scenarios were only incorporated in the second workshop. However, in the first workshop an explanation of the scenarios was already given, as to make the users aware of this step and already familiarise them with the way the scenarios are incorporated in the model.

Another stakeholder indicated that the complexity of the model is a logical result of the complexity of the decision. In the pilot company, a large number of stakeholders have to make decisions on real estate locations. As the company consists out of multiple entities, conflict can arise between two entities on the preferences they have. This stakeholder pointed out that the necessity to make the preferences and weights explicit, makes the stakeholders think of what they really want.

The systems **performance** can seem quite daunting for the users of the model. The large number of alternative portfolio's (in this case, without constraints 1,073,741,824) can make it quite difficult for the users to understand what the actual result is. However, by self-designing portfolio alternatives during the workshops, the users gain experience in how one of these alternatives is calculated. By observing the relations between the preference curves, the preference score per decision variable and the overall preference score, the users trust the system in that it calculates this overall preference score for every possible alternative. However, one stakeholder said:

“It is sometimes difficult to generalise the input required on a portfolio level. Some considerations such as Criterion_I may be important on the portfolio level, but on a smaller scale it can be relatively less important.”

This shows that the performance of the system is closely aligned to the input that is given. If the input is incorrect, the performance of the system drops significantly.

The model is considered by the stakeholders as an excellent supporting tool for starting the discussion on real estate locations, forcing them to think beyond the costs of real estate. The process also helped the stakeholders in gaining insight in the various elements of the decision making process. However, one stakeholder said:

“It would be great if the model would be dynamic, for example changing the weights could be reflected in real-time, as to support the discussion during a workshop even better”

This shows that even though the activities of the framework are laid out such that iteration is incorporated in the model, the loop of feedback and results should be shorter in order to be more efficient. A more real-time ability to change the input is considered extremely helpful.

As the model is specifically build for the problem at hand, the **purpose of the system** is aligned with the actual system itself. By tailoring the mathematical model to the input received from the users, the model serves the purpose of the system, whilst keeping the activities and procedure identical. The users understood that the model is tailored to their requirements, which increased the acceptance of the system and therefore the effectiveness of the system.

In the process, it was indicated by the stakeholders that it is important to always refer back to the purpose of the framework. As the framework is intended for use by any relevant stakeholder, some stakeholders may not be involved with real estate decisions on a daily basis. Referring back to the purpose and explaining in general terms how the model reaches the conclusion helps these stakeholders to keep in mind the overall picture and goal. As one of the stakeholders pointed out:

“The model helps in reaching a substantiated conclusion and making an informed decision on a lot more variables than in the current decision making process.”

The users indicated that in terms of the **ease of use** of the framework, two perspectives can be taken. On the one hand, the use of the model for the users seemed to be a quite easy experience. By asking multiple concrete questions during the workshops, they indicated that the users understood how the model worked, and they found it easy to select the alternative locations and calculate the overall preference score. The use of a design interface played a significant role in this. However, on the other hand, one user indicated that the development of the model itself is very complex, and is not easy to use. The amount of back-end modelling is dependent on the number of preferences and the complexity of the algorithms that need to be created as to calculate the relevant values of each portfolio. However, as the model is specifically tailored to one case, the model requires some extensive remodelling before it can be applied to another case. This does hamper the ease of use significantly. However, for the decision-making process itself, the ease of use of the model is considered good.

For the stakeholders, the **incorporation of risks** in the framework has a lot of added value. It forces one to think about the business and differentiate what really matters. Also, the stakeholders indicated that the discussion becomes more strategic and pro-active, as discussions focussed more on how the business will evolve over time. However, in the specific case of the pilot company, the business is less linked to a location. The offices of Engie are mostly used for preparatory work, which could virtually be done in any place. This decreases the added value of a future perspective.

When the question was raised whether the model was **effective**, the stakeholders responded that in the end, with enough iterations, it would be possible to come to a result. Therefore, the model is indeed deemed effective. Also the risk analysis was effectively represented in the model, and brought forward a discussion on how robust each location is to the future and to future changes in some of the criteria.

12.2 Conclusions

Overall, the LDM-framework is evaluated positively. The stakeholders accept the system and trust its outcomes. The stakeholders were especially positive about the model forcing them to think in very precise terms regarding their preferences. The involvement of the stakeholders through workshops helped them to get acquainted with the model and helped them in accepting the system. The model is also seen as effective in the decision-making process by the users, and in quantitative measurements by the system engineer.

However, there are some improvements that can be made. The complexity of the model was mentioned by most stakeholders as a complicating factor for using the LDM-framework. As the model consists out of 30 variables and multiple moments in time, it became difficult for the stakeholders to understand every step of the model. This can be mitigated by providing a detailed manual of the model and a gradual explanation of the model, explaining different elements at different moments in time.

Another aspect is the graphical representation of the model. The users indicated that although the current representation is effective, it would be helpful to have a more visual representation of the results. Including a map on which the locations are rendered could help in understanding better where the locations are. Moreover, making this map interactive, such that a criterion can be selected and the corresponding location data is visualised (for example an increased size of the location pointer for larger locations) can help the user in understanding the relationship between the overall preference score and the location data better.

The last main improvement that can be made is with the performance of the system. Allowing the users to make changes in their input in real time, even if this is only in the reference points for the decision variables and the weights of each variable, enables the users to work far more efficient and shorten the time between a change and the results of that change.

The incorporation of risks in the model is seen as an added value, despite the added complexity of the model. One stakeholder indicated that the future perspective elevated the discussion to a strategic level, rather than an operational one. Even though in the pilot company the location of the offices is not very important for the operations, the consideration of changes in for example market conditions were seen as an added value to the stakeholders.

PART V: DISCUSSION AND CONCLUSION

13. The framework in perspective

The LDM-framework is developed as a new iteration of the PAS design approach. This chapter places the development of this research in perspective to the results of earlier PAS pilot studies.

13.1 Comparison of current pilot with previous pilot studies

As described in section 6.2, the LDM-framework can be seen as a further development of the PAS procedure. Therefore, it is interesting to consider the pilot study in relation to the other pilot studies. Table 17 provides a basic comparison of the cases.

Table 17: Comparison of pilot studies; Pilot #1 (Arkesteijn et al., 2016), Pilot #2 (Arkesteijn et al., 2015), Pilot #3 (de Visser, 2016)

Characteristic	Food facilities, Delft University of Technology (pilot #1)	Lecture halls, Delft University of Technology (pilot #2)	EMEA location portfolio Oracle (pilot #3)	Engie location portfolio South-Netherlands (pilot #4)
New or existing case	New	New	Existing	Existing
# stakeholders	4	6	1 (one person representing an inclusive set of criteria)	6 (7 people, of which two people represented one stakeholder)
# criteria	17	28	22	30
# constraints	6	5	4	8
# interventions	5	11	1	1
# objects	14	18	32	30
Preference rating current portfolio	43	58	61.43	48.17 (not compliant with constraints)
Preference rating optimum alternative	96 (+53)	69 (+11)	65.88 (+4.45)	55.31 (+7.14)
Future forecast	No	No	No	Yes (10.000 scenarios)
Modelling programme	Excel	Excel	Matlab	Matlab

What can be seen from the table above, is that the third and fourth case are similar in complexity, which are ambiguous in their level of complexity compared to the first two pilot studies. On the one hand, the number of objects has increased compared to the first two pilot studies (as the number of alternatives is the number of interventions to the power of the number of objects, as explained in section 9.5). These, combined with the number of interventions, determine the number of alternatives available. However, on the other hand, the pilot study described in this thesis only has one intervention available. This is due to the fact that the case is based on location selection, which only requires a location to be chosen or not. This can be seen as a reduction of the complexity of the model compared to pilot #1 and pilot #2. However, the model does reflect the real-life situation and possibilities.

Moreover, in the case of Engie, some other interventions were included in the model using a detour. For two current locations, non-binding negotiations had already started prior to the pilot study. This resulted in an option for lower costs per square meter and some alterations to the building. Instead of defining an intervention for this, the locations were added to the set of objects, though with the new values.

The number of stakeholders remained similar to previous pilot studies, with the exception of pilot #3. It should be noted however that in pilot case #3, one stakeholder represented the different perspectives, which could still be conflicting. In the pilot study held at Engie, complexity between the stakeholders had an added layer of complexity. First of all, the stakeholders had different perspectives, as explained in section 10.3. Secondly, the decision-making process involved stakeholders from two entities: Engie Services and Engie Refrigeration. Although both part of the Engie conglomerate, they are only related to each other on the executive level. This results in each company having their own employees, clients and requirements. This engendered that some criteria were stated by both stakeholders. This was for example reflected in their size requirements for the office space. Both stakeholders provided an individual preference for the required size. However, the location alternatives only provide a total square meterage. The solution to this conflict was to divide the total size of the alternative proportionally.

Compared to the three previous pilot studies, the main novelty added in this research is the ability to forecast changes in the location characteristics and that these changes are taken into account in calculating the overall preference score. This was not yet present in any of the previous pilot studies. It should be noted that it was possible to apply the PAS procedure multiple times, once to the current data and once for each possible future scenario and its respective data. Nonetheless, the LDM framework automates this process, and takes the necessary steps to obtain the data for the future scenarios. This improves the efficiency of the process, and reduces the room for error in the input data. Moreover, the use of multiple scenarios in the model requires some adaptations to the model, as to calculate a new overall preference rating that is based on all scenarios. This is also embedded in the LDM framework. As described in chapter 12, although the addition of a risk analysis in the form of scenario analysis added another layer of complexity of the model, it was considered an added value by the stakeholders involved:

“Integrating the future in the model is certainly an added value. It forces us to think better on what we find important in a location, and how we should run our business.”

13.2 The LDM framework in perspective of the current decision making process

In comparison to the current decision-making process, the LDM-framework is considered an added value. The subject owner mentioned that the model allows them to consider far more variables than previously. The explicit nature of the model in which everything is quantified in exact numbers, helps the users who are not faced with real estate decisions on a daily basis to think about their preferences and requirements.

Compared to the current decision-making process, which is more ad-hoc and mainly cost-driven, the LDM-framework allows the stakeholders to make a decision that is based on data. The stakeholder pointed out that:

“The model helps in reaching a substantiated conclusion and making an informed decision on a lot more variables than in the current decision making process.”

The LDM-framework is considered by the subject owner as a significant improvement to the current decision-making process.

