Master Thesis

System Dynamics-based Scenario Planning

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Executive Summary

Companies are involved in complex environments driven by uncertainty and rapid development of technology and change. In order to remain competitive in complex environments driven by uncertainty, companies have to make strategic decisions which are robust in multiple futures. Therefore, a wide variety of management processes, frameworks and techniques are available in which technology planning becomes increasingly important. An appropriate management of these tools helps to improve productivity and to sustain in competitive environments.

A popular strategic management tool which helps to cope with strategic direction in changing business environments is scenario planning. Popularized by companies such as Royal Dutch Shell, scenario planning is a widely used tool in order to understand future environmental uncertainty. The great value in scenario planning is the ability to present all complex elements together into a coherent, systematic, comprehensive and plausible manner.

Scenario planning is conducted in environments or ''systems'' which are highly complex. This complexity could refer to combinatorial complexity or dynamic complexity. It has been found, people face difficulties in dealing with complex systems. Therefore, it is important to understand the system on which scenarios are based. The combination of system dynamics and scenario planning could leverage strengths, as system dynamics allows to address complexity in scenario planning. System dynamics is a method which could be used to study the world around us. The central concept of system dynamics includes understanding the basic structure of a system and how objects interact with each other.

To address the issue of complexity in scenario planning, this research aims at: ''creating a new technique to address dynamic complexity in scenario planning by combining scenario planning and system dynamics in order to increase understanding in dynamic complex environments and possible futures of such environments''. To meet this research goal, the report is structured by three main research question. The first question refers to the features of scenario planning and system dynamics, and which features could be combined in order to address dynamic complexity. The second question refers to how these features practically will be combined to create a combined approach. As last, the third question refers to testing the approach to develop complex dynamic scenarios.

To address the research goal, the study starts with a literature review to investigate the definition, features, schools of thought and approaches of scenario planning and system dynamics. Thereafter both theories are compared to uncover similarities, differences, and complementary factors. Based on the literature review, a combined approach of scenario planning and system dynamics is designed. In iterative experimenting with combing both methods while maintaining strengths of both theories, the following phases are proposed: preparation, definition, conceptualization, scenario definition, formulation, testing, scenario development and validation and evaluation & strategic decision making.

After the approach had been designed, a short case study was conducted to illustrate and test the technique in order to assess the technique in an iterative way, and draw conclusions about the usability. The case study is conducted by using the oil and gas industry as subject. Within the case, dynamic scenarios are created based on a system dynamics model of the oil and gas industry. Besides following the approach, the case study also shows the possibility of creating multiple scenarios. This is done by creating twenty-two scenario themes containing two variables and creating eighty-eight scenarios based on scenario themes. The scenarios show the behaviour of variables when two variables of the themes behave in a certain way.

The case study showed it was possible to follow the structured approach and create scenarios while considering dynamic complexity. The system dynamics model was created by using an iterative approach in which each iterations led to a better model. It is important to verify the linkages in order to create a credible model. When wrong linkages are used, or when linkages change over time in the real world this will have influence on the further process of creating scenarios and will lead to a bias in the understanding of participants. When the model is created, it is possible to create consistent stories as the relationships are pre-specified. This is also confirmed by constructing the eighty-eight scenarios based on the scenario themes. However, as this case is based on a qualitative causal loop model, room exists for intuition. Furthermore, it is expected a quantitative model could better map how systems behave and show how the structure of the system leads to complex dynamic behaviour. The creation of a quantitative model demands time and expertise which increases the complexity of the approach. Although no quantitative model is created, the qualitative case made it possible to construct a system dynamics model and create scenarios while considering complexity and uncertainty. The proposed approach does allow for flexibility and eventual implementation of quantitative modelling. It is recommended to investigate the implementation of quantitative models in future studies.

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1 Introduction & Research Design

Companies are facing turbulent environments driven by high uncertainty and rapid development of technology and change. Managers need guidance on how to cope with turbulent environments in order to improve corporate performance, mitigate risk and uncertainty. These turbulent environments could be defined as: ''having high levels of inter-period change that creates uncertainty and unpredictability, dynamic and volatile conditions with sharp discontinuities in demand and growth rates, temporary competitive advantages that continually are created or eroded, and low barriers to entry/exit that continuously change the competitive structure of the industry'' (Calantone, Garcia, & Dröge, 2003). For a business, the external environment is increasingly characterized as dynamic, e.g. in terms of legal, technological, economic, supplies, customer, competitive, financial and social environments (Davis, Morris, & Allen, 1991). In order to cope with turbulent environments, a wide variety of management processes, frameworks, and techniques are used in which the role of technology planning becomes increasingly important. Managing these tools helps to improve the productivity and to sustain in competitive environments (Jin, Jeong, & Yoon, 2015; J. H. Lee, Kim, & Phaal, 2012; Phaal & Muller, 2009).

1.1 Scenario Planning

A management technique which helps executives to cope with strategic direction in uncertain business environments is scenario planning (Oliver & Parrett, 2017). Scenario planning is a widely used strategic management tool in order to understand future environmental uncertainty (Bowman, MacKay, Masrani, & McKiernan, 2013). Scenario planning is an old practice as records show people were early interested in desired future states of society. The first scenarios, therefore, were more based on the 'desired society'. However, as strategic planning tool, scenario planning has roots in the military and modern day tools emerged in the post-war period. Most scenario planning methods which are currently used, have origins in the Rand Corporation. Herman Kahn is considered as founding father of popular scenario planning methods. Meanwhile in France, Gaston Berger was working on a long-term scenario planning approach which was further developed by Godet (Bradfield, Wright, Burt, Cairns, & Van Der Heijden, 2005; Schnaars, 1987). Both developments resulted in three school of thoughts: Intuitive Logics, Probabilistic Trend Modifications, and La Prospective. Based on Intuitive Logics, a well-known user of scenario planning throughout the years is Royal Dutch Shell. Pierre Wack started using intuitive scenario planning techniques with his team in Shell. Throughout the years, Shell extensively used scenario planning and it has been considered Shell is better in forecasting than other oil companies (Coates, 2000).

Since the 1970's scenario planning gained prominence as a strategic tool and it recently took a front seat in developing roadmaps (H. Lee & Geum, 2017; Miller & Waller, 2003). Scenario planning has main advantages such as thinking in a non-numerical ways, thinking in systems, being a flexible and adaptive tool, being externally focussed and fostering coordination and communication (Miller & Waller, 2003). It has been stressed, the great value of scenario planning is being able to present all complex elements together into a coherent, systematic, comprehensive and plausible manner (Coates, 2000). Within the scenario planning literature, no single approach is dominant and the review of Amer, Daim, and Jetter (2013) reveals several scenario planning methodologies exist.

1.2 Problem Definition

Companies are involved in complex systems driven by uncertainty and rapid development of technology and change. Therefore, competitive advantages must be sustained in order to survive, and a wide variety of management processes, frameworks and techniques are used in which technology planning becomes increasingly important. The use of scenario planning is considered as an important issue in today's business in order to deal with dynamic environments and uncertainty (H. Lee & Geum, 2017). However, people face difficulties in dealing with complex systems. While the world is complex and changing, decisions are based on mental models which risks being static and narrow. Studies found subjects have poor understandings of dynamic and complex systems. Past methods failed to recognize the increase in complexity and change, which led to methods causing problems and undesired side-effects (J. D. Sterman, 2000). This is problematic for scenario planning, as people have to base scenarios on complex systems . Therefore, complex systems must be analysed while developing scenarios.

1.2.1 System Dynamics to Cope with Complex Systems

Scenarios create several possible stories of the future and consist of several drivers which could be causally related towards each other. Creating a coherent and systematic story of interacting elements in dynamic complex environments requires an understanding of the system in which companies are operating. The implementation of system dynamics allows making consistent stories which consist of interrelated factors. A storyline based on system dynamics creates an understanding of complex systems in which companies are operating and could assess the outcome when one or more factors change. Besides scenario creation, system dynamics allows testing assumptions and assessing impacts of changes in the system: identified policies/ strategies could be judged in multiple scenarios. This creates a better understanding of the complex system in which companies are operating and the fit between chosen strategic direction and the uncertain future. By better understanding the complex system, it is expected companies are better able to respond to turbulent markets. System dynamics is created in the 1950's by professor Jay Forrester at the Massachusetts Institute of Technology (MIT). As he argues, everyone speaks of systems but only a few are aware of the persuasiveness of systems, to which extent we are involved in systems, and how systems are influential in creating difficulties in our environment (Forrester, 1993). System dynamics could be seen as a method for studying the world around in which system dynamicists look at systems as a whole. The central concept in system dynamics is understanding the basic structure of a system and how the objects in the system interact with each other. Systems could refer to anything such as economic, financial, engineering or social systems (Forrester, 1993). The interactions of the objects in the systems go through feedback loops, in which a change in one variable causes a change in another variable. Furthermore, system dynamics use computer models as advantage for dealing with greater complexity and carrying out multiple calculations at the same time. System dynamics is widely used for problems focussed on understanding a wide variety of systems.

1.3 Research in Strategic Management

This research elaborates on a broader research at the University of Twente in the field of Strategic Management. The overarching research aims at improving strategic management tools regarding aligning internal company strategies with long-term developments in the external market by providing robust approaches while maintaining communicative and directive strengths. As part of this research a published paper of Siebelink, Halman, and Hofman (2016) aims at providing insight in the topic of dealing with uncertainty of business roadmaps and provide an decent approach which enables companies to benefit from guiding strategic innovation activities while being successful under a wide range of possible future environments. The output of the study was a developed business roadmap able to respond to a range of future environments while retaining communicative strengths.

1.4 Research Goal

The utility of this report could be found in responding to the overarching research of improving strategic management tools while keeping communicative strengths. Scenario planning is a popular tool to deal with future uncertainties but is based on factors interacting with each other in a system. Within this system complexity could occur and people have difficulties dealing with complex systems. Besides dealing with uncertainty, this research focuses on dealing with complexity in scenario planning. Therefore the research goal of this research is stated as:

" Create a new technique to address dynamic complexity in scenario planning by combining scenario planning and system dynamics in order to increase understanding in dynamic complex environments and possible futures of such environments.''