13.3 Quantifying the added value of future scenarios

The main added value of the LDM-framework in comparison to previous (PAS) models, is the incorporation of future scenarios in the decision-making process. As to test the impact of this incorporation, a sensitivity analysis is performed on the current pilot study. In this analysis, the overall preference rating of the top 10 alternatives is compared to the overall preference rating, only taking into account current values, just as PAS. The results are shown in Table 18.

Table 18: sensitivity analysis of including future scenarios in the decision-making process (own illustration)

LDM-framework including future scenarios		LDM-framework excluding future scenarios (PAS)	
Alternative	Overall preference score	Alternative	Overall preference score
Alternative_076104	55.31	Alternative_163486	51.98
Alternative_076206	54.65	Alternative_076104	51.46
Alternative_028193	53.98	Alternative_163507	51.32
Alternative_076067	53.51	Alternative_154293	51.20
Alternative_076073	53.33	Alternative_076206	50.79
Alternative_163486	52.99	Alternative_163477	50.19
Alternative_002669	52.92	Alternative_076099	50.03
Alternative_028499	52.81	Alternative_154395	49.89
Alternative_070596	52.69	Alternative_028193	49.89
Alternative_076201	52.65	Alternative_154256	49.89

Two things can be observed from this table. First of all, the highest scoring alternative when including future scenarios has a different preference score than the highest scoring alternative excluding future scenarios. This difference can be explained by the calculation method of the preference scores. In the calculation of the overall preference score including the future scenarios, a risk element is added. The increase in preference score shows that in general, it is expected that the conditions of the locations will improve, which results in a higher overall preference score for the future.

The second important conclusion from Table 18, is that the 10 best alternatives are not the same in both processes. The best alternative of the PAS design approach is at place 2 in the LDM framework. This is because one of the locations is expected to perform worse in the future than another location alternative. The highest scoring alternative of the LDM however, is found in second place in the PAS procedure. This shows that the locations in this alternative score high now, and are robust to future change.

The comparison shows that incorporating risk in a preference-based model does yield different results, and can have an impact on the decision-making process. In a more detailed analysis, it was found that the difference between the best scoring alternative of the LDM framework and the best scoring alternative of PAS is in one of the five selected locations. Selection of location_0005 instead of location_0030 resulted in a higher future preference score, showing that location_0005 is in a location that is more interesting to the pilot company in the future.

Table 19: Overview of selected locations for top-10 highest scoring alternatives (own illustration)

Alternative	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
Alternative_076104																															
Alternative_076206																															
Alternative_028193																															
Alternative_076067																															
Alternative_076073																															
Alternative_163486																															
Alternative_002669																															
Alternative_028499																															
Alternative_070596																															
Alternative_076201																															

13.4 Risk analysis and sensitivity analysis

In the development of the LDM framework risk analysis is used to decrease risks. Another approach commonly used is a sensitivity analysis. Risk analysis and sensitivity analysis

are connected, but do have a fundamental difference. When a sensitivity analysis is performed one considers the impact of an event unfolding. The analysis shows to what extent the performance of a portfolio is influenced by an event occurring.

In risk analysis however, not only the influence on performance is measured, but also the likelihood of that event occurring is taken into account. In this research, this likelihood is determined by a time series analysis and Monte Carlo simulation. The result of this is a cumulative distribution function, showing the probability a variable will be lower or equal to the corresponding value. A sensitivity analysis can therefore be seen as only a part of risk analysis. For this reason a risk analysis approach was taken in development of this thesis.

14. Final conclusions and recommendations

This chapter describes the final conclusions that can be formulated from this hybrid research. This is done by following the structure of the report, and therefore by answering the sub-questions described in section 2.2. Also, the main question is answered in this chapter. Next to the final conclusions, recommendations for further research and development of the framework is given.

14.1 Answers to the sub-questions

This research revolves around the question of choosing the appropriate locations for one's real estate, whilst the characteristics of these locations change as time passes. These changing characteristics present a risk in the decision-making process, as it is unknown what the future value of the characteristics will be. In order to find a solution for taking these risks into account in the location decision, the following main research question was formulated: "How can risk management effectively be incorporated in a preference-based location decision-making process?"

First, answers need to be sought on a theoretical level, gaining insight in the critical elements this research refers to. The answers to these sub-questions can be found below:

- **What are location decisions based on and how are location decisions currently made?**

Each company has their own process of making location decisions, each with their own unique set of requirements and/or preferences. However, a number of common grounds can be found. Where a company decides to locate is mainly dependent on the driving forces of the company: what is the *raison d'être* of the company and what should it pursue. These driving forces can then be translated into location characteristics. Demographics, environmental constraints or availability of workforce are examples of such characteristics.

In general, seven overarching elements can be identified that play a role in location decision making: talent and skills (the availability of the necessary talent and workforce), real estate (availability of the right quality of real estate, in the right size, for the right price), clusters (availability of preferred amenities in the vicinity of the location), regulation and taxations (legal regulations that favour the business process), new visions (changes in the business strategy), city dynamism (the positive or negative way a city is developing), and accessibility (access to your required network in terms of clients, personnel, current locations).

Location decisions are currently made based on a unique combination of requirements. In research, it is found that location decisions are often based mainly on accessibility by car, representativeness of the location and accessibility by public transport.

In the case of the pilot company, real estate decisions are often made from a cost perspective, as the focus is on a reduction of number of locations and yearly expenses. The location decision is made ad-hoc, as a result of upcoming lease expirations. When such event occurs, the current real estate is roughly analysed, including the size requirements from the respective business units. Based on this, several alternatives are sought in the market, and a decision is made on where to locate.

- **How can demands and preferences be quantified and modelled?**

Demand is defined in economics as the quantity that customers are willing and able to buy at each and every price, all other things being unchanged. It expresses what the stakeholder wants, which in corporate real estate can be formulated as demand preferences. Preferences are per definition subjective. The term preference refers to the liking of a person, and can be seen as prioritised needs and requirements. Measuring preferences is therefore an identification process of the needs and requirements, including a prioritisation of these

values. Measuring preferences enables one to apply mathematical analysis and calculations to the subject matter.

Preference measurement involves the translation from an empirical system to a mathematical model. Preference is translated into a numerical value, or a scale, which can in turn be fed into a mathematical model.

Main difficulty in preference measurement is the principle of reflection: operations within the mathematical system are applicable if, and only if they reflect corresponding operations within the empirical system. This implies that only operations that can take place in the empirical system are allowable operations in the mathematical system.

Preferences are mapped, and a mathematical model is constructed using three objects or points. This follows from the formula used to generate a scale, namely $\frac{A-B}{C-D} = k$. 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).

Using these three reference points, one can construct the preference curve, that correctly corresponds to the empirical system. The curve is constructed using a Lagrange curve, which interpolates between a given number of polynomials. The curve can be calculated using:

$$P(x) = \left(\frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} \right) * y_0 + \left(\frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} \right) * y_1 + \left(\frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)} \right) * y_2$$

It should be noted that there is a differentiation between stated and revealed preferences. A stated preference is the identification of a stakeholder what he/she would like, whereas a revealed preference is the observation of an action, from which a preference can be distinguished. These preferences could differ, and in this thesis, stated preferences predominate.

- **What are the recent trends and developments in real estate decision making processes?**

Corporate Real Estate decision processes involve multiple objectives, which are often also found to be conflicting. Therefore, use is often made of MCDM tools. MCDA tools seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. In essence, in a MCDM process a number of alternatives are developed, which are assessed against the criteria set, and the best alternative is chosen.

In real estate management, several MCDM models exist. In an assessment of various models it was found that a large number of models do not allow for mathematical operations, which therefore cannot make proper use of preference measurement. As to tackle this issue, the Preference-based Accommodation Strategy (PAS) design approach was developed.

The PAS design approach, in its definitive form, is a procedure, a mathematical model supporting the analysis, and a number of activities. The procedure consists out of the following steps:

- Step 1: Each decision-maker specifies the decision variable(s) that he/she is interested in.
- Step 2: Each decision-maker rates his/her 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 (x_0, y_0) .
- 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 (x_1, y_1) .
- 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 (x_2, y_2) .

Step 3: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.

Step 4: Each decision-maker determines the design constraints he/she is interested in.

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 portfolio.

Step 6: The decision-makers select the design alternative with the highest overall preference score from the set of generated design alternatives.

First pilot studies of this model yielded positive results, finding alternative portfolios that suited better to the preferences stated.

▪ **How can risk be assessed, managed and quantified?**

Risk can be defined as the probability of an event occurring times the magnitude of loss or gain. A significant distinction can be made between risks and uncertainty. Risks is when an outcome may or may not occur, but its probability of occurring is known, whereas uncertainty is when an outcome may or may not occur, but its probability of occurring is not known.

Risks are managed by first conducting a risk analysis, identifying the risk and assessing it. Then, the respective manager is able to respond to the risk and control the risks. Managing risks can in general be done by taking one of four control measures: avoiding the risk, reducing the risk, transferring the risk or accepting the risk. This is dependent on the probability of an event occurring, and the impact it can have.

The first step of risk management is the identification of the risks. For this, a large number of tools are available, but it is found that often stakeholder help and previous experience are used as a basis for risk identification. This is mainly due to the ease of access of these resources.

Risk analysis can be done in two ways: quantitatively or qualitatively. The advantage over a quantitative analysis compared to a qualitative analysis is that a quantitative analysis is more objective, and enables one to create a probability curve of an event. This way, more detailed knowledge is gained on the probability of an event occurring, enabling the manager to better respond to the risk.

Risk analysis can be done by using a forecasting technique. A large number of forecasting techniques exist, of which an overview can be found in Table 20.

Table 20: Overview of forecasting techniques (own illustration based on (Armstrong, 2001; Chambers et al., 1971))

Category	Qualitative techniques				Time series analysis				Causal methods		
	Delphi method	Basic market research	Panel consensus	Scenario planning	Moving average	Box-Jenkins	Trend projections	Regression models	Econometric models	Input-output models	Life-cycle analysis
accuracy	Good	Fair	Good	Fair	Poor	Very good	Good	Very good	Excellent	Not applicable	Poor
timeliness in providing forecasts	Very good	Fair	Good	Good	Poor	Very good	Good	Good	Excellent	Very good	Fair
flexibility	Depends on accessibility experts	High	Depends on accessibility experts	High	High	High	High	Low	High	Low	Medium
ease of use	High	High	High	High	Medium	Medium	Medium	Low	Low	Low	Medium
incorporating judgemental input	Yes	Yes	Yes	Yes	Only as an extra step	Only as an extra step	Only as an extra step	Only as an extra step	Yes	Yes	Yes

For the research, use is made of Box-Jenkins time series analysis. A time series is a set of observations x_t , each one being recorded at a specific time t . Making use of historical data, a prediction is made of future developments of the variable. The available observed historical data is first represented as a realisation of the process

$$X_t = m_t + s_t + Y_t,$$

where m_t is a slowly changing function, known as the trend component. s_t is the seasonal component, with a known period d and Y_t is a residual random noise component that is stationary. A process can be called stationary if:

- (3) $\mathbb{E}[X_t] = \mu$ is independent of t
- (4) $Cov(X_{t+h}, X_t)$ is independent of t for each h

Through a large series of statistical tests (ACVF, ACF, PACF, ADF, BIC, see Section 7.8 and Appendix B for a detailed description) and simulations, an autoregressive integrated moving average (ARIMA(p,D,q)) process is fitted to the historical data, as to closely reflect the historical process. The resulting model is a mathematical process, that can be written in the form

$$X_t = c + \varepsilon_t + \sum_{i=1}^p \varphi_i X_{t-i} + \sum_{i=1}^q \theta_i \varepsilon_{t-i}$$

Where c is a constant value, ε_t is white noise, p is the autoregressive order, q the moving average order and φ_i and θ_i are the parameters of the model.

The mathematical process can be used to define the future value of the variable. However, a point forecast, which is often given, does not give the required insights for a risk analysis, as it does not provide a probability curve for the risk occurring. As a solution to this, a Monte Carlo Simulation can be applied to the model. In the Monte Carlo Simulation, the residual white noise component is simulated a large number of times, making use of the probability distribution function identified from the historical data from the same variable. The Monte Carlo simulation draws a random number from this probability distribution and applies this to the time series model. This process is repeated for a large number of times, creating various scenarios. By means of a histogram, a probability curve can be abstracted from these values.

▪ **How can risk be incorporated in a preference-based location decision-making process?**

As a basis for a preference-based decision-making process, use is made of the Preference-based Accommodation Strategy (PAS) design approach. The procedure provides a good basis for incorporating risks in such decision-making process. The model is built on the three levels of rationality in decision-making: substantive rationality, procedural rationality and

structural rationality. The developed framework is named the location decision-making (LDM) framework.

The procedure of the PAS design approach was changed in a number of places. The new procedure can be found in Section 9.3 and 14.2:

- Step 4 (addition): in step 4, risk identification is incorporated in the procedure. This can be done either by the decision makers or by (external) experts.
- Step 6 (addition): step 6 is meant to clarify the flexibility of the framework, and explicitly asks the decision-makers which alternative locations next to the current locations in the portfolio should be included.
- Step 7 (addition): in this step, the risk acceptance level is defined. The decision-makers jointly decide on the level of risk they are willing to accept. This is necessary for the model to be able to decide which locations are considered too much of a risk.
- Step 8 (addition): the framework is adapted such that two time periods are considered. As to come to a decision, the model requires input on how important the future rating is compared to the preference rating of the current time period. Step 8 asks this question.
- Step 11 (adaptation): in the last step of the procedure, a slight alteration is made, by including the need to take into account the insights of the risks of portfolio alternatives in the decision-making process.

- **How can decision-making tools be evaluated?**

Decision support systems are tools that allow users to make complex decisions by utilising data through models to solve semi-structured and unstructured problems. This implies that an interaction between humans and the model is necessary. This interaction is critical to the effectiveness of the model, as rejection of the model by the users results in the model not being used at all.

Decision-making tools can be evaluated on two main effects: system acceptance, and trust in the system, and can be evaluated using four categories: (1) experience with the system, (2) attractiveness of the system, (3) participant's perceived effectiveness of the model, and (4) observer's perceived effectiveness of the model.

Experience with the system can be gained through user participation and involvement in the (development) process of the system. It creates an understanding of the system, reducing the chance of rejection of the system. The experience with the system can be observed in several moments of interaction, and in an evaluation interview with the stakeholders.

Attractiveness of the system refers to whether the users like the method that is used and whether they feel comfortable using it. The users should have a high perceived control and perceived usefulness of the model. This again can be evaluated in an interview with the stakeholders.

Participant's perceived effectiveness of the method is a category that concerns the perceived added value of the method on the outcomes of the process. In research, it is found that often this category is closely linked to the attractiveness of the method, rather than to the quality of the results.

Therefore, the last category is the observer's perceived effectiveness of the model. The observer can make use of quantitative tests as to test the effectiveness of the method. In the case of the LDM-framework, effectiveness can be evaluated for this category by testing whether the model can find an alternative portfolio that is better aligned with the business strategy. Moreover, the added value of incorporating risk in the preference-based location decision-making process can partly be tested by comparing the results of the LDM-framework to a version that does not take into account the scenarios.

▪ **How is the method perceived by the stakeholders in practice?**

The LDM framework is seen as an added value in the real estate decision-making process. Experiences with the system showed that the stakeholders liked the active involvement in the process, testing and refining the model. Also the possibility of self-design enhanced the experience with the model for the stakeholders, resulting in higher system acceptance.

The stakeholders saw the system as *attractive*, as they indicated they felt comfortable using the system. A critical note here however is that it was difficult for some of the stakeholders to comprehend the time element in the model. A detailed explanation of especially these steps is vital in creating system acceptance and trust in the system.

The framework is considered to be effective, in the sense that the stakeholders agreed that the model helps them in complex cases, where multiple criteria are relevant. The transparency of the model is perceived to be beneficial in this, as the link between the results and the input is visible and the decision-making process is rational. The stakeholders agreed that the results comply with their preferences stated.

Incorporating risk in the framework yielded positive results, despite the increasing complexity of the model. One stakeholder indicated that the discussion during the workshops was on a more strategic level than normally would be the case, as changes in for example economic conditions were suddenly of importance as well.

From an observer's perspective, the framework is also perceived effective. In the first workshop, the model was able to find an alternative with a higher overall preference score compared to both the current portfolio and the manual selection of the stakeholders. Moreover, the use of the model helped the stakeholders in thinking about more factors than they originally did.

14.2 Answering the main research question

The main research question of this research is: "**How can risk management effectively be incorporated in a preference-based location decision-making process?**"

The Location Decision-Making framework, applied in the pilot study conducted during this research, is an effective decision-making process, which incorporates the risk of changing location characteristics in a preference-based location decision-making process.

The LDM-framework is an adaptation of the PAS design approach. This approach was used as a foundation, on which some alterations were made to incorporate risk analysis in the process. The LDM-framework consists out of three pillars (procedure, activities and model), which are explained below.

Procedural rationality: the procedure

The procedure of the LDM framework consists out of 10 steps the involved stakeholders need to take, as to complete the entire decision-making process:

Step 1: Each decision-maker specifies the decision variable(s) that he/she is interested in.

Step 2: Each decision-maker rates his/her 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 (x_0, y_0).

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 (x_1, y_1).

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 (x_2, y_2) .

Step 3: Each decision-maker assigns weights to his/her decision variables. The subject owner assigns weights to each decision-maker.

Step 4: Each decision-maker/expert indicates for each decision variable whether there is a risk that the value of the decision variable will change over time.

Step 5: Each decision-maker determines the design constraints he/she is interested in.

Step 6: The decision-makers define the locations in consideration other than the current locations in the real estate portfolio.

Step 7: The decision-makers jointly decide on an acceptable risk, formulated as a probability level between 0 and 1, that the alternative will not take a value lower than the corresponding preference score.

Step 8: The decision-makers jointly assign a weight to the current and future overall preference score of the portfolio.

Step 9: 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.

Step 10: Use an algorithm to yield an overall current and future preference score and one overall preference score.

Step 11: The decision-makers decide group wise based on the overall preference score of the alternative portfolios and insights in the risks of these portfolios.

What can be seen, is that risk identification is incorporated in the procedure. In step 4 of the procedure, using stakeholder help and interviews, the variables that actually have a risk are identified. Moreover, in step 7 and 8, the stakeholders are asked how important they think the risks are in the decision-making process.

Structural rationality: the activities

The steps of the procedural rationality are taken in a number of activities: three interviews and workshops, that alternate in the pattern I-W-I-W-I, as did the PAS design approach (Arkesteijn et al., 2015). The interviews are held individually per stakeholder, where in the first interview, the first six steps of the procedure are followed. In the first workshop, the model is tested, and the stakeholders jointly take step 7 and 8 of the procedure. Interview 2 provides the opportunity for the stakeholders to make amendments to their input provided in the first interview. The second workshop presents the updates made to the mathematical model, resulting from the second interview, and shows the best alternative. The third interview is used as a confirmation that the alternative that is calculated as the best alternative, is indeed the accepted alternative. If this is not the case, the stakeholders are able to adapt their input once again, and a third workshop is necessary.

Substantive rationality: the mathematical model

The mathematical model is the supporting tool for the location decision making. The model serves the purpose of determining the preference rating per criterion for a set of potential future portfolio alternatives. Also, the model is able to provide a weighted overall preference rating for each possible future portfolio, both given the current moment and a future moment in time.

The model is structured according to the scheme presented in Figure 51.