1.5 Research Questions

To meet the requirements of the research goal, this research first focuses on the features of scenario planning and system dynamics and which features can be used to combine both methods. Therefore, the first central research question is addressed as:

1. ***Which features of system dynamics and scenario planning can be combined to develop a system dynamics-based scenario planning approach, in order to address dynamic complexity in scenario planning?***

In this research question ''features'' relate to a typical quality or an important part of something. This thus relates to scenario planning theory and system dynamics theory. Furthermore, dynamic complexity relates to behavior of complex systems that emerges from the interactions of variables over time. To investigate the features of both theories, both theories will be mapped. Therefore, the following sub-questions will be considered:

1.1 What are the definitions of scenario planning and system dynamics?
1.2 What are the features of scenario planning and system dynamics?
1.3 What schools of thoughts and approaches exist in the literature of scenario planning and system dynamics?
1.4 What are the similarities between approaches of system dynamics theory and scenario planning theory?
1.5 What are the differences between approaches of system dynamics and scenario planning?

When the theories are mapped in terms of definitions, features, schools of thought/ approaches, similarities and differences, there will be investigated in which way a combined method could be designed to address dynamic complexity in scenario planning. Therefore the second central research question will be addressed:

2. ***In which way could a system dynamics-based scenario planning approach be designed on the basis of the concepts in order to create a credible approach to address dynamic complexity in scenario planning?***

In this research question, a ''credible approach'' relates to an approach which maps the process of system dynamics-based scenario planning in a structured and understandable way. In order to create an approach, the features of both theories will be investigated in terms of complementary features and bottlenecks. The following sub-questions are considered:

2.1 What complementary factors exist between the method of scenario planning and system dynamics?

As last, the approach will be illustrated by providing a short case study. The case study will test the approach and eventually provide some concluding remarks regarding the system dynamics-based scenario planning approach. Therefore, the last central research considered is:

3. To what extent does the system dynamics-based scenario planning approach provide a credible approach to develop dynamic complex scenarios?

1.6 Research Model

This research aims at creating a new technique based on scenario planning and system dynamics to address dynamic complexity in scenario planning. The research model guiding this research is provided in Figure 1. In order to combine scenario planning and system dynamics theory, both theories were studied in terms of definitions, features, schools of thought, and approaches. This was done by conducting a literature review on both theories. When both theories were studied and an overview was provided, theories were compared in order to uncover similarities, differences, complementing factors and eventual constraints. Based on these insights, the theory development phase took place. By the acquired insights, the goal was to increase the strengths of a combined theory by adding complementary strengths. Theory development was done in an iterative way. It was tested while conducting a short case study concerning the oil & gas industry. Iterative theory development and applying the technique to a case study led to a proposed ''System Dynamics Based-Scenario Planning Technique''.

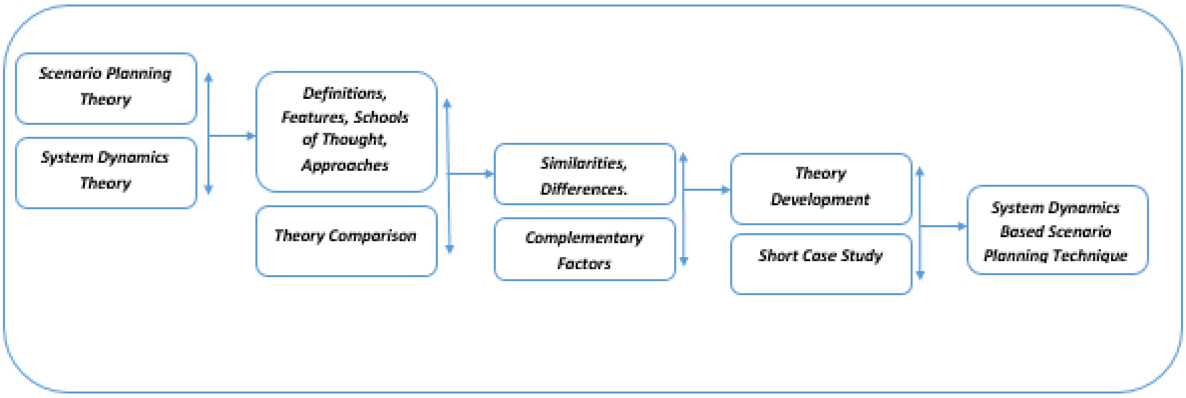


Figure 1: Research Model

1.7 Research Methods

1.7.1 Literature Review

A substantial part is dedicated to reviewing the literature. So, In the first phase, a literature review is conducted in order to identify relevant literature which will be used to identify what is present in the field and in order to provide a foundation for this research. Literature in the field of scenario planning and system dynamics theory provides research guidance in this research. The outcomes of the literature review act as input for theory creation regarding system dynamics based scenario planning.

While conducting the literature review, the first three steps in the five-stage grounded-theory method for reviewing the literature in an area, proposed by Wolfswinkel, Furtmueller, and Wilderom (2013) were considered. The first three steps consist of define, search and select (Wolfswinkel et al., 2013).

The defining stage consists of four steps. The first step consists of defining criteria for inclusion and/ or exclusion of an article in the data set. In this research, the author is interested in developing a new approach by combining system dynamics in scenario planning. Therefore, the inclusion of articles must contain a theory about these theories in strategic planning. Other strategic methods will not be addressed in this research and will be excluded. In the second step of the defining process, appropriate 'fields' of research should be identified. In this research, the strategic management field will be approached as these theories are part of strategic management, in particular, strategic management planning and decision making methods. In step 3 of the defining process, the appropriate sources must be selected. In this study, databases will be used as Google Scholar, Web of Science and Scopus. Step four consists of a formulation of variously possible search terms. Regarding scenario planning, search terms as scenario(s), scenario planning will be used, and in case of system dynamics, system dynamics, system thinking, system learning will be used.

The search stage includes the actual search through identified sources (Wolfswinkel et al., 2013). In this stage, the databases are used to find relevant articles. Based on the requirement, articles are selected.

In the third stage, samples of texts were selected. The theory of Wolfswinkel et al. (2013) provides a clear framework for this stage which consists of filtering out doubles, refine sample based on title and abstract, refine sample based on full text, forward and backward citations, new articles by iteration and finally the final sample which is used in this report.

1.7.2 Case Study

The literature review is used as the foundation of this research and act as input for theory development. To develop the technique, theory of scenario planning and system dynamics were confronted with each other in terms of similarities, differences, and complementary factors. After theory development, a short case study was conducted. This case study aims at testing and illustrating the technique in order to assess the technique in an iterative way and draw conclusions about the usability.

The case study follows the steps created in the theory development phase which could be found in the Theory Development chapter. Furthermore the case study will be connected to the overarching research as explained in chapter 1.4. During the research the author attended an experiment conducted concerning the oil and gas industry. Within this research, drivers regarding the oil and gas industry are identified and used to develop scenarios. As the author is not exclusively involved in the oil and gas industry, academic articles were addressed to further identify drivers and structures to develop the system in order to increase credibility of the system.

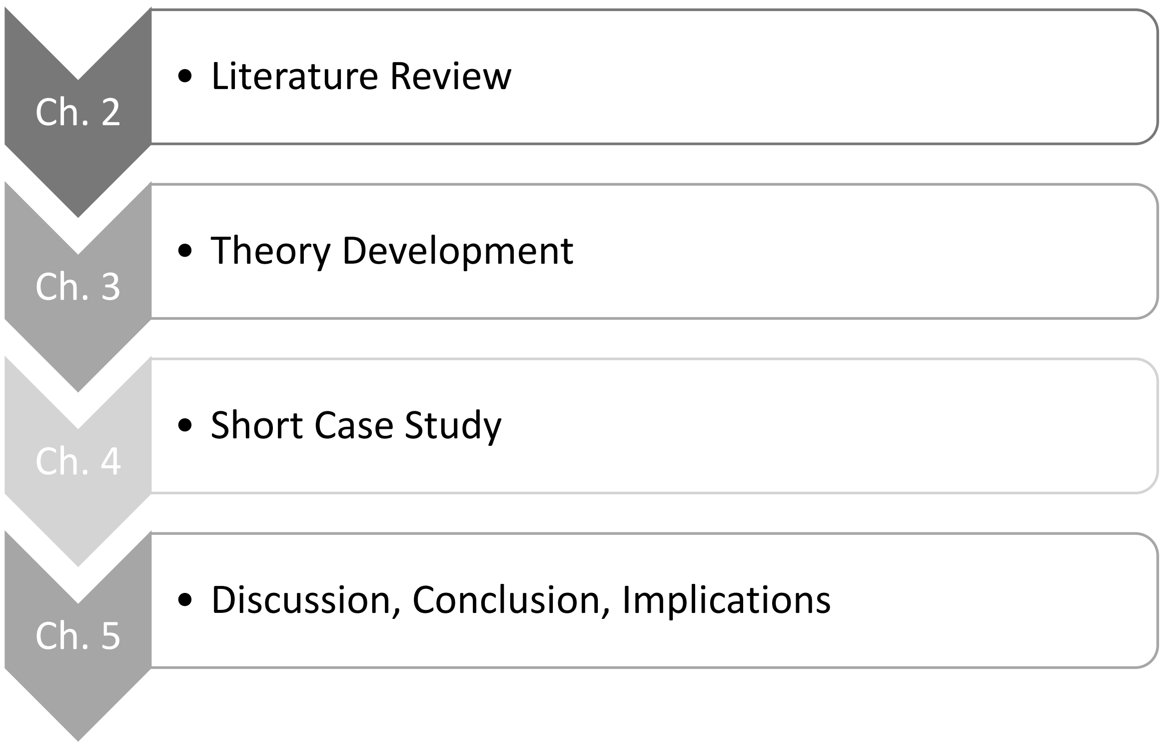
System dynamics enables the possibility to develop causal loop models and computer simulations. Therefore, software is needed in order to create models including dynamic complex elements. The software used in this study is AnyLogic. Among other methods, Anylogic support System Dynamics modelling processes. Furthermore, the publisher provides a guide to learn about making system dynamic models. The author will use Grigoryev (2012) to learn about the practical modelling aspect of system dynamics. This book provides a course in simulation modelling while using Anylogic as software.

1.8 Overview

The structure of this report is in line with the research model to develop theory and provide a case study. This provides a structured approach to develop theory based on academic background.

Chapter two starts with the literature review of scenario planning and system dynamics. Theory will be researched in terms of definitions, features, schools of thought and approaches. Thereafter, theory will be discussed in terms of similarities, differences, and complementing factors. Insights will provide input for theory development. In order to test and adjust theory, chapter four provides a short case study regarding the oil and gas industry. As last, chapter five provides a discussion, conclusions and implications.