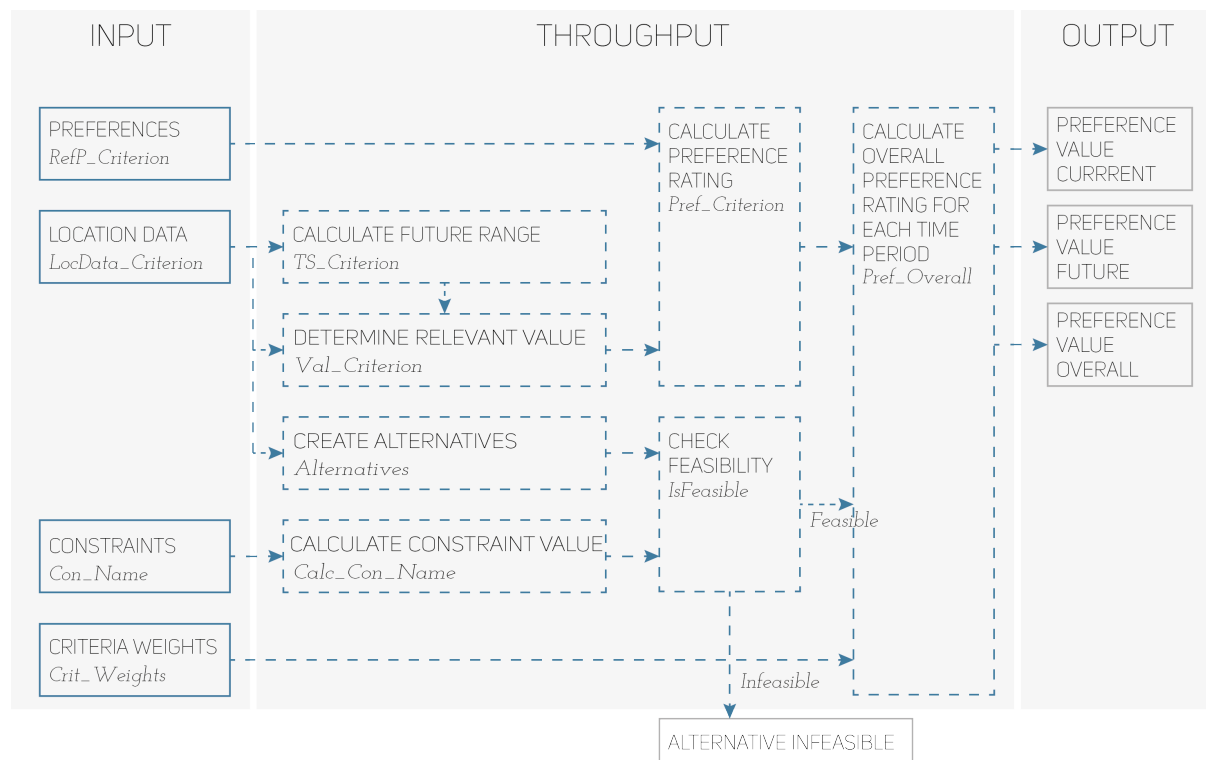


Figure 51: principal structure of the model (own illustration)

The input is retrieved by taking the steps from the procedure, when the activities are completed. These are fed into the model, where it generates the relevant values for each preference. These values are both calculated for the current moment in time and a large number of scenarios.

The values are used to check whether the selected portfolio alternative is feasible or not, by comparing these values to the constraints. If the alternative is feasible, the preference rating is calculated, by using the preferences stated in the interviews, and the relevant values calculated. By using weights, an overall preference score for both the current moment and each scenario can be calculated.

The future preference scores are ranked in an cumulative distribution function, which shows that given a certain value X , the probability that the alternative will score a preference score equal or higher to this value, is y . By using the input of step 7 of the procedure, for a determined probability level all preference scores can be calculated, as visualised in Figure 52.

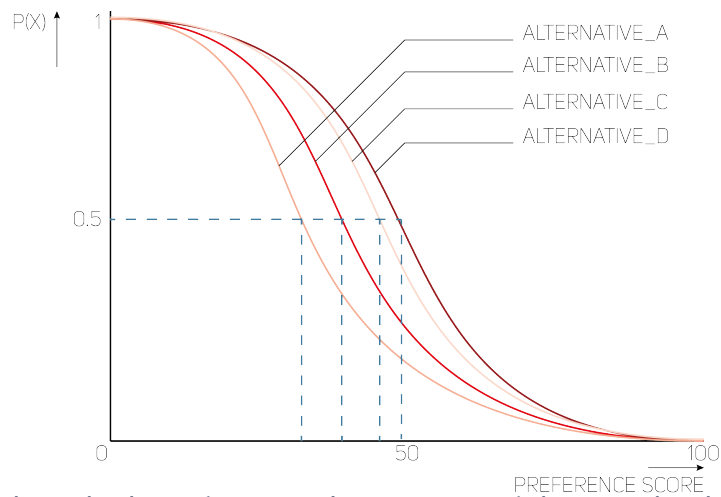


Figure 52: inverse cumulative distribution function, with an assessment of alternatives based on a probability level of 50% (own illustration)

The model calculates an average overall preference score of each alternative, based on the current overall preference score and the calculated future preference score, and the weights determined in step 8 of the procedure. The alternative that has the highest average overall preference score, is selected as the best portfolio.

A flowchart of the framework can be found in Figure 53.

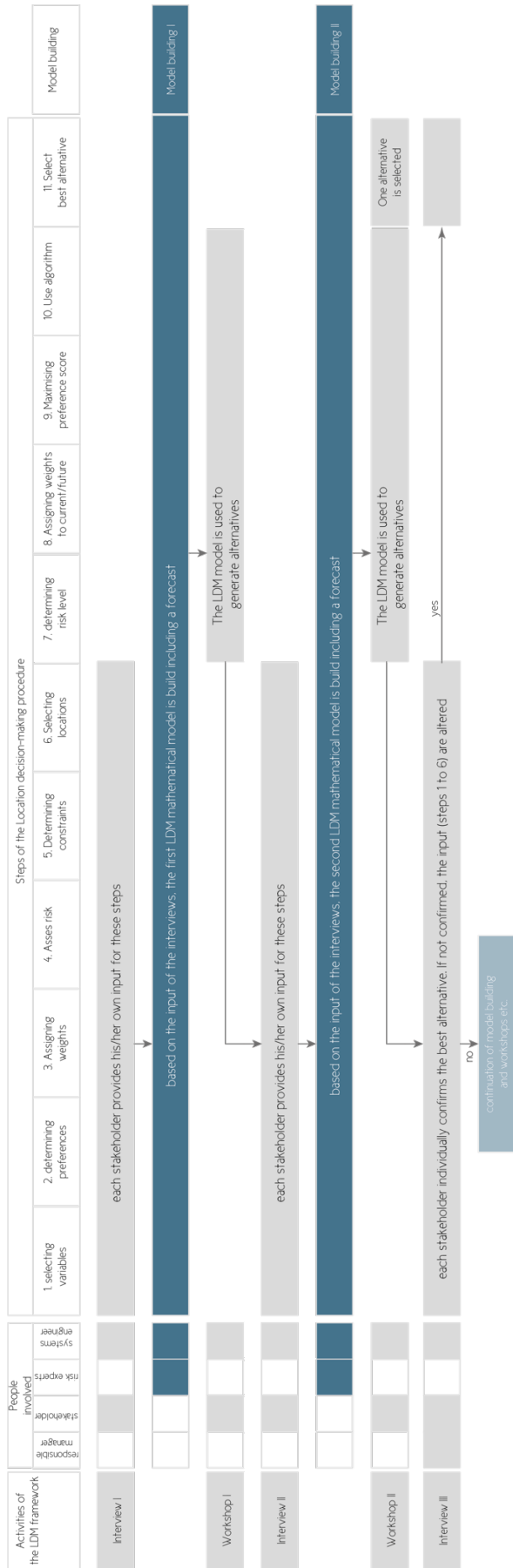


Figure 53: Flowchart of the framework (own illustration based on personal communication with Arkesteijn)

14.3 Limitations to the research

The research has some limitations where it comes to the professional application of the LDM-model. First of all, the availability of data is a concern always present in such models. As mathematical models always follow the adagio 'Garbage In is Garbage Out', high quality research data is required. In the pilot study, it became clear that some data is difficult to obtain. Professional application is therefore limited to having proper data.

Types of locations

An important limitation to the LDM-framework is the number of types of locations in the model. In the event of an analysis of a large number of locations, are of a different type, often a large number of different interests should be taken into account in the model. Although the number of interests or preferences in the model is not limited, these interests can be so specific for part of the real estate, that it can be difficult to model the entire process.

Processing power

Another possible limitation to application of the LDM-framework, is the processing power required. As the mathematical model calculates a preference score for each possible alternative, the workload quickly becomes large. In the pilot study, 30 locations were selected, resulting in $2^{30} = 1,073,741,824$ possible combinations of locations, not taking into account constraints. Each alternative receives 10.001 overall preference scores (10.000 scenarios and the current overall preference score), resulting in 10,738,491,981,824 scores. As one can assume, this requires vast amounts of processing power. In the pilot study, it was possible to make use of the high-powered computing clusters offered by the Delft University of Technology. However, it can be difficult to have such calculating power.

Utilisation potential

For the utilisation potential of the model, it is helpful to make a (large) predefined set of preference variables, from which the stakeholders can choose from. This reduces the programming time required for each time the model is build. Moreover, it becomes easier to obtain the relevant data, as part of the preference variables is known in advance. However, the stakeholders should at all times be able to define their own list, which can be a combination of part of the predefined variables and other variables they deem important.

Such predefined set can be made per sector, who often have overlapping preferences. The development of a database with supply data, specifically build for each sector, can speed up the process significantly, and allows for a large number of alternatives to be considered. However, one should always take into account that the model is tailored to the specific requirements of the company, and therefore will always require some adaptations.

Use of Lagrange curves

In the translation of preferences from the empirical system to the mathematical model, use is made of the Lagrange curves, as explained in Section 5.3. However, as explained by Binnekamp (2010, pp. 101-104), a Lagrange curve can take negative values: "*Lagrange polynomials oscillate between their roots (knots), therefore they can take negative values. [...] which is not what the decision maker intended, making the Lagrange curve not a suitable representation of the decision variable value - preference rating curve*" (Binnekamp, 2010, p. 102). In this pilot study, it was found that the opposite can also hold true, where values higher than 100 were observed, even though the most preferred value was not reached yet. This effect is due to the same problem as described above, due to the polynomial oscillating between their roots. This limitation is also found in pilots with the preference-based accommodation strategy models (Arkesteijn et al., 2016, 2015; de Visser, 2016).

Binnekamp however indicates that the use of a cubic Bézier curve can mitigate this limitation (Binnekamp, 2010, pp. 104-110). This is because instead of fitting a curve through

three points, the Bézier approach requires the decision maker to construct the curve him/herself. This is done by defining four points. Two points are the end points (x_0, y_0) and (x_3, y_3) . Two other points, (x_1, y_1) and (x_2, y_2) are the control points. The control points are used to control the curve's slope. They only serve to shape the curve and do not represent decision variable values and associated preference ratings. This approach is shown in Figure 54. Using the control points, the allowed variable values can range between x_0 and x_3 , and the preference ratings range between y_0 and y_3 , resulting in a correct representation of the preferences in the mathematical model.

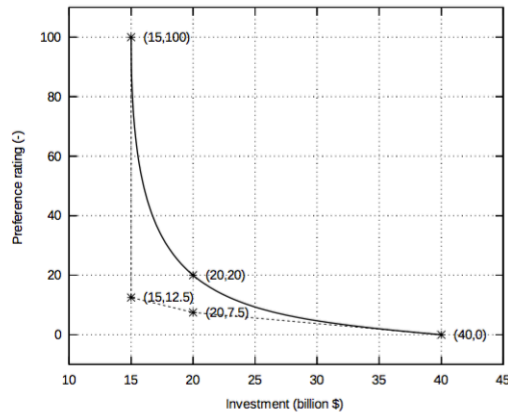


Figure 54: Investment variable value vs. preference rating by means of a cubic Bézier curve (Binnekamp, 2010, p. 111)

The choice for a Lagrange curve instead of a cubic Bézier curve is based on two factors. First of all, the limitation of a Lagrange curve only presents itself when the third reference point is located far from the straight line that could be drawn between reference points (x_0, y_0) and (x_2, y_2) . When the third reference point (x_1, y_1) is close to this straight line, the Lagrange curve serves as a sufficient approximation of the empirical preference values. Secondly, for the construction of a Bézier curve by the decision maker can be particularly complex and can take a long period of time. Binnekamp describes a solution to this increased complexity, by incorporating a graphical interface such that a decision maker can visually find a Bézier curve that approximates the relation between decision variable values and preference ratings (Binnekamp, 2010, p. 122). However, the development of such interface is beyond the scope of this research. As to simplify the procedure, it was chosen to use a Lagrange curve.

Requirement of external stakeholder

The incorporation of risks in the framework requires that the risks are identified. Following from literature described in Section 7.7, these risks can amongst other possibilities be identified using stakeholder interviews and expert opinion. As the stakeholders involved in the decision-making process could potentially not be aware of the risks of all criteria, the involvement of risk experts can be a necessity. The use of such an external stakeholder can limit the use of the model, as accessibility to such expert can be limited.

14.4 Recommendations for further research

This research comprises of the development of a framework and a first pilot study with the LDM framework. In future research, the framework can be tested in other pilot studies, as to validate the conclusions from this research. Next to this, some other recommendations can be made.

Optimisation of the mathematical model and making the model more dynamic

The mathematical model now requires significant computational power to come to a solution. This is mainly brought forward by the large number of locations and scenarios. The use of a high-performance computing cluster was necessary to be able to come to a solution. In future research, the mathematical model could potentially be optimised, reducing the needed computational power. This could be in the form of optimisations in the

code, or by rewriting the model in a computational language better suited to these types of calculations.

Furthermore, the stakeholders in the pilot study indicated that it would be helpful if the model could be used in a more dynamic way. During the workshops, from the discussions it followed that sometimes adaptations in the weights of the decision variables were necessary. However, in the current model, it is difficult to change this quickly. A more dynamic model, where the results of these changes are shown instantaneous, can help speed up the process, and makes the decision-making process more efficient. It should be noted that in one of the early versions of PAS, the model was indeed dynamic (Arkesteijn & Binnekamp, 2014). However, in the translation to a Matlab model, the dynamicity was lost.

Visual support of the model

In application of the model, it was found that users sometimes found it difficult to fully understand the model. This can be improved by adding more visual support to the model. Including a map on which the locations are rendered could help in understanding better where the locations are. Moreover, making this map interactive, such that a criterion can be selected and the corresponding location data is visualised (for example an increased size of the location pointer for larger locations) can help the user in understanding the relationship between the overall preference score and the location data better.

Testing the model back in time

An interesting test for the capability of the model to determine the future values, is to test the model on a case that lies in the past. This way, the future values that come out of the model can be compared to the actual values, as to test whether the model approximates the developments correctly. Moreover, it can be determined whether the decision that was made is the correct decision according to the model.

Substituting the Lagrange curve for a graphically supported Bézier curve

An important recommendation for further development of the framework is to substitute the Lagrange curve for a cubic Bézier curve, as described in the limitations. This approach better approximates the empirical system. It should be noted however, in order to not increase the complexity of the framework, the substitution should be accompanied by a graphical interface, which allows the decision-maker to quickly determine the curve without much difficulty.

Re-assessment of tool for risk analysis

In this research, Box-Jenkins time series modelling was used as a tool for risk analysis. This was done as the result of a comparison of various techniques. However, being a pilot study, factors such as Implementation costs, Maintenance costs and Ease of implementation were not considered. A new assessment on the various risk analysis techniques available where these factors are included could yield different results. For the utilisation potential, this is an interesting topic to research.

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APPENDICES

A. List of key performance indicators

The following list shows a list of key performance indicators (KPI's) in real estate. This list can be used an overview of the most common KPI's, which translate demand in measurable variables.

Criterion / measure	Literature reference	Category (by author)	Category (based on Den Heijer, 2011)
Threat of expropriation	Zaghdoud, 2013	push factor	controlling risk
Length of lease terms	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	controlling risk
Physical condition of facilities	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	controlling risk
Time used in project versus time budgeted for the project	Riratanaphong, 2014	Organisational development	controlling risk
CRE integrated with HR strategies	Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Productivity	controlling risk
Contaminated sites management	BCBC, 2003 in Riratanaphong, 2014	Environmental responsibility	controlling risk
Actual extra occupancy cost versus predicted cost	Masheder and Finch, 1998 in Riratanaphong, 2014	Cost efficiency	controlling risk
Technical condition of installations	Appel-Meulenbroek and Feijts, 2007	Installations	controlling risk
Lease term	Verhoeff, 2014	Liabilities	controlling risk
Technical condition of space	Zaghdoud, 2013	push factor / pull factor	controlling risk / decreasing costs
Price of land	Zaghdoud, 2013	pull factor	decreasing costs
Budget management	RPS, 2003 in Riratanaphong, 2014	Financial health	decreasing costs
Return on property management	Statsbygg, 2003 in Riratanaphong, 2014	Financial health	decreasing costs
Result before finance costs as percentage of invested capital per year	Statsbygg, 2003 in Riratanaphong, 2014	Financial health	decreasing costs
Total income from consulting and planning	Statsbygg, 2003 in Riratanaphong, 2014	Financial health	decreasing costs
Accommodation usage	Hagarty and Wilson, 2002; Kaczmarky and Morris, 2002; RPS, 2003 in Riratanaphong, 2014	Organisational development	decreasing costs
Area leased as percentage of total area	Statsbygg, 2003; Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	decreasing costs
Percentage of space occupied	Nourse, 1994; Bdeir, 2003 in Riratanaphong, 2014	Organisational development	decreasing costs
Gross floor area per usable floor area	Masheder and Finch, 1998 in Riratanaphong, 2014	Organisational development	decreasing costs
Space supply and demand ratios	RPS, 2003 in Riratanaphong, 2014	Organisational development	decreasing costs
Percentage of surplus assets sold	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	decreasing costs
Effective utilisation of space	Hinks and McNay, 1999 in Riratanaphong, 2014	Organisational development	decreasing costs
Number of workstations per employee	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	decreasing costs
Vacancy rates	Hagarty and Wilson, 2002; GSA, 2006; BCBC, 2003; RPS, 2-3; Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	decreasing costs
Employees housed	GSA, 2006 in Riratanaphong, 2014	Organisational development	decreasing costs
Square feet per employee	Arthur Andersen, 1993; Nourse, 1994; Masheder and Fitch, 1998; Bdeir, 2003; Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	decreasing costs
Total square feet employees housed	GSA, 2006 in Riratanaphong, 2014	Organisational development	decreasing costs
Area managed/employee	BCBC, 2003 in Riratanaphong, 2014	Organisational development	decreasing costs
Time wasted with interruptions (due to open space layout)	Riratanaphong, 2014	Organisational development	decreasing costs
Absentee rates by buildings	Masheder and Finch, 1998 in Riratanaphong, 2014	Productivity	decreasing costs
Occupancy cost per square foot	Arthur Andersen, 1993; Nourse, 1994; Bon et al. 1994; Masheder and Fitch, 1998; Bdeir, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy costs per employee	Arthur Andersen, 1993; Masheder and Finch, 1998; Bdeir, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost as a % of operating revenue by building or business unit	Arthur Andersen, 1993; Bdeir, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost per dollar or per unit of revenue	Masheder and Finch, 1998 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost per seat	Nourse, 1994 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost per customer	Bdeir, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost per sales or turnover	Riratanaphong, 2014	Cost efficiency	decreasing costs
Occupancy cost per business unit	Riratanaphong, 2014	Cost efficiency	decreasing costs
Building Occupancy Charge savings to customers	Riratanaphong, 2014	Cost efficiency	decreasing costs
Lease costs per square metre	Riratanaphong, 2014	Cost efficiency	decreasing costs
Total annual building occupancy charge	BCBC, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Cost of services and resources	NEN 2748 in Riratanaphong, 2014	Cost efficiency	decreasing costs
External facilities costs	NEN 2748 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Costs per square foot (owned/leased)	GSA, 2006 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Costs per CRE employee	Bdeir, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Operation cost/square metre	Statsbygg, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Maintenance cost/square metre	Statsbygg, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Different costs per square metre such as energy consumption	NPB, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Cost of leased vs. owned inventory	Hagarty and Wilson, 2002 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Total project cost in relation to budget	Statsbygg, 2003 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Number of moves per year	Riratanaphong, 2014	Cost efficiency	decreasing costs
Cost of under utilized space	Riratanaphong, 2014	Cost efficiency	decreasing costs
Workplace standards in use	Riratanaphong, 2014	Cost efficiency	decreasing costs
Cost of acquisitions versus returns	Masheder and Finch, 1998 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Holding costs per year	Masheder and Finch, 1998 in Riratanaphong, 2014	Cost efficiency	decreasing costs
Total amount of square metres	Appel-Meulenbroek and Feijts, 2007	Building	decreasing costs
Standardisation of elements	Appel-Meulenbroek and Feijts, 2007	Building	decreasing costs
Controlling possibilities of installations in general	Appel-Meulenbroek and Feijts, 2007	Installations	decreasing costs
Logistic infrastructure	Appel-Meulenbroek and Feijts, 2007	Accessibility	decreasing costs
Layout of lettable floor area	NEN 8021:2014	Space utilisation	decreasing costs
LFA per FTE	Verhoeff, 2014	Building quantity	decreasing costs
Quality of indoor environment	Kincaid, 1994 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	improving quality of the place