It should be noticed while the structure seems consecutively, theory development is done iteratively. The thesis starts with literature review and comparison to create an overview of both theories and is used as input for theory development. However, during theory construction new insights could appear. Unexpected complementary elements and/ or bottlenecks could arise. Therefore, iteration allows flexibility in order to develop theory and explore insights. The structure of this report is stated below.



2 Literature Review

To develop a new approach which aims at addressing complex systems in scenario planning, the relevant theoretical background will be discussed per theory in terms of definitions, characteristics, and schools of thought/ approaches. First theory regarding scenario planning will be discussed, thereafter system dynamics will be addressed. After the literature review, scenario planning and system dynamics are compared in terms of similarities and differences, and complementary factors are identified. The literature review and the analysis in terms of similarities, differences and complementary factors, provides an overview of possible inputs for developing the new approach.

2.1 Scenario Planning

In dynamic business environments in which uncertainty and rapid changes occur, value propositions, strategies and business models of companies are exposed to the threat posed by competitors and new competitive entrants. Such a competitive environment makes it more difficult for business executives to develop and sustain corporate strategies. A corporate-level strategy is centered on long-term direction and competitive market positioning. Firms need to consider how their corporate strategy remains relevant in turbulent and uncertain conditions and in which way the company can develop a long-term certainty in their strategic approach. The essence of the corporate strategy is about choosing the strategic direction of an organization and strategic fit with the business environment. Companies must properly make use of strategic planning tools and techniques which significant could contribute to the competitiveness and productivity. Making strategic decisions and implementing associated change programs are key managerial competencies in order to develop and keep a sustainable advantage. A wide variety of management processes, frameworks and techniques are used to support strategic management. A management technique which helps executives to cope with strategic direction in uncertain business environments is scenario planning (Jin et al., 2015; J. H. Lee et al., 2012; Oliver & Parrett, 2017; Phaal & Muller, 2009).

2.1.1 What is Scenario Planning?

Scenario planning has become a widely used strategic management tool in order to understand future environmental uncertainty (Bowman et al., 2013). H. Lee and Geum (2017) describes the use of scenarios as one of the most important issues in today's business, as the dynamic environment makes organizations more competitive. Therefore, companies need to respond to dynamic environments by creating a strategy which is sustainable in several futures.

Within the literature, multiple definitions of scenario planning exist. The terms range from movie scripts and loose projections to statistical combinations of uncertainty (Schoemaker, 1993). Bishop, Hines, and Collins (2007) found in their review a variety of definitions of scenarios in throughout literature. The latter authors argue its suffice to say that a scenario is ''a product that describes some possible future state and/ or that tells the story about how such a state might come out'' (Bishop et al., 2007). In this definition, we can find a distinction in which the former refers to an end-state while the latter refers to a chain of events. Furthermore, Schoemaker (1993) argues scenario planning is an important tool to assess fundamental uncertainties and expand people's thinking. This author defines scenarios broadly as ''focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion''. This description clarifies that scenarios consist of coherent stories. Within these stories, each scenario tells about the interaction of various elements under certain conditions in which consistency among the stories is important. Scenario planning is applicable to most situations in which decision-makers want to create an image of the future and the great value considered is being able to present all complex elements together into a coherent, systematic, comprehensive and plausible manner (Coates, 2000; Schoemaker, 1995). The scenario planning approach, which considers and manages business uncertainty, enables executives to surpass fixed future forecasts and create a more robust competitive strategy, so scenario planning is important in examining fundamental uncertainties and expand people thinking (Oliver & Parrett, 2017; Schoemaker, 1993). It is argued scenarios are the archetypical of future studies as it addresses the central principles of this discipline. Future studies consider it is important to think deeply and creatively about the future in order to avoid risk of being surprised and unprepared, and simultaneously the future is uncertain so executives must consider strategies for multiple futures. Scenarios contain stories of multiple futures varying from the expected to extreme futures (Bishop et al., 2007). As these authors describe: ''A good scenario grabs us by the collar and says, 'Take a good look at this future. This could be your Future. Are you going to be ready?'''. Coates (2000) states that scenario planning used in business broadly could be divided into two categories. On the one hand, scenarios could be used to tell about a future state or condition in which the situation is embedded. These scenarios are referred to as descriptive scenarios and are used to motivate users to develop practical choices, policies, and alternative actions which could deal with the consequences of the scenario. The second category of scenarios assume policy has been established and will be integrated with its consequences into a story about some future state. This category is refered to as normative scenarios and rather than stimulating policy choice, it displays consequences of a set of choices. So, the first category aims to stimulate thinking about policies and the second aims to explore the consequences of policy decisions (Coates, 2000).

Scenario planning has become popular as the world is more complex and the tools enable executives to deal with uncertain business environments, e.g. in terms of customers, suppliers, regulators, cultural social, governmental, and economic factors which differs from their comfort zone (Coates, 2000). Other techniques also exist, but it is argued other techniques are more limited in scope and organizational friendliness (Schoemaker, 1993). Furthermore, scenario planning distinguishes itself from other techniques as it addresses uncertainty rather than risks, it provides a qualitative and contextual description rather than numerical, and develops multiple possible futures which could occur rather than one fixed future (Schnaars, 1987; Tapinos, 2012). As Schnaars (1987) describe, the combination of offering multiple possible futures in the form of narratives is considered more reasonable than an attempt to predict what will happen in the future. They further argue writing the scenarios is a highly qualitative process and is derived from guts rather than a computer, although quantitative models could be established.

2.1.2 Origins of Scenario Planning: USA and France

To address the approaches and schools of thought in the literature, a discussion will be provided on the history, school of thoughts and approaches. It has been considered that no single approach of scenario planning exists. Multiple terms exist which are attached to scenario planning such as planning, thinking, forecasting, learning, and analysis. Furthermore, it has been argued there is principally no area in which a wide-spread consensus exists (Bradfield et al., 2005). The literature consists of multiple definitions, characteristics, and methods regarding scenarios. However, the scenario planning literature could be divided into several camps of descriptions, schools of thoughts and approaches. On an abstract level scenarios could be descriptive or normative, in which the first tells about a future state and the latter aims at considering consequences of a set of choices. Furthermore, three main schools have been developed throughout the history: the Intuitive Logics school, probabilistic Modified Trends school, and the French school called La Prospective. On a more practical level, multiple approaches exist of which the approach of Schoemaker and Schwartz are considered as often cited and popular methods within the literature (Amer et al., 2013).

The scenario planning method has been considered as very old practice. Records show people were early interested in scenarios as historical philosophers were interested in desired future states of society. As a strategic planning tool, scenario planning has its roots in the military in the 1950's, and modern day techniques emerged in the post-war period. In the 1960's two geographical centres emerged in the USA centre and the French centre. The USA centre concerns the Intuitive Logic school and the probabilistic Modified Trends, and the French centre concerns the La Prospective school (Bradfield et al., 2005; Schnaars, 1987).

Most scenario planning methods which are currently used have their origins in the Rand Corporation in which Herman Kahn and Olaf Helmer were involved in defense-related projects at Rand. After World War 2, the US defense department needed to decide which projects must be funded for new weapons systems which were difficult because of a complex and uncertain environment faced by decision makers. Therefore, the decision makers needed a tool which captures consensus of opinions of a wide range of experts, and the urgency of developing an approach which investigates future environments which permits policy alternatives and its consequences. The need for developing opinions and achieving consensus led to the development of the Delphi method and the need for an approach to investigate futures and policies led to systems analysis from which scenario planning emerged. Within the Rand Corporation, Kahn was a pioneer of scenario planning while Helmer developed the Delphi technique. In that time, Kahn developed scenarios for the Air Defence Systems. Kahn criticized the military planning relied on wishful thinking rather than reasonable expectations. He mentioned that one should ''think about the unthinkable''. His work had the objective of searching for serious alternatives and this impacted the way the Pentagon was thinking throughout the 1950's and 1960's. His approach was based on identifying basic trends underlying a future problem, create projections to construct a surprise-free scenario and modify projections to create alternative futures. He favored a qualitative method as he criticizes quantitative methods as focusing only on aspects which are easy to quantify and so, only partly address the problem. In 1960 he left the Rand Corporation and started to apply scenario planning methodology for public issues. Although scenarios were used as a tool in public planning, the scenario planning methodology was adopted in businesses. Meanwhile when Kahn was working on his approach, in France Gaston Berger developed a long-term scenario planning approach which was called La Prospective. This method was developed because former forecasting methods failed. Berger focussed on the long-term political and social future in France in which he assumes the future is not a 'predetermined temporal continuity' but something which must be created and modeled. The La Prospective objective was formulating scenarios for developing desired images or normative scenarios. Berger died in 1960, but the method was during the 1960's widely used in public issues as the environment, regional planning and education (Bradfield et al., 2005; Schnaars, 1987). The schools of thoughts, Intuitive Logics, Probabilistic Modified Trends and La Prospective will be discussed in further detail in the following parts.

Intuitive Logic School

The intuitive Logics school received most attention in the literature of scenario planning. As described in the story about the origins above, these approaches originate from Kahn's approach at the Rand Corporation. After he left and applied the method for the public domain, it did not take long before scenario planning was used within business planning. Shell companies in 1969 received the task to look in the future and create stories of the year 1985. In that time, Pierre Wack was a planner of Shell located in France. He was familiar with the approach which was proposed by Kahn and started experimenting. The first attempts were not considered successful, as the technique did not provide new insights. However, at Shell, they realized that a promising tool was discovered. Throughout the years Shell extensively used scenario planning and it has been considered Shell is better in forecasting than other oil companies. Therefore, there is also referred to this technique as 'Shell approach'. Furthermore, Intuitive logics is still leading as school of thoughts for scenario planning methods. Intuitive logic assumes that business decisions are based on a complex set of relationships among the economic, political, technological, social, resource, and environmental factors. This can be used to develop flexible and internally consistent scenarios and relies on commitment, credibility, communication skills and knowledge of team members. Intuitive Logic methods could serve multiple purposes, ranging from one-time sense-making or strategy development activity to an ongoing learning activity. Referring to the distinction made between descriptive or normative, there could be said Intuitive Logic methods could serve both scenario planning purposes. Originally methods are focussed on the long term, but this could vary from 3 till 20 or more years and the team involved in the process normally contains an internal team of the concerning organization. The starting point of the scenario planning process is generally a management decision, issue or concern. As Kahn favored, this method is mostly qualitative in nature and does not contain probabilities. Important for the scenarios is that stories are coherent, internal consistent, novel and supported by analysis and logics (Amer et al., 2013; Bradfield et al., 2005; Coates, 2000).

However, besides the various approaches in intuitive logics, Wright, Bradfield, and Cairns (2013) identified various stages of the basic scenario planning process considering intuitive logics. Their intuitive logics scenario planning method is derived from number of writers and organizations over many decades, and is focused on developing multiple scenarios. This intuitive logics method considers the relation between critical uncertainties, important predetermined trends and behaviour of actors. The intuitive logics embraces and integrates considering PESTEL elements (political, economic, social, technological, ecological and legal) which shape the future (Wright et al., 2013). The main stages of the basic intuitive logics scenario process are displayed in Table 1.

The following is a list of the main stages of the basic intuitive logics scenario process:

Stage 1: *Setting the agenda* — defining the issue of concern and process, and setting the scenario timescale
Stage 2: *Determining the driving forces* — working, first, individually, and then as a group
Stage 3: *Clustering the driving forces* — group discussion to develop, test and name the clusters
Stage 4: *Defining the cluster outcomes* — defining two extreme, but yet highly plausible – and hence, possible – outcomes for each of the clusters over the scenario timescale
Stage 5: *Impact/uncertainty matrix* — determining the key scenario factors, A and B — i.e., those which have both the most impact on the issue of concern and also the highest degree of uncertainty as to their resolution as outcomes.
Stage 6: *Framing the scenarios* — defining the extreme outcomes of the key factors, A1/A2 and B1/B2
Stage 7: *Scoping the scenarios* — building the set of broad descriptors for four scenarios
Stage 8: *Developing the scenarios* — working in sub-groups to develop scenario storylines, including key events, their chronological structure, and the "who and why" of what happens.

Table 1: Intuitive Logics Scenario Planning Process

Probabilistic Modified Trends school

The school of probabilistic modified trends emerged from work of Olaf Helmer and Ted Gordon at the Rand Corporation. The Probabilistic Modified Trends school consists of two different matrix based technologies: trend impact analysis (TIA) and cross-impact analysis (CIA). These methods are considered as probabilistic modification of extrapolated trends (Amer et al., 2013).

Trend impact analysis is developed in the early 70's. The concept of TIA is modifying simple extrapolations and involves four steps. First, historical data related to the issue is examined and collected, then an algorithm selects specified curve-fitting historical data and extrapolates this to generate so-called surprise-free future trends. Thereafter a list is developed of unprecedented future events which could cause deviations from extrapolated trends. As for last, experts judge the probability of occurrences of these unprecedented events as a function of time and expected impact, so adjusted extrapolations are created. Although TIA is used frequently, there are relatively few references in literature (Bradfield et al., 2005).

Among other sources, cross-impact analysis (CIA) originated from work on Delphi technique. The method was developed by Helmer and Gordon in 1966 at Rand and used for Kaiser-Aluminium. CIA takes causality into consideration as it is unrealistic to forecast an event in isolation without considering other key drivers. A general assumption of the CIA is that no development occurs in isolation. The technique captures cross-impacts from experts' judgemental estimates and relies on experts estimates on the likelihood of occurrence of certain events. This data is used to run mathematical programming or computer simulations which results in a most likely scenario or scenarios ranked by probability. Even as in TIA, CIA evaluates changes in the probability of occurrence of events which could cause deviations, and underlying assumptions are simple. However, CIA adds complexity by including an extra layer which determines the conditional or proportional probabilities of pairs of future events given that events did or did not occur. So, underlying to CIA is that many events are interdepend (Amer et al., 2013; Bradfield et al., 2005; Schnaars, 1987).

La Prospective

La Prospective has its origin in the work of Gaston Berger, who presented scenario planning approach for public issues in the long term. Godet considers his approach as an integrated approach by the use of mixed methods. La prospective considers that the future is not part of a predetermined temporal continuity, and it can be deliberately created and modeled. In general, La Prospective methods aim to develop more effective policies and strategic decisions. To a large extent, this approach combines intuitive logic with probabilistic logic but exists for almost as long as intuitive logic and probabilistic modified trends. La Prospective is considered more elaborate, complex and mechanistic than intuitive logics as its relying heavily on computer and mathematical models which have roots in the probabilistic modified trends school. Among other things, La Prospective use morphological analysis for scenario development, Micmac to identify important variables and Mactor for actors' analysis strategies and Smic-Prob-Expert in order to determine the probability of scenarios. Furthermore, La Prospective is mostly used in the public sector (Amer et al., 2013; Bradfield et al., 2005). A comparison of the Intuitive, Probabilistic Modified Trends and La Prospective schools is provided in Appendix A: Scenario Planning Techniques & Features.

2.1.3 Approaches

As earlier discussed, it has been considered a lack of consensus exists within areas of scenario planning. No single approach of scenario planning exists, but it several camps of opinions can be found in literature. In the former paragraphs, the literature of scenario planning is introduced by providing the origins of scenario planning and elaborating on the developed schools of thought. Among other authors, Bradfield et al. (2005) reviewed the origins and schools of scenario planning. It has been considered authors of such reviews did an admirable and useful job in providing different ways to think about scenarios. However, these authors identified schools of thoughts within the scenario planning literature to high-level attributes, and actual techniques in use were not considered (Bishop et al., 2007). The review of Bishop et al. (2007) aims at providing a deeper level by outlining existing methods and techniques within the literature that fit within the considered higher level categories. Based on their review, these authors identified eight general categories of scenario techniques including two to three variations per type. The eight categories of scenario building consist of judgemental, baseline/ expected, elaboration of fixed scenarios, event sequences, backcasting, dimensions of uncertainty, cross-impact analysis, and modeling. Based on the review of Bishop et al. (2007) will be discussed below.

Judgemental techniques are easiest to describe and are considered the most common practice of scenario planning. Judgemental techniques rely on the judgement of an individual or group who describe the future. These techniques could use information, analogy, and reasoning to support assertions, but do not include other methods. Variants of judgemental techniques consist of genius forecasting, visualization, role-playing, Coates and Jarratt.

Baseline/ expected methods produce only one scenario which is considered as expected or baseline future. This approach is considered as the foundation of all alternative scenarios. It is stated that the expected future is a plausible future state. Even though unexpected events change the future, it does not change the future in all ways according baseline/ expected methods. The technique behind this approach is measuring existing trends and extrapolate effects into the future, which could be done by judgment or mathematical techniques. Besides judgment, this approach is considered as the most common approach of scenario planning. Trend extrapolation, Manoa, System Scenarios and TIA are approaches of baseline/ expected future.

The elaboration of *fixed scenarios* starts with considering multiple scenarios. In general, scenarios are developed from scratch and starts with pre-specified scenarios. Thereafter, there will be elaborated on scenario logics and implications of alternative futures are discussed. Methods based on the elaboration of fixed scenarios are incasting and SRI.

Event sequences assume that future series of events could be seen just as past sequences of events, except occurrence of events are not known. Therefore probabilities will be assigned to events. If an event happens the future will be steered in that direction. Approaches within the event sequences are probability trees, sociovision, and divergence mapping.

The fifth collection of approaches, *backcasting* consists of horizon mission methodology, impact of future technologies and future mapping. These approaches assume most people see the future as an extension of the present, which is a disadvantage as ''baggage'' of the past and present is carried into the future. This limits creativity and assumes safe future. Therefore, the first step in this approach is to explore a future state at a certain time which can be plausible or imaginable. Thereafter it is case to connect the dots from present to the future. So, instead of forecasting, this approach makes use of backcasting.

The *dimensions of uncertainty* assume the reason to use scenario is uncertainty in predictive forecasting. Information is incomplete, theories of human behavior are not as good as physical phenomena theories and an unpredictable state of chaos and emergent states exists. Scenario development in the dimension of uncertainty is created by identifying unpredictable states and used as the basis for alternative futures. Approaches are morphological analysis, field anomaly relaxation, GBN, MORPHOL and OS/SE.

The seventh stream, *cross-impact analysis* consists of SMIC PROF-Expert or IFS techniques. This approach is discussed before as variant of the Probabilistic Modified Trend school of thought. The objective is not only to identify characteristics of conditions, events, and scenarios but also to calculate relative probabilities of occurrence. In this approach, it is also considered that probabilities of an event is also based on occurrences of other events. These conditions/ events are inserted in the rows and columns of the matrix and the conditional probability is provided given the occurrence of other conditions/ events. This matrix could be run in order to create a distribution of probabilities.

The last approaches, *modeling*, consists of trend impact analysis, sensitivity analysis and dynamic scenarios. These system models are mostly used for baseline forecasting, which means predicting the expected future. The approach makes use of equations which relate effects of variables on others to model the expected values of target variables. It is stated this method could also produce scenarios by changing inputs or structure of models.

Besides identifying and describing the approaches, Bishop et al. (2007) compare the techniques. First, the starting points, processes, and products of scenario techniques are discussed. There could be concluded the starting point ranges from open to beginning with draft scenario logic. The first approaches start scanning the environment to develop materials which could be crafted in logics of scenarios. The latter extreme starts with scenario logics and elaborating or customize this to explore implications. Furthermore, the greatest distinctions of the approaches could be found in the process of scenario development and the end-product varies per technique. Most methods develop one or more scenarios by using logic or probabilities. The starting points, processes, and products per approach are summarized in Appendix A: Scenario Planning Techniques & Features, derived from Bishop et al. (2007).

Besides Bishop et al. (2007), Schnaars (1987) also identified different characteristics throughout scenario planning methods. Schnaars (1987) first describe characteristics of scenario planning approaches throughout the literature ranging from scope, content, time horizon, number. Scenario planning approaches within literature know a wide variety of scopes. On the one extreme, the worldview exists, which is popularized by Herman Kahn. A world-view scenario approach simply encompasses the goal of identifying a set of plausible futures and consequences. On the other hand, more focused scenarios exist. Executives, involved in corporate planning, are more focused on aspects which affect their business environment. The latter is considered more feasible while there is a risk of a scope which is too narrow as accuracy could be influenced by events which are not considered. A trade-off is faced regarding the number of variables included as too many variables lead to an unwieldy analysis and including too few variables could lead to a risk of a narrow focus. Regarding the content of scenarios, there is a confusion within the literature regarding which kinds of information should be included in scenarios. On the one hand, the scenario planning approach could identify multiple possible futures which the firm could face. In this case, the strategic direction could be based on these scenarios. On the other hand, not only (business) environmental forecasts could be created, but several plans could be assessed within certain scenarios. So in the latter case, the performance of several plans must also be estimated.
Scenario planning is most often focussed on the long-term perspective, however, no empirical evidence exists which considers a short-term focus as inappropriate. Several authors address that long-term and short-term are not absolute terms. In practice, within most approaches, the time horizon of scenarios is generally focused on the long-term. The number of scenarios addressed generally consists of three or four scenarios.