Noise level	Kincaid, 1994 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	improving quality of the place
Ratio of office space to common areas	Lubnieniecki and Desrocher, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	improving quality of the place
Quality of facilities	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	improving quality of the place
Number of building quality audits	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	improving quality of the place
CRE unit quality	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	improving quality of the place
Building Orientation	Appel-Meulenbroek and Feijts, 2007	Building	improving quality of the place
Amount of glass in façade	Appel-Meulenbroek and Feijts, 2007	Building	improving quality of the place
Detailing of elements and connections	Appel-Meulenbroek and Feijts, 2007	Building	improving quality of the place
Exposition, orientation and climate	Appel-Meulenbroek and Feijts, 2007	Environmental influences	improving quality of the place
Orientation within the building	NEN 8021:2014	Accessibility	improving quality of the place
Experience of light in the building	NEN 8021:2014	Comfort	improving quality of the place
Amount of natural light in building	NEN 8021:2014	Comfort	improving quality of the place
Internal air quality	NEN 8021:2014	Comfort	improving quality of the place
External air quality	NEN 8021:2014	Comfort	improving quality of the place
Ability to cool building	NEN 8021:2014	Comfort	improving quality of the place
Ability to heat building	NEN 8021:2014	Comfort	improving quality of the place
External noise	NEN 8021:2014	Comfort	improving quality of the place
Internal noise	NEN 8021:2014	Comfort	improving quality of the place
Materials forms and colours of floor	Appel-Meulenbroek and Feijts, 2007	Floor	improving quality of the place / supporting culture
Expansion potential	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Flexibility	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Vertical zoning	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Space with deviating weight capabilities	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Unit size	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Size per floor	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Ability to grow within building	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Zoning difficulties	REN 2003 in Vermeer, 2007	Flexibility	increase flexibility
Building form	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Construction type	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Expanding possibilities	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Building depth	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Building Height	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Building volume	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Number of floors	Appel-Meulenbroek and Feijts, 2007	Building	increase flexibility
Floor layout	Appel-Meulenbroek and Feijts, 2007	Floor	increase flexibility
Spatial characteristics and flexible elements	Appel-Meulenbroek and Feijts, 2007	Floor	increase flexibility
Room/workplace layout	Appel-Meulenbroek and Feijts, 2007	Room/workplace	increase flexibility
Installations capacity	Appel-Meulenbroek and Feijts, 2007	Installations	increase flexibility
Connection possibilities of installations	Appel-Meulenbroek and Feijts, 2007	Installations	increase flexibility
Standardisation of installation	Appel-Meulenbroek and Feijts, 2007	Installations	increase flexibility
Connection of installation elements	Appel-Meulenbroek and Feijts, 2007	Installations	increase flexibility
Vertical accessibility in the building	NEN 8021:2014	Accessibility	increase flexibility
Flexibility in case of change of layout	NEN 8021:2014	Flexibility	increase flexibility
Flexibility in change of size of floor space	NEN 8021:2014	Flexibility	increase flexibility
Building depth	NEN 8021:2014	Space utilisation	increase flexibility
Room for expansion	Zaghdoud, 2013	push factor / pull factor	increase flexibility
Distance employees commute	Duckworth, 1993 in Riratanaphong, 2014	Productivity	increasing (user) satisfaction
Accessibility for disabled	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Accessibility for cars	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Accessibility for pedestrians	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Accessibility public transport	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Accessibility parking spaces	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Size parking spaces	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Amount of local amenities	REN 2003 in Vermeer, 2007	Functionality	increasing (user) satisfaction
Congestion sensitivity	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Accessibility public transport	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Proximity to airport	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Routing, accessibility	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Public parking for visitors	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Parking on own terrain	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Parking norm	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Parking for bicycles	REN 2003 in Vermeer, 2007	Logistics	increasing (user) satisfaction
Ability to open windows	REN 2003 in Vermeer, 2007	Flexibility	increasing (user) satisfaction
Thermal comfort summer	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Therma comfort winter	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Allowable internal heat load	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Reduction of sun	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Air quality	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Controllability climate installations	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Controllability lighting	REN 2003 in Vermeer, 2007	Comfort	increasing (user) satisfaction
Security of entrances	REN 2003 in Vermeer, 2007	Safety	increasing (user) satisfaction
Presence of restaurants	REN 2003 in Vermeer, 2007	Facilities	increasing (user) satisfaction
Employee satisfaction with work environment	Arthur Andersen, 1993; Nourse, 1994; Bdeir, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Provision of amenities	Bdeir, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Absentee rates by buildings	Masheder and Finch, 1998 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Proximity to required transportation modes	Duckworth, 1993; Lubnieniecki and Desrocher, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction

Access to employees	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Amount of local amenities	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Employee satisfaction with CRE services	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Amount of workplace reforms and space modifications	Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Distance to employees' homes	Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Employee satisfaction with professional skills	Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Employee satisfaction with information sharing	Riratanaphong, 2014	Employee satisfaction (stakeholder perception)	increasing (user) satisfaction
Customer satisfaction	Bdeir, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Number of helpdesk calls per square foot	Bon et al, 1993 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Customer satisfaction with responsiveness	Amaratunga and Baldry, 2000 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Proximity to required transportation modes	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Access to costumers	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Distance to other sites and businesses	Duckworth, 1993; Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Rating based on building attributes	Duckworth, 1993 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Customer satisfaction with facilities	Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Service level agreements in use with service providers	Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
BSC for partners in use	Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Audits for service providers in use	Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Loyalty	Bradley, 2002 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Community sentiment	Bradley, 2002 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Contribution to public policy and societal priorities	Hogarty and Wilson, 2002; RPS 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Customer choice rating	BCBC, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Percentage of customers with service level agreements in place	BCBC, 2003; Lindholm and Gibler, 2005 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Overall tenant satisfaction with property management services	RPS, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	increasing (user) satisfaction
Employees' opinion on how well the workplace supports their productivity	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Productivity	increasing (user) satisfaction
Control of environmental characteristics	Appel-Meulenbroek and Feijts, 2007	Floor	increasing (user) satisfaction
Controlling possibilities of installations in specific locations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Production of noise of installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Characteristics of ventilation installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Characteristics of lighting installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Characteristics of cooling installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Characteristics of heating installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Characteristics of air moisturising installations	Appel-Meulenbroek and Feijts, 2007	Installations	increasing (user) satisfaction
Proximity of labour market	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Proximity of selling market	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Proximity of suppliers/sources	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Proximity to related organisational departments	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Proximity of collaboration parties	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Presence of supporting facilities	Appel-Meulenbroek and Feijts, 2007	Location	increasing (user) satisfaction
Accessibility of facilities on site	Appel-Meulenbroek and Feijts, 2007	Accessibility	increasing (user) satisfaction
Sources of noise	Appel-Meulenbroek and Feijts, 2007	Environmental influences	increasing (user) satisfaction
Accessibility of main entrance for people	NEN 8021:2014	Accessibility	increasing (user) satisfaction
Controllability climate installations	NEN 8021:2014	Comfort	increasing (user) satisfaction
View from workplace	NEN 8021:2014	Comfort	increasing (user) satisfaction
Social security	NEN 8021:2014	Safety	increasing (user) satisfaction
Safety measures	NEN 8021:2014	Safety	increasing (user) satisfaction
Facilities for consumption	NEN 8021:2014	Facilities	increasing (user) satisfaction
Sport facilities	NEN 8021:2014	Facilities	increasing (user) satisfaction
Extra facilities (in neighbourhood)	NEN 8021:2014	Facilities	increasing (user) satisfaction
Sanitary facilities	NEN 8021:2014	Facilities	increasing (user) satisfaction
Storage facilities	NEN 8021:2014	Facilities	increasing (user) satisfaction
Book value building	Verhoeff, 2014	Juridical properties	increasing real estate value
Juridical structure building	Verhoeff, 2014	Juridical properties	increasing real estate value
LFA per user profile	Verhoeff, 2014	Building quality	increasing real estate value
Price of building	Zaghdoud, 2013	pull factor	increasing real estate value

Building age	Appel-Meulenbroek and Feijts, 2007	Building	increasing real estate value
Marketability	Verhoeff, 2014	Liquidity	increasing real estate value
Building condition	Verhoeff, 2014	Liquidity	increasing real estate value
Value for money	Hinks and McNay, 1999 in Riratanaphong, 2014	Financial health	increasing real estate value
Economic/market value added	Bradley, 2002 in Riratanaphong, 2014	Financial health	increasing real estate value
Return on Investment	Hagarty and Wilson, 2002; BCBC, 2003; RPS, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Net Income	BCBC, 2003; NPB, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Return on invested capital	Kaczmarezyk and Morris, 2002 in Riratanaphong, 2014	Financial health	increasing real estate value
Return on equity	NPB, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Value of property, plant and equipment	Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Total proceeds on properties sold	BCBC, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Return on investmentment for Owned Market-Comparable office buildings	BCBC, 2003 in Riratanaphong, 2014	Financial health	increasing real estate value
Waste disposal	REN 2003 in Vermeer, 2007	Logistics	reducing ecological footprint
Number of energy audits	Riratanaphong, 2014	Environmental responsibility	reducing ecological footprint
Amount of garbage	Riratanaphong, 2014	Environmental responsibility	reducing ecological footprint
Energy	Appel-Meulenbroek and Feijts, 2007	Installations	reducing ecological footprint
Production of heat in installations	Appel-Meulenbroek and Feijts, 2007	Installations	reducing ecological footprint
Energy label	NEN 8021:2014	Sustainability	reducing ecological footprint
Use of renewable sources	NEN 8021:2014	Sustainability	reducing ecological footprint
Energy	REN 2003 in Vermeer, 2007	Environment	reducing ecological footprint / decreasing costs
Energy consumption	Riratanaphong, 2014	Environmental responsibility	reducing ecological footprint / decreasing costs
Energy use/square meters	Statsbygg, 2003 in Riratanaphong, 2014	Environmental responsibility	reducing ecological footprint / decreasing costs
Amount of teamwork space	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	stimulating collaboration
Amount of distance work settings in use	Lindholm and Gibler, 2005 in Riratanaphong, 2014	Organisational development	stimulating collaboration
Amount of advice given to other business units	Riratanaphong, 2014	Organisational development	stimulating collaboration
CRE actively involved in firm-wide initiatives such as special asset use	Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Productivity	stimulating collaboration
Variety in workplaces and activities	NEN 8021:2014	Space utilisation	supporting culture
Representativeness	Zaghdoud, 2013	push factor / pull factor	support image
Type of location	REN 2003 in Vermeer, 2007	Image	support image
Attractive power location	REN 2003 in Vermeer, 2007	Image	support image
Environmental quality	REN 2003 in Vermeer, 2007	Image	support image
Social environment location	REN 2003 in Vermeer, 2007	Image	support image
Publicity	REN 2003 in Vermeer, 2007	Functionality	support image
Appearance	REN 2003 in Vermeer, 2007	Image	support image
Identity of building	REN 2003 in Vermeer, 2007	Image	support image
Common space	REN 2003 in Vermeer, 2007	Image	support image
Main entrance	REN 2003 in Vermeer, 2007	Image	support image
Positive market profile	Kaczmarezyk and Morris, 2002 in Riratanaphong, 2014	Customer perception (stakeholder perception)	support image
Political results	Kaczmarezyk and Morris, 2002 in Riratanaphong, 2014	Customer perception (stakeholder perception)	support image
Percentage of positive and neutral press coverage	Statsbygg, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	support image
Registration of all properties according to plan for protection of historical/cultural values	Statsbygg, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	support image
Media monitoring	NPB, 2003 in Riratanaphong, 2014	Customer perception (stakeholder perception)	support image
Charisma/image location and environment	Appel-Meulenbroek and Feijts, 2007	Environmental influences	support image
Coherence between architectural form, function and construction	NEN 8021:2014	Representativeness	support image
Monumental status	NEN 8021:2014	Representativeness	support image
Recognisability of building	NEN 8021:2014	Representativeness	support image
Organisational reasons	Zaghdoud, 2013	push factor / pull factor	supporting culture
CRE involved in corporate strategic planning	Lubieniecki and Desrocher, 2003 in Riratanaphong, 2014	Productivity	supporting culture
Materials, forms and colours	Appel-Meulenbroek and Feijts, 2007	Building	supporting culture / improving quality of the place
Cleanability	NEN 8021:2014	Facilities	supporting user activities
Accessibility for cars	Zaghdoud, 2013	push factor / pull factor	supporting user activities
Location target consumers	Zaghdoud, 2013	pull factor	supporting user activities
Data and IT amenities	REN 2003 in Vermeer, 2007	Flexibility	supporting user activities
Proximity to highway	REN 2003 in Vermeer, 2007	Logistics	supporting user activities
IT	REN 2003 in Vermeer, 2007	Flexibility	supporting user activities
Accessibility	REN 2003 in Vermeer, 2007	Logistics	supporting user activities
Equipment provided meets business needs	Hinks and McNay, 1999 in Riratanaphong, 2014	Organisational development	supporting user activities
Productivity (%)	Carder, 1995; van der Voordt, 2004 in Riratanaphong, 2014	Productivity	supporting user activities
Working environment	Kaczmarezyk and Morris, 2002 in Riratanaphong, 2014	Productivity	supporting user activities
Alternative Workplace Arrangements	GSA, 2006 in Riratanaphong, 2014	Productivity	supporting user activities
Characteristics of IT installations	Appel-Meulenbroek and Feijts, 2007	Installations	supporting user activities
Accessibility of resources	NEN 8021:2014	Accessibility	supporting user activities
IT facilities	NEN 8021:2014	Facilities	supporting user activities