Techniques vary in their basis, perspective, number of participants and estimated difficulty. The base consists of judgement and quantification. As earlier mentioned, judgement is the most-used and is the basis of scenario planning methods. Furthermore, the perspective is considered as ‘’timeline’’ which could be chronological or backward, as with backcasting. Most methods start with the present and work towards the future as it could be easier and so more popular. Regarding groups, the genius forecast is the only technique which is not used in a group as it relies on the ‘genius’. Also, in most cases, computers are not used, besides a couple of quantitative methods. This provides eventual opportunities in developing scenarios. As last, a scale of 1 to 4 is used to mark the difficulty in carrying out the method (Bishop et al., 2007). As last, these authors also provided a table in which the advantages and disadvantages of methods are described. These will also be provided in Appendix A: Scenario Planning Techniques & Features.

2.1.4 Summary

In this part the definition, features, schools of thought and approaches are researched for scenario planning. A brief overview of the outcomes is presented below. In general, it can be concluded scenario planning is a method to develop scenarios that describes some possible future state and/ or that tells the story about how such a state might come out. Scenario planning focusses on uncertainty rather than risk. Complex elements are presented together into a coherent, systematic, comprehensive and plausible manner. Based on multiple possible futures, companies could develop strategic direction or display consequences of a set of choices. The scenario planning literature consists of three main scholars which is the intuitive logics school, probabilistic modified trends school and La Prospective school. Intuitive logics is most popularized in literature. On a more practical level eight approaches exist: judgement, baseline, elaboration of fixed scenarios, event sequences, backcasting, dimensions of uncertainty, cross-impact analysis and systems modelling. These approaches also have their own variants which makes scenario planning rather dispersed.

Scenario Planning	
Definition	''A method to develop scenarios that describes some possible future state and/ or that tells the story about how such a state might come out''
Features	- Complex elements together presented into a coherent, systematic, comprehensive and plausible manner - Focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion - Future state or condition in which the situation is embedded; or displayed consequences of a set of choices - Addressing uncertainty - Driving Forces - Flexible Tool - In general long-term perspective
Schools of Thought	- Intuitive Logics School - Probabilistic Modified Trends School - French La Prospective School
Approaches	- Judgement - Baseline - Elaboration of Fixed Scenarios - Event Sequences - Backcasting - Dimensions of Uncertainty - Cross-Impact Analysis - Systems Modelling

Table 2: Scenario Planning Overview

2.2 System Dynamics

The environments which companies face increases in complexity and change. Past methods fail to recognize these problems and might even cause them. With their best intention, methods could cause unforeseen or unconsidered side-effects which influence the system. Therefore, in an increasingly changing and complex world, business leaders, educators, environmentalists, and scholars are calling for developing system thinking in order to improve our ability to take effective actions (Dörner, 1980; J. D. Sterman, 2001). System dynamics is created in the 1950's by professor Jay Forrester at the Massachusetts Institute of Technology (MIT). As Forrester (1993) argues everyone speaks of systems, such as social systems, economic systems, computer systems etc. However, only few are aware of how pervasive systems are, how embedded we are in systems, and how systems are influential in creating difficulties we face every day. System dynamics provide a common foundation by combining theory, methods and philosophy to analyse behaviour of systems in which people are interested to understand and influence changes over time. Possible fields could be management, environment, economics, politics, engineering etc. (Forrester, 1993). The approach is created to consider learning about structures and dynamics of complex systems we face, design policies for sustained improvement and to catalyze successful implementation and change (J. Sterman, 2002). The Massachusetts Institute of Technology (1997) define in their introduction page of system dynamics that system dynamics is a method for studying the world around us. Rather than 'other' scientist who break things up into smaller pieces, system dynamicists look at the system as a whole. The central concept in system dynamics is understanding the basic structure of a system and how the objects in the system interact with each other. This interaction goes through feedback loops, in which a change in one variable causes a change in another variable. Furthermore, system dynamics use computer models as advantage for dealing with greater complexity and carrying out multiple calculations at the same time. System dynamics acknowledge the existence of bounded rationality and the human inability to think in complex systems and addresses the occurrence of policy resistance. Characteristics of system dynamics further include elements as feedback mechanisms, stock & flows and time delays.

2.2.1 Policy Resistance and Mental Models

In complex systems, decision makers often introduce policies which are difficult to implement because constructs of complex systems are neglected. The main principle considered in system thinking is ''policy resistance'' which could be defined as ''the tendency for well-intentioned interventions to be defeated by the response of the system to the intervention itself'' (J. Sterman, 2002). Policy resistance occurs because of the human mind being unable to understand the complexity of the world and having limited, internally inconsistent and unreliable mental models. Complexity could be separated in combinatorial complexity and dynamic complexity. The first refers to the number of links among the elements of a system, or the dimensionality of a search space, while the latter refers to the counterintuitive behavior of complex systems that emerges from the interactions of the agents over time. Policy resistance mostly occurs because of dynamic complexity. Characteristics of dynamics complexity could be found in Table 3.

Dynamic complexity arises because systems are

- **Constantly Changing** – Change in systems occurs at many time scales, and these different scales sometimes interact.
- **Tightly Coupled** – The actors in the system interact strongly with one another and with the natural world.
- Governed by Feedback – Because of the tight couplings among actors, our actions feed back on themselves.
- **Nonlinear** – Effect is rarely proportional to cause, and what happens locally in a system often does not apply in distant regions.
- **History-dependent** – Taking one road often precludes taking others and determines where you end up. Many actions are irreversible.
- **Self-organizing** – The dynamics of the systems arise spontaneously from their internal structure.
- **Adaptive** – The capabilities and decision rules of the agents in complex systems change over time.
- **Characterized** by Trade-offs – Time delays in feedback channels meant the long-run response of a system to an intervention is often different from its short-run response.
- **Counterintuitive** – In complex systems cause and effect are distant in time and space while we tend to look for causes near the events we seek to explain.
- **Policy Resistant** – The complexity of the systems in which we are embedded overwhelms our ability to understand them.

Table 3: Dynamic Complexity Sources (J. Sterman, 2002)

Advocates of system thinking suggest the art of system thinking involves being able to represent and assess dynamic complexity in a textual and graphical way. More specific, required skills are being able to understand the behavior of the system as a result of interactions of its agents over time, discover and represent feedback processes as underlying pattern of behavior, identify stock and flow relationships, recognize delays and understand their impact, identify nonlinearities and recognize and challenge boundaries of mental models (Sweeney & Sterman, 2000). According the study of Sweeney and Sterman (2000) high educated subjects have a poor understanding of basic concepts of system dynamics, and specifically stocks and flows, time delays and feedback. Furthermore, a study of Dörner (1980) focussed on the ability or inability of human thinking in very complex systems. The study made a distinction between ''good'' and ''bad'' subject in which good subjects were better able to deal with complex systems and vice versa. In the study, the author found primary mistakes, which almost all subjects made, and characteristics of thoughts of ''bad'' subjects. In general primary mistakes consists of:

- Insufficient consideration of processes in time – most people are not interested in existent trends and developmental tendencies but in the status quo.
- Difficulties in dealing with exponential developments – people have no intuitive feeling for exponentially developed processes.
- Thinking in causal series instead of causal nets –people tend to see the main effect and not the side-effects.

According to the author, failure threatens the individual and continual failure of one's action implies the subject does not control the area which leads to further loss of control and fear of failure. This results in the following consequences:

- Thematic vagabonding – individuals change topic during experimental sessions relatively quickly often without ending themes.
- Encystment – in opposite to the latter point, this point considers sticking to a subject matter so subjects are enclosed in areas which do not offer difficulties.
- Decreased willingness of decision making – the number of decisions decreases.
- Tendency to delegate – subjects try to delegate decisions to other authorities.
- Exculpation tendency – the subject tries to blame external factors for their failure in order to avoid responsibility.

The authors also believe the sinking intellectual level, which was caused by subjects losing control, leads to a reduction in self-reflection and number of plans, increased stereotyping and a decreased control over the realization of plans. This will lead to a superficial look at conditions in the decision-making problem which will lead to an increase in risky behavior, increase in a number of violations of rules and regulations and an increasing tendency to escape (Dörner, 1980).

2.2.2 The Feedback View

A main principle of system dynamics which is the consideration of feedback. People tend to interpret experiences as series of events which allow people to blame others for difficulties rather than the system. This worldview is called an event-oriented open-loop worldview in which the state of affairs is assessed and compared to goals, the gap between desired situation and the current situation is defined as a problem, and several options considered and selected (J. Sterman, 2002). This process could be found in the Figure 2 below.

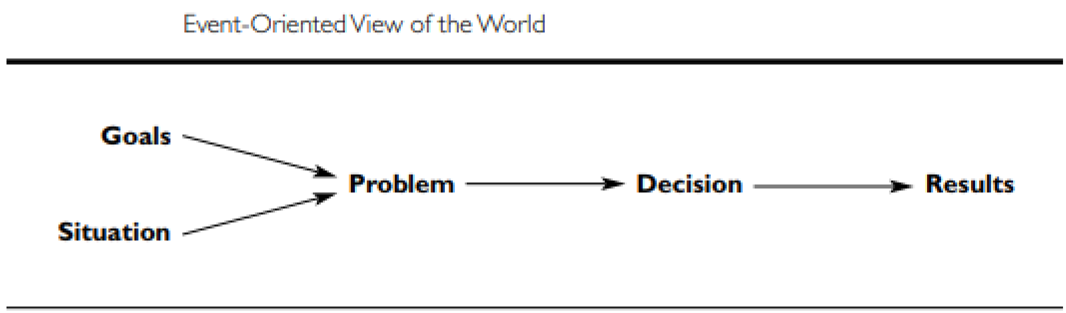


Figure 2: Event-Oriented View (J. D. Sterman, 2001)

As an example of an event-oriented view of the world, one could consider a company of which profit fall below expectations and so, risks financial difficulties. The goal of the company was to reach an x amount of profit, so the company would do a good job and do not face financial difficulties. However, the profit within the certain time amount did not meet its target and the company risks facing financial difficulties. The gap between the expected and real profit is considered as the problem. In order to solve this problem, the company wants to boost its profit by considering and implementing certain plans. The company could lower its costs or increase sales.

Based on analysis, certain decisions are taken to boost sales and decrease costs. Everybody moves on and the problem seems to be solved. However, in real complex environments, the environment responds to one's actions and so, people have to deal with feedback. This picture shows systems respond to intervention and lead to new situations in the future. This new situation changes the view of the problem and leads to new situations. This could be found in the upper part of Figure 3. However, besides the world changing because of one's actions, side effects which were not anticipated on appears. Following the example described above in which plans for cost reduction and sales increases could also cause other companies improving their operations in terms of cost reduction and sales increases. This could lead to policy resistance as the full range of feedbacks were not understood throughout the system (J. D. Sterman, 2001).

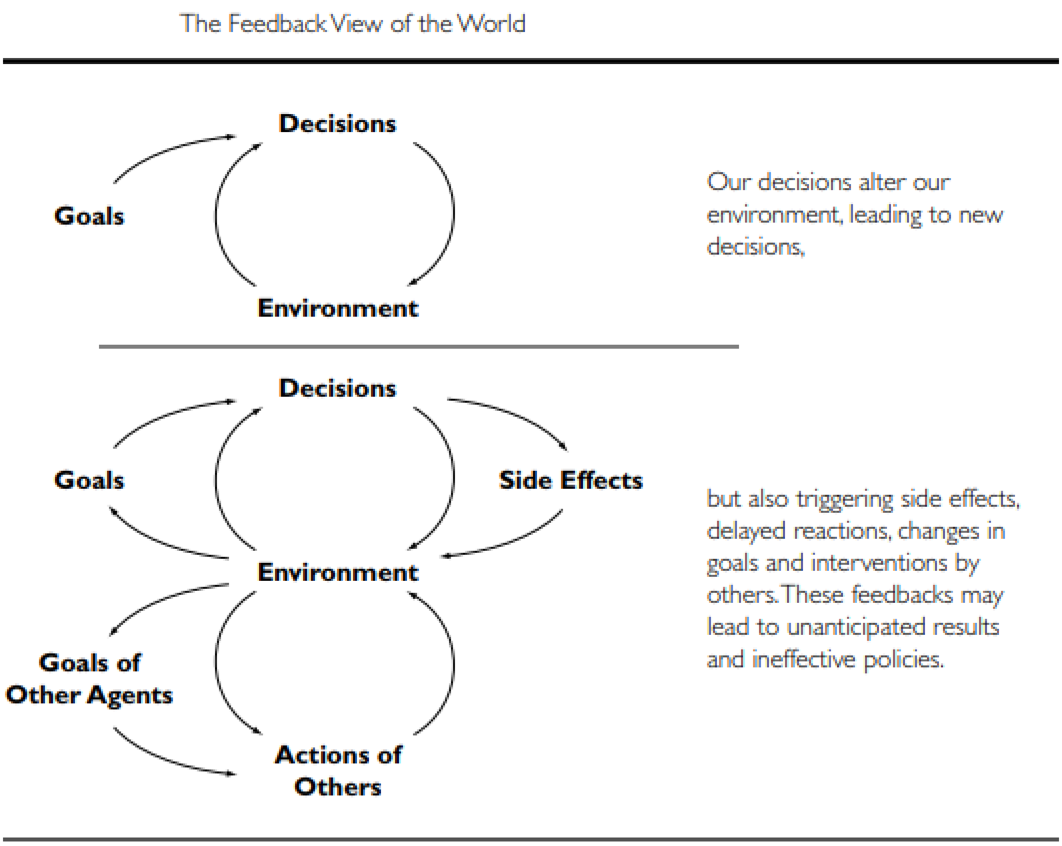


Figure 3: Feedback View of the World (J. D. Sterman, 2001)

Within system dynamics, a substantial part is dedicated to representing feedback processes and other elements of complexity. The dynamics from interacting factors could simply exist of positive and negative feedback loops (J. D. Sterman, 2001). Positive and negative feedback loops could be best explained with an example. Among author sources, a clear example could be found in J. D. Sterman (2000).

Positive Feedback Loop

A positive feedback loop causes one variable increases the other variable, but also a reduction in one variable means a reduction in the other variable. Furthermore, a positive feedback loop is self-reinforcing so it tends to move away from an equilibrium. Positive loops which are growing produces exponentially increasing behavior (Dangerfield, 2014). The example states that more chickens lay more eggs which leads to an increase in chicken population and therefore an increase in more eggs etc. The arrows in the diagram state the causal relationship, in this case, a + arrow which indicates a positive relation. This feedback loop is self-reinforcing, which is indicated by an R in an arrow. In case the feedback loop is going one way, e.g. an increase in chickens causes an increase in eggs etc., the feedback loop will grow exponentially. However, it has been stated grow is not unlimited because of limits to growth which are created by negative feedback loops (J. D. Sterman, 2000).

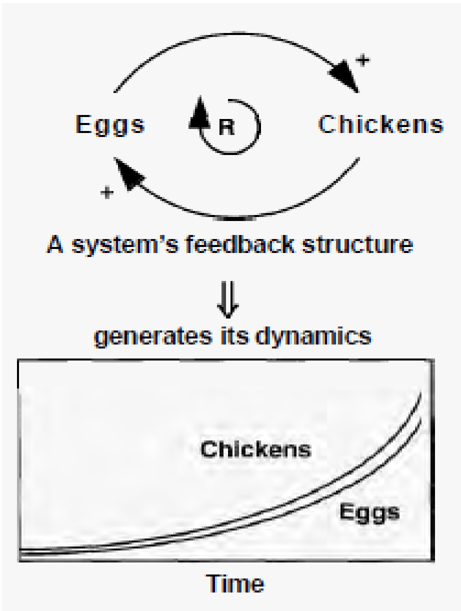


Figure 4: Positive Feedback Loop (Sterman, 2000)

Negative Feedback Loop

Negative loops tend to be self-correcting or self-limiting processes which create balance and equilibrium (J. D. Sterman, 2001). When the chicken population is growing, several negative loops will balance the chicken population. The example of J. D. Sterman (2000) states an increase in chicken populations causes more risky road crossing which decreases the chicken population. In this case, instead of an R, the B in the loop stand for a balancing feedback. When the road-crossing loop was the only one active, the number of chickens decline until no one is left.

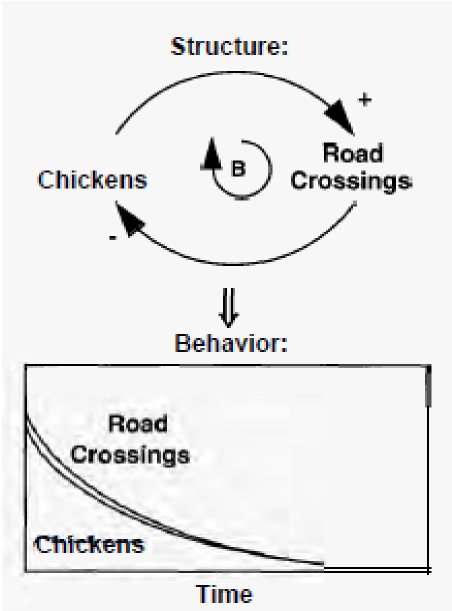


Figure 5: Negative Feedback Loop (Sterman, 2000)

All systems, whether it is complex or not, consists of positive and negative feedback networks and all dynamics arise from the interaction of these loops with each other.

The network of the positive and negative feedback could be found in Figure 6. This figure shows the chicken population is influenced by the positive and negative feedback loops.

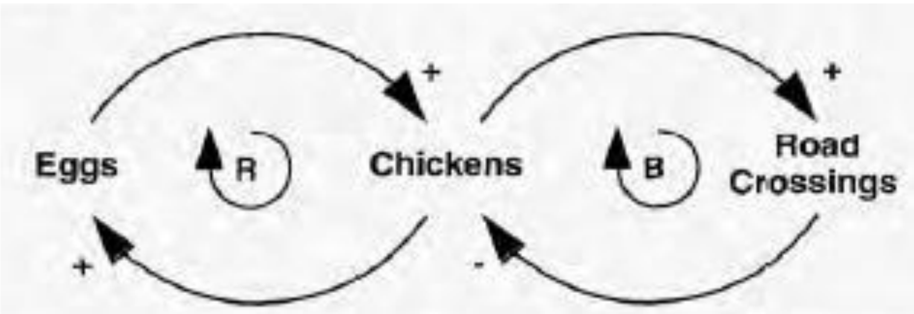


Figure 6: Causal Loop Diagram (Sterman, 2000)

2.2.3 Learning as Feedback Process

Even as the dynamics which arise from feedback, learning also depends on feedback. Learning is being considered as a feedback process in which our decision modify the real world, information is being received as feedback, and new information is used to revise decisions and mental models that motivate these decisions (J. D. Sterman, 1994). A single feedback loop contains the basic learning process. Decision makers compare information of the real world to goals, considering the desired and actual state. Based on this gap decisions are taken in which decision makers believe it will cause the real world moving towards their desired state. However, inputs are not limited by the real world. In case mental models are not changed, the single feedback loop exists. This, however, does not lead to a deeper change in our mental models and so, an understanding of the complex system. J. D. Sterman (1994) mentions mental models in system dynamics ''stresses the implicit causal map of a system we hold, our beliefs about network of causes and effects that describe how a system operates, along with the boundary of the model (the exogenous variables) and the time horizon we consider relevant - our framing or articulation of a problem''. However, in general, these mental models are not appreciated or recognized while our view is constructed and modeled by sensors and cognitive structures. Rather than single loop feedback learning, the development of system thinking consists of a double-loop learning process. This replaces a simplistic, short-term worldview with a holistic, broad, long-term dynamic worldview. In this model feedback about the real world does not change decisions within existing models and decision rules, however, it feeds backs to change the mental models. When mental models are changed different decision rules are created and strategy and structure of organizations will be changed. So similar information will be processed via different decision rules and will lead to different decisions (J. D. Sterman, 1994).