B. Detailed description of the mathematical model

This appendix describes the process that is followed to provide a solution to the problem description in more detail. The problem is modelled in a mathematical model written in Matlab. Matlab is a mathematical calculation software that makes use of input from matrices. The user can write functions that interrelate, performing mathematical operations on the matrices. Advantage to such structure is that the structure can remain intact if the input changes, and adding objects or alternatives only require a single adaptation of the model.

The model

The model is built on two types of elements: the required input in the form of matrices, and functions in the form of scripts, allowing to make mathematical operations on the input. The model itself consists out of two main steps. First, location data is used as an input, from which multiple scenarios are created. These scenarios serve as an input for the second step, where the overall preference rating for each portfolio alternative is calculated. Each of these two steps is explained in the following sections.

Step I: creating scenarios

The first step in the modelling process is to create the scenarios for each location. Some location characteristics may change over time, which could result in the location being more or less favourable compared to the current situation. As to model this change, use is made of time series analysis as described in Chapter 7. As to explain the steps that are taken, an example is used. In this case, use is made of data on the number of USA domestic airline flights from 1987 to 2008.

```
load('Data.mat');
y = log(Data);
T = length(y);

% test stationarity
h = adfctest(ts, 'model', 'TS', 'lags', 0:2);

% find if one is rejected
if any(1==h)
    ix = find(h>0,1);
else
    ix = 0;
end

% differencing so time series is stationary, if prior test failed
Y = diff(ts,ix);
y = ts;
```

First, the data is loaded into Matlab and the log of the data is taken. This is done as to make the data stationary, as explained in Chapter 7. This stationarity is tested using an ADF-test. If the hypothesis is rejected, the time series is differenced. The result of these steps is a time series that is stationary, on which various time series models can be applied.

```

% test various models
LOGL = zeros(4,4); %Initialize
PQ = zeros(4,4);
for p = 1:4
    for q = 1:4
        mod = arima(p,0,q);
        [fit,~,logL] = estimate(mod,Y,'print',false);
        LOGL(p,q) = logL;
        PQ(p,q) = p+q;
    end
end

LOGL = reshape(LOGL,16,1);
PQ = reshape(PQ,16,1);
[~,bic] = aicbic(LOGL,PQ+1,100);
reshape(bic,4,4)

[M,I] = min(bic(:));
[I_row_AR, I_column_MA] = ind2sub(size(bic),I);

% Modelling
Mdl = arima(I_row_AR,ix,I_column_MA);

```

The time series model that is applied is an ARMA(p,q) model, as the time series is already differenced if necessary. As to find the parameters p & q , first, a 4x4 matrix with zeros is made. Then, combinations of p and q values are made and fitted on the time series. The appropriateness of fit is calculated using the Bayesian information criterion "bic". Then, the script searched for the column and row index of the lowest value in the *bic* matrix, as these represent the p and q parameter values of the model with the best fit to the time series. The last step is the creation of an ARIMA model (with $D = 0$) with the p and q parameters determined.

```

% Estimate parameters of model applied to the time series
EstMdl = estimate(Mdl,y);

```

Next, the other parameters of the model need to be estimated. This is done by fitting the model to the original, non-differenced time series. The resulting *EstMdl* is the model that best represents the historical data fed into the model.

```

% Check the residuals for normality.
res = infer(EstMdl,y);
stres = res/sqrt(EstMdl.Variance);

figure
subplot(1,2,1)
qqplot(stres)

x = -4:.05:4;
[f,xi] = ksdensity(stres);
subplot(1,2,2)
plot(xi,f,'k','LineWidth',2);
hold on
plot(x,normpdf(x),'r--','LineWidth',2)
legend('Standardized Residuals','Standard Normal')
hold off

% Check the residuals for autocorrelation.
figure
subplot(2,1,1)
autocorr(stres)
subplot(2,1,2)
parcorr(stres)

[h,p] = lbqtest(stres,'lags',[5,10,15],'dof',[3,8,13])

% Check predictive performance.
y1 = y(1:100);
y2 = y(101:end);
numobs = length(y2);
Mdl1 = estimate(Mdl,y1);
yF1 = forecast(Mdl1,numobs,'Y0',y1);
pmse = mean((y2-yF1).^2)

```

As to check whether the model is a good fit, a number of statistical tests are performed (residual normality check, autocorrelation check, predictive performance check on actual data). These tests are meant as a controlling element, to check whether the chosen model does indeed represent the historical data sufficiently.

```
%% Simulate the forecast using MC
L = 5;
yF2 = simulate(Mdl1,L,'NumPaths',10000,'Y0', y);
```

The last phase of Step 1 is to simulate the forecast, based on a Monte Carlo Simulation. In this case, a forecast is made with 5 steps in the future, with 10.000 paths. Thus, the model runs 10.000 scenarios of how the future could unfold. This data is stored in variable yF2, which holds the values of the variable in all scenarios.

The data is copied to a .mat file consisting of all data needed for the LDM model. This .mat file is called 'Load_workspace'. This process is repeated for all variables that have a risk.

Step 2: Calculating the overall preference score of each alternative

Instruction

Step A: Loading the file

Extract the zip-file in an empty directory/folder, and select that folder in the Matlab environment as the current folder.

Depending on your Matlab settings, the following could differ from your observations: On your left, a list of functions can be found, as well as the workspaces and other files in the folder. On the right, the workspace can be found where all arrays that are used in the model will be loaded.

Step B: Loading the variables

In the command window, type 'Load_workspace' to load the workspace into the memory. The workspace is named InitData. The script also clears the workspace and the command window beforehand.

Running the model

Step C: Opening the GUI

The GUI can be opened by running 'MainIO', by either typing this in the command window, or by opening it through a right click > run. This action runs the GUI, which is the primary interface of the model. On the left, the locations can be turned on or off, by clicking on the check box. This allows for making personalised combinations of locations as a possible portfolio. Each combination can be calculated by pressing 'calc. preference score'. Results can be stored by saving the alternative.

The model can also calculate the overall best portfolio. This can be done by running the function Do_All.m, or HPC_Do_All.m, depending on whether the model is ran on the local computing environment using one processor, or on a server/multiple processors respectively.

Explanation of all functions

Pref_Overall

Syntax: Pref_Overall(pAlternative, pScen)

pAlternative is an alternative in the form (x_1, \dots, x_{30}) where x_j is the state of the location j , that can be switched on (1) or off (0) in the alternative.

pScen is the respective scenario which is calculated, in the form of (y_1, \dots, y_{10000}) , where y_i is the scenario in question.

Return value: This function returns the overall weighted preference rating of the alternative, based on the physical values for all criteria in the portfolio, taking into account the design constraints.

Pref_All

Syntax: Pref_All(pAlternative, pScen)

Return value: This function returns the portfolio preference ratings for all criteria, based on the given portfolio

Pref_n

Syntax: Pref_n(pAlternative, pScen)

Return value: Given a physical value, calculated in Val_n, this function returns the corresponding preference value for the criterion n.

Val_n

Syntax: Val_n(pAlternative, pScen)

Return value: This function returns the physical value of the variable n, based on the respective input and required calculation (e.g. average, total sum, minimum or maximum).

Calc_n

Syntax: Calc_n()

Return value: This function is used to calculate the physical value for a number of criteria, and calculates the weights per preference, based on the stakeholder weights and their preference weights.

Con_n

Syntax: Con_n(pAlternative, pScen)

Return value: The constraint function calculates whether, given a scenario, the alternative complies with the constraints set forward in the model. The return value is 1 or 0, respectively for being compliant or not compliant.

Do_All

Syntax: Do_All()

Return value: This function calculates the preference score for each alternative for each scenario, and determines which alternative has the highest overall preference score. This is presented in an array, with in the first column the respective scenario, the index of the alternative in column 2, the overall preference score in column 3, number of locations in column 4, the total costs in column 5 and the selected locations in column 6:35.

Gen_n

Syntax: Gen_n()

Return value: The generator functions calculate a number of variables based on a cell array. This simplifies input, as all preference input, the weights and preference points are now summarised into one cell array.