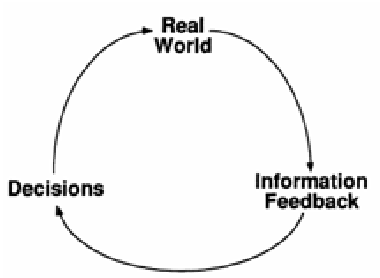


Figure 7: Single and Double Feedback Loop (J. D. Sterman, 1994)

2.2.4 System Dynamics Complexity Sources

In order to improve learning in complex systems tools are needed which capture feedback processes, stocks and flows, time delays, and other sources of dynamic complexity (J. D. Sterman, 2001). In this part, dynamic complexity sources will be discussed further in terms of causal loop diagrams, stocks and flows, and time delays.

Causal Loop Diagrams

As mentioned within system dynamics, a substantial part is dedicated to representing feedback processes and other elements of complexity. The representation of feedback processes is done by using Causal Loop Diagrams (or influence diagrams) which is an important tool to represent feedback. Causal loop diagrams capture hypothesis about causes of dynamics, elicit and capture mental models of the individuals and communicate important feedbacks which are considered responsible for a problem. A causal loop diagram consists of connected variables in which arrows denote the influence among variables. As been discussed, relations could be positive or negative and feedback loops could be positive (reinforcing) or negative (balancing). Important loops are highlighted by loop identifiers which note whether loops are positive or negative. The identifier in the loop further shows to which direction the loop corresponds (J. D. Sterman, 2000). A simple example can be found in the before mentioned positive feedback loop of the chicken population. However, we saw there was also a negative feedback loop influencing the chicken population which led to a broader model. This was only a simple example of a positive and negative feedback loop influencing the chicken population. In the real world, the chicken population is depending on more factors than a number of eggs and road crossing, and on this turn, the number of eggs and road crossings is depending on its own variables. So, one can imagine the causal loop diagram of the chicken population could be much more extended to a more complex causal loop diagram.

Stocks and Flows

An important aspect of system dynamics consists of stocks & flows. In their study, Sweeney and Sterman (2000) found out subjects tend to violate fundamental relationships between stock and flows. Stocks and flows are a fundamental principle of dynamic complex systems. The principles of stocks and flows can be found within calculus which considers that state variables are changed by the rates that change them. Calculus is not needed however to understand stocks & flows principle. A commonly used example is filling and draining a bathtub. The water in the tub could be considered as stock. The bathtub (stock) could be filled or drained by inflow and outflow (flows) (J. Sterman, 2002). This principle could be found in more applications, for example as warehouse stock or bank accounts.

Within system dynamics, the flow rates are displayed by ''tap-like'' symbols, which represents a device which can control the flow and a stock is represented by a rectangle. Furthermore, a cloud-like symbol represents a boundary of a flow at the edge of the system. (Dangerfield, 2014) Assume the example derived from Dangerfield (2014) provided in Figure 8.

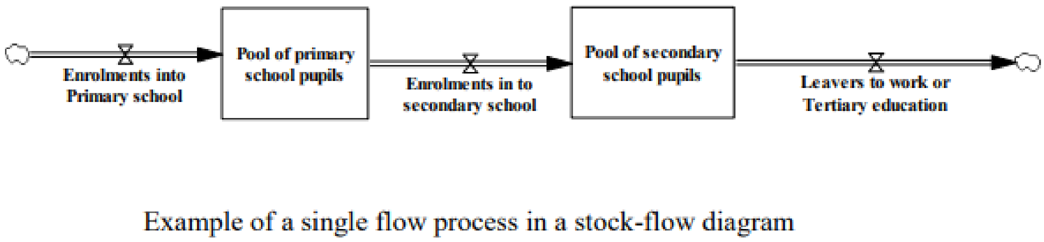


Figure 8: Stock and Flow Diagram Example (Dangerfield, 2014)

The cloud-like symbol, in the beginning, represents the boundary of the flow, in this case, the start of the system. The pool of primary school pupils, which in this case is a stock-variable, is ''filled or drained'' by the enrolments into primary school, which represents a flow-variable. The transition from the pool of primary school pupils to pool of secondary school pupils is controlled by the flow-variable ''enrolments into secondary school''. As last school peoples leave secondary school by going to work or tertiary education. After this stage, the system is closed by a boundary symbol which represents the end of this system.

Time Delays

The last factor causing dynamic complexity described here, are time delays. Time delays are considered as an important factor of system dynamics as it introduces extra complexity within the system. When people take actions, most of the time, feedback does not immediately return to the action-taker/ decision maker: there is a delay. The time between taking decisions and the effects on the system, the time delay, is problematic considered and could cause more harm than good. Delays in receiving feedback lead to systems to fluctuate. As a result, decision-makers are trying to intervene and find an equilibrium between the actual and desired state. However, rather than coming to an equilibrium the time delays causes decision makers overreacting towards the situation. Furthermore, delays reduce abilities to accumulate experiences, test hypothesis and learn: longer delays slow learning and hamper organizational improvements (Sterman, 2002).

Dynamic Complex Behaviour

The structure of a system defines the behaviour. The structure consists of the feedback loop, stocks and flows, delays, and nonlinearities created by interaction of the structure of the system. So, system behaviour depends on the structure in which certain kinds of structures lead to a certain kind of behaviour. A positive feedback loop leads to ''growth'' behaviour, negative feedback leads to ''goal seeking behaviour, and negative feedback in combination with time delays leads to oscillation. As last, nonlinear interaction of these basic structures could lead to other complex types of behaviour such as S-shaped growth, overshoot and collapse (Sterman, 2000).

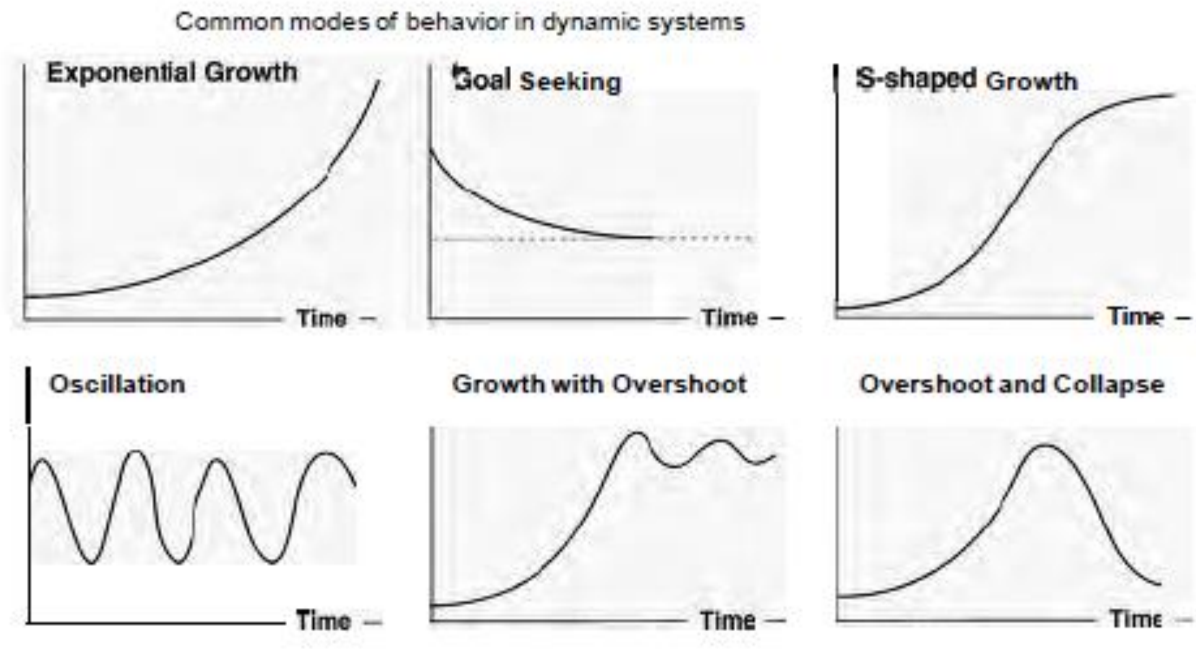


Figure 9: Behaviour of Dynamic Complexity (J. D. Sterman, 2000)

2.2.5 Approaches

In this part the approaches of system dynamics will be discussed. System dynamics consists of various basic characteristics, discussed before, but also multiple approaches and ''branches''. This part aims at providing a short but structured discussion of approaches and additions.

System dynamics has been applied within many disciplines such as physics, engineering, economics, management etc. Among these disciplines, the application in strategic management has a particular relevance and could be considered as flexible research methodology which can be integrated with strategic management approaches and frameworks. In the beginning years of System Dynamics application within management practices, the methodology was mainly used as consultancy tool. It was used to analyse a business and building models and providing recommendations without key actor involvement. There was a main focus on improving strategy formulation and corporate planning. Since the 90's, key actors within companies were more involved in the process of system dynamics by the introduction of 'group model building' which was introduced simultaneously with System Thinking stream (Cosenz & Noto, 2016).

System dynamic approaches

Since the beginning of System Dynamics, founders within the field have developed guidelines for building and testing system dynamic models. It is recognized by the classic literature, developing system dynamic models is an iterative process in which each iteration should result in better and more robust models. System dynamic models could consists of mathematical models, however it is recognized that most information available consists of qualitative data (Luna-Reyes & Andersen, 2003). These authors further describe multiple approaches from experts in which the number of activities varies from three to seven different stages in the modelling process. This is inserted in Table 4.