IsFeasible

Syntax: IsFeasible(pPortfolio, pScen)

Return value: This function returns the value 1 if the alternative meets all constraints, and 0 if the alternative does not.

C. Written introduction of the model for Interview I (Dutch)

Vanuit de stakeholders zijn er altijd verschillende voorkeuren voor de huisvesting. Om te zien hoe goed een pand aansluit bij de voorkeuren, moeten deze gemeten worden. Daarnaast kunnen er beperkingen gelden, welke een locatie (of een combinatie van locaties) bij voorbaat uitsluit. Hierbij kan bijvoorbeeld gedacht worden aan de maximale jaarlasten van het huisvestingsportfolio. Om het een en ander uit te leggen, wordt hier gebruik gemaakt van een voorbeeld.

Voorbeeld

Stel u bent op zoek naar een nieuwe koopwoning in Utrecht. Hiervoor heeft u een aantal voorkeuren op een rijtje gezet, waarmee u een keuze wilt maken. Daarnaast zijn er nog een aantal beperkingen, die u in ieder geval in het nieuwe huis wilt hebben. In dit voorbeeld zijn de volgende voorkeuren en beperkingen gedefinieerd:

Voorkeuren	Beperkingen
Koopprijs (€)	Aantal kamers (minimaal 4)
Grootte (m ²)	Aanwezigheid buitenruimte (ja)
Afstand tot centrum (km)	

Zoals te zien is, zijn de beperkingen al volledig bepaald. Mocht er een woning bijvoorbeeld maar 3 kamers hebben, dan zal de woning afvallen.

Aan de voorkeuren echter, moeten nog waarden gehecht worden. Voor elke variabele, moeten drie waarden bepaald worden. Ten eerste moet de meest optimale waarde worden bepaald. Deze krijgt een referentiewaarde van 100. Dit is de waarde die u het liefste hebt. Vervolgens wordt de minst gewenste waarde bepaald. Dit is de waarde die je het minst graag wilt hebben, en krijgt een referentiewaarde van 0. Ten slotte wordt er nog een waarde bepaald die hier tussenin ligt, welke een referentiewaarde krijgt van 50. In dit voorbeeld zijn de volgende waarden gekoppeld aan de voorkeuren:

Voorkeur	Waarde 0	Waarde 50	Waarde 100
Koopprijs (€)	375.000	300.000	100.000
Grootte (m ²)	90	110	125
Afstand tot centrum (km)	20	8	5

In het voorbeeld van de voorkeur 'afstand tot centrum', leidt dit tot een voorkeurscurve zoals te zien is in figuur 1. Door deze curve kunnen alle gebouwen een voorkeursscore krijgen. Stel bijvoorbeeld dat er een alternatief beschikbaar is dat 10 kilometer van het centrum ligt. Dit levert dan een voorkeursscore van 42 op.

Deze curves kunnen van elke variabele gemaakt worden, waardoor elke geschikte woning (welke voldoet aan de beperkingen die opgelegd zijn) drie voorkeursscores krijgt, een voor de koopprijs, een voor de grootte en een voor de afstand tot het centrum. Stel dat er 4 woningen beschikbaar zijn, zou het volgende eruit kunnen komen:

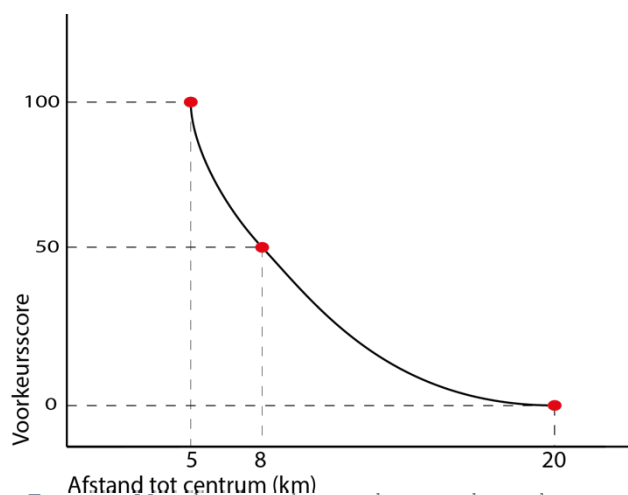


Figure 55: Vertaling van de waarden naar de voorkeursscores

Woning	Koopprijs	Grootte	Afstand centrum	tot
Alternatief_1	76	53	42	
Alternatief_2	48	78	54	
Alternatief_3	64	42	90	
Alternatief_4	57	54	63	

Om te bepalen welke locatie de beste is, moet ook een verdeling worden gemaakt van hoe belangrijk je de verschillende variabelen vindt. Het kan bijvoorbeeld zo zijn dat de koopprijs het meest van belang is, de grootte ondergeschikt, en de afstand tot het centrum hier tussenin. Dit kan vertaald worden in gewichten die aan elke voorkeur gekoppeld worden. Hoe groter de waarde, hoe belangrijker de voorkeursvariabele. In totaal moeten de gewichten bij elkaar 1 worden. In het voorbeeld gaan we uit van de volgende gewichten:

Koopprijs: 0.5

Grootte: 0.2

Afstand tot het centrum: 0.3

Nu kan de totale voorkeursscore berekend worden. Dit wordt gedaan voor elke voorkeursscore te vermenigvuldigen met het gewicht, en dit bij elkaar op te tellen. Hieruit volgende de volgende totaalscores:

Woning	Berekening	Totaalscore
Alternatief_1	$=0.5*76+0.2*53+0.3*42$	61,2
Alternatief_2	$=0.5*48+0.2*78+0.3*54$	55,8
Alternatief_3	$=0.5*64+0.2*42+0.3*90$	67,4
Alternatief_4	$=0.5*57+0.2*54+0.3*63$	58,2

Hieruit blijkt dat alternatief 3 het meest overeenkomt met je voorkeuren. Deze woning zou dus gekozen moeten worden.

Het ontwikkelde model

Het model dat ontwikkeld wordt voor Engie, heeft enkele verdiepingsslagen ten opzichte van dit voorbeeld. Ten eerste zullen er meerdere stakeholders betrokken worden bij het proces, welke onderling ook een gewicht toegekend krijgen. Daarnaast focust het model zich op een portfolio, ofwel een combinatie van verschillende gebouwen. Hierdoor wordt niet naar een locatie gekeken, maar naar meerdere plekken.

Ten slotte wordt in het model ook gekeken naar de toekomstige ontwikkelingen. De karakteristieken van een locatie zijn altijd aan verandering onderhevig. Hierdoor kan het zo zijn dat een locatie die nu goed past bij de voorkeuren, over 5 jaar totaal niet meer bij de voorkeuren past. Deze ontwikkeling wordt ook meegenomen in de beslissingsprocedure.

D. Evaluation interview protocol

After both workshops, the development of the model was discussed with each stakeholder individually. This document shows the protocol that was used for these interviews. For this protocol, use is made of the checklist developed in Chapter 8. The protocol is developed in English, although the interviews are held in Dutch. For the evaluation, the evaluation protocol of de Visser (2016) is used as a basis.

Introduction

This interview will take about thirty minutes. Are you comfortable with me recoding this interview?

This interview is meant to evaluate the LDM-framework and the process we have gone through the last months. I would like to know from you how you have experienced this process and what you think of the framework. For this, I have some questions I would like to ask.

Evaluation questions

Main question	Optional follow-up questions
1. Did you have sufficient possibility in the process to use the model and to adapt input and the model itself if necessary?	<ul style="list-style-type: none"> • If not; did this complicate your involvement in the process? <ul style="list-style-type: none"> ○ Did this influence your decision making process, i.e. did you still want to adjust things to the model? ○ Do you have any suggestions for changes which could have prevented this? • If yes; did the iterative nature of this process help you in becoming involved in the process? <ul style="list-style-type: none"> ○ Did the iterations help you in development of your preferences? ○ Do you have any suggestions for improvement? • Did the modelling process influence your acceptance of the model and its outcomes? • In your experience with the model, do you feel that you trust the system in providing the correct answer?
2. To what extend do you think the model reflects the complexity of the real-life decision-making process?	<ul style="list-style-type: none"> • If not properly reflected; could you identify any cause for this? <ul style="list-style-type: none"> ○ Do you have any suggestions for improvement? • If properly reflected: when was this alignment achieved? <ul style="list-style-type: none"> ○ How do you think this was achieved? ○ Do you therefore consider the process sufficient or do you have any suggestions for improvement? • Does the complexity of the model influence your acceptance of the model? • Are your preferences closely reflected in the model?

	<ul style="list-style-type: none"> ○ How does this influence your trust in the system?
3. What is your perception of the usefulness of the model?	<ul style="list-style-type: none"> ● If low; could you indicate why you think the model is not useful? <ul style="list-style-type: none"> ○ Do you have any suggestions for improvement? ● If high; why do you think the model is useful? <ul style="list-style-type: none"> ○ What do you think the advantages of the model are in practice? ○ Do you have any suggestions for improvement? ● Do you think the model can easily be used in practice? <ul style="list-style-type: none"> ○ Why do you think this is the case? ○ Do you have any suggestions for improvement? ● Does the usefulness of the model influence your acceptance of the model?
4. Is the performance of the model in line with the expectations you had?	<ul style="list-style-type: none"> ● If not; what is the cause of this? <ul style="list-style-type: none"> ○ Is the performance of the model too low, or do you think your expectations were particularly high? ○ Do you have any suggestions for improvement? ● If yes; what is the cause of this? <ul style="list-style-type: none"> ○ Is the performance of the model high, or do you think your expectations were particularly low? ○ Do you have any suggestions for improving the model even further? ● Is the outcome of the model understandable for you, i.e. does the model justify the outcome sufficiently? <ul style="list-style-type: none"> ○ If so, do you consider this useful? ○ If not, what don't you understand in the outcome of the model?
5. Do you see the model as an added value compared to your current decision making process?	<ul style="list-style-type: none"> ● If not; what is lacking in the model compared to the current decision making process? <ul style="list-style-type: none"> ○ If this element is included in the model, would that change your answer? ● If yes; what are the most important factors this model has added value over the current process?
6. Do you think that the addition of a time perspective in the form of scenarios is of added value in the decision-making process?	<ul style="list-style-type: none"> ● If not; what is the cause of this? <ul style="list-style-type: none"> ○ Do you have any suggestions for improvement? ● If yes; what is the reason you think it is an added value? <ul style="list-style-type: none"> ○ Does this influence the trust in the system? ○ Does this influence the acceptance of the system?