Randers (1980)	Richardson and Pugh (1981)	Roberts *et al.* (1983)	Wolstenholme (1990)	Sterman (2000)
Conceptualization	Problem definition	Problem definition	Diagram construction and analysis	Problem articulation
	System conceptualization	System conceptualization		Dynamic hypothesis
Formulation	Model formulation	Model representation	Simulation phase (stage 1)	Formulation
Testing	Analysis of model behavior	Model behavior		Testing
	Model evaluation	Model evaluation		
Implementation	Policy analysis	Policy analysis and model use	Simulation phase (stage 2)	Policy formulation and evaluation
	Model use			

Table 4: The System Dynamics Modelling Process across the Classic Literature (Luna-Reyes & Andersen, 2003)

On the one hand, the approach of Wolstenholme (1990) consists of only three phases while on the other hand, the theory of Richardson and Pugh (1981) consists of seven phases. Other theories varies from four till six phases. Despite several approaches exists, Luna-Reyes and Andersen (2003) identified phases which exists in all approaches as stages remain reasonably consistent. The authors summarize the approaches of the classic literature in four stages: the conceptualization stage, formulation stage, testing stage and implementation stage. Besides the identification of system dynamics modelling in the classical literature by these authors, Martinez-Moyano and Richardson (2013) conducted a research by exploring opinions of a group of experts in the field regarding best practices of system dynamics modelling. These authors investigated what experts think about the best way of conducting system dynamics modelling, essential specific core activities for exemplary action during the stages and most important practices during the different stages. Among other things, this research resulted in a list of factors of high important aspects and high/ low agreement level. These authors also considered the approaches of Randers (1980), Richardson and Pugh (1981), and Sterman (2000), selected stages based on these approaches and assigned practices of importance to these stages. In the following part the description of the approaches will be structured around the ‘’fundamental’’ stages of Luna-Reyes and Andersen (2003) which consists of stages to which all approaches could be traced back. This will be complemented by the practises discussed by Martinez-Moyano and Richardson (2013). The latter approaches considered could be found in Table 5.

System Dynamics Approaches Review	
Luna-Reyes & Andersen, 2003	Martinez-Moyano and Richardson (2013)
Conceptualization Stage	Problem Identification and Definition
	System Conceptualization
Formulation Stage	Model Formulation
Testing Stage	Model Testing and Evaluation
Implementation Stage	Model Use, Implementation, and Dissemination
	Design of Learning Strategy/ Infrastructure

Table 5: Adjusted from Luna-Reyes and Andersen (2003); Martinez-Moyano and Richardson (2013)

Conceptualization Stage

In the conceptualization stage, the problem is defined and the system conceptualized. As could be seen in the table, the authors of classic system dynamics literature indicate this stage as, conceptualization stage, problem definition and system conceptualization, diagram construction and analysis, and problem articulation and dynamic hypothesis. This stage focusses on a part of the real world based on the mental models including feedback loops. It is addressed this stage is mainly qualitative in nature, as there is often a dynamic problem which consists of variables which are traditionally not quantified and it is likely the modeller or client is familiar with the dynamic process without using data. However, there is a debate whether or not to simulate models based on qualitative data. In the classic literature, several variants are used regarding the conceptualization stage. In this stage, Martinez-Moyano and Richardson (2013) identified there is a high agreement among experts regarding the importance of involving problem owners, identifying the purpose, formulating a dynamic hypothesis and clearly articulating dynamics of the problem using the current and expected behavior. This leads to a shared understanding of identifying and defining dynamic problems. However, experts do not share the agreement regarding the focus of the modelling, which could be a focus on the system or a focus on the problem. Furthermore, regarding conceptualization, experts agree about using different approaches creatively to gain an understanding of the problem owners. This could lead to the identification of critical stocks which are important in the system and thinking in terms of dynamic hypothesis. In this stage, there is a high agreement of identifying critical stocks, however there is a lower agreement on whether to use a causal-loop diagram or stock-and-flow diagram to conceptualize which results in differences in approaches. Martinez-Moyano and Richardson (2013) argue that causal-loop thinking prefers an endogenous perspective (focus on feedback loops) while using a stock-and-flow diagram prefers the identification of critical system elements. However, the best results come from a combination and iterative use of both approaches.

Formulation Stage

In classic literature, this stage knows variants as formulation, model formulation, model representation, and simulation phase (stage 1). In the formulation stage a detailed structure is posited and parameter values are selected. Also in this stage, qualitative data elements exists and importance of inclusion of qualitative constructs has been stressed. However, it has been asked whether qualitative mapping approaches can produce reliable inferences, when qualitative mapping yield unreliable/ false inferences, whether word-and-arrow maps are more reliable while less accessible and whether it is possible to state conditions which require quantitative modelling. However it is argued there is a high level of agreement of using evidence, whether it is data or expert's experience, so the model has real-life meaning and dimensional consistency (Martinez-Moyano & Richardson, 2013). These authors further identifies two approaches of formulating models. The first approach starts small while adding complexity when necessary, and the second approach considers big chunks complexity at a time. Second disagreement found by the authors relates to operational thinking on one hand, versus extreme conditions thinking on the other hand. The authors mention that some experts believe implementing extreme conditions is crucial in model building while others think this pushes a model to a regime which will never exists.

Testing Stage

In the model testing stage the stages in the literature varies from testing, analysis of model behavior and model evaluation, model behavior and model evaluation and simulation phase (stage 1). Luna-Reyes and Andersen (2003) argue in their review that Senge and Forrester (1980) provides great detail in describing 17 tests at this model development stage. E.g. One verification tests includes testing whether the model does not contradict knowledge about the structure of the real system. This qualitative test is the first test conducted on basis of model builder's personal knowledge and include criticisms by others with direct experience from the real system. Furthermore, it is argued modellers' biases must be addressed and model testing should include all sources of available knowledge whether it is qualitative or quantitative. However, Luna-Reyes and Andersen (2003) found a high level of agreement in using statistical measures of pattern fit to model testing and evaluation, and comparing simulated behavior patterns with real behavior (data). This practice could be used in quantitative models to uncover flaws and to add/ decrease complexity or restructure the model. Regarding the iterative approach to test and build confidence, low agreement was found. Some authors prefer incremental actions while others prefer more radical approaches. As last, in this stage low agreement was found in testing dimensional consistency, which might signal this practice is considered for the formulation stage.

Implementation Stage

As last, the implementation stage in the classic literature varies from implementation, policy analysis and model use, simulation phase (stage 2), and policy formulation and evaluation. According to Luna-Reyes and Andersen (2003) this stage requires transferring study insights to users of the model in which the model will be described to individuals who not necessarily are modellers themselves. This stage is considered as qualitative and requires thorough discussion. Interpretation and use of the models by policy makers face various challenges described by classis literature. This is related to several types of judgements needed during the building process and assessing the output. In this stage it has been found, it is important to the modelling process is centered on the concerns of the problem owners and having a high level of agreement among the members. Furthermore, it is important simplified causal-loop diagrams must be used to tell systems theories rather than relying on the model itself. Communicating findings must be purposeful and deliberative. As last, there is less agreement regarding the important topics which should be emphasized. A distinction could be found in focusing on the model itself as source of learning providing insights, others favor emphasize using the model to focus on providing insights (Martinez-Moyano & Richardson, 2013).

Client involvement: Group Model Building

System dynamics applications have been used since the 1950's. In the first applications, system dynamics was more used as a consulting tool in which modellers worked on the tools and provided recommendations based on system dynamics (Cosenz & Noto, 2016). Although Forrester (1961) argued the importance of addressing mental models of managers in the system dynamics modelling process, it was in the late 1970's publications started on describing procedures in which clients were involved in the process of system dynamics. Nowadays, it has been considered the system dynamics modelling process can be conducted throughout two types of projects. In first place, projects could be managed by one or more modellers which acquire data, gain expertise and design the model. A second type of projects could be introducing experts on the system which are not only used as source, but also as participant of the modelling process with help of an expert/ team in the system dynamics field (Bérard, 2010). The main reasons to include clients in the process is risking a lack of implementation. This could be the case when the model does not match with prevailing discussions within the form or a lack of ownership of the model. Therefore, approaches were developed to structure the involvement of clients within the process which are referred to as ''group model building'' (Rouwette & Vennix, 2006). Vennix (1999) describe group model building as ''a system dynamics model-building process in which a client group is deeply involved in the process of model construction''. Based on research, the author mentions system dynamicists involve clients in order to capture required knowledge in mental models of the client, to increase the chance of implementation of the model and to enhance the client's learning process. This led to a deeper reflection on client involvement in the system dynamics literature. Andersen, Richardson, and Vennix (1997) described the goals of group model building on the individual, group and organizational level. These goals states on individual level is learning in terms of the improvement of mental models, the goal on team level is the alignment on mental model, creating consensus on a decisions/ policy, and generating commitment with a decisions, and on organizational level the goal includes a system process/ outcome change.

Group Model Building Approach

During the years, the literature derived a certain degree of consensus regarding principal challenges in modelling. The literature follows a model of eliciting information, developing model structure and testing the structure. Even as in the classical literature regarding system dynamics, group model building also knows several approaches. The difference in these approaches are based on general discussions which are also present in the classical system dynamics literature. Even as in classic literature, in group model building two important debates include the use of qualitative or quantitative models, and the appropriate size of the models (Rouwette & Vennix, 2006). Even as in the classic literature, the findings of Martinez-Moyano and Richardson (2013) could be applied in Group Model Building in terms of listening to clients, formulate dynamic hypothesis, use methods creatively to conceptualize, generate dialogues etc. In a group model building project, one or more models are created by the participants with help of a facilitator (Vennix, 1999). The sessions which take place in order to create one or more models are referred to as ''group modelling workshops, work session or conferences''. In these sessions, besides system dynamics expert(s), the participants consists of clients/ problem owners, eventual researchers/ specialists/ practitioners of the systems (Bérard, 2010). This research further describes the group modelling projects and makes a distinction between two dimensions in the process, which are the structural and process dimensions. The structural dimension described is derived from the research of Andersen et al. (1997) who states two structural components based on their structure. These components consists of the group structure and the logistic component. The group structure takes the participants, the composition of groups and sub-groups involved and the facilitation aspects into account while the logistic component includes all aspect related to location, fitting and equipment of the room. The process dimension is derived from Sterman (2000) and is earlier described in this report. These approaches involves problem articulation, formulation of dynamic hypotheses, formulation of the simulation model, testing of the model and formulation of potential strategies and evaluation. Both 2 approaches led to seven components which are further used in the study of Bérard (2010) to characterize group modelling projects while using system dynamics. To illustrate their dimensions and components, Table 6 is inserted below.

Dimension	Components	
Structure	Group structure	S1
	Logistics	S2
Process	Problem articulation	P1
	Dynamic hypotheses	P2
	Simulation model formulation	P3
	Testing	P4
	Formulation of potential strategies and evaluation	P5

Table 6: Dimensions and Components of Group Modelling Projects

2.2.6 Summarized Results

A summary of the results regarding definition, features, schools of thought and approaches could be found below. In general there could be said system dynamics is a method for studying the world around us while looking at the system as a whole by understanding the basic structure and interacting objects of system, and represent and assess dynamic complexity. It is a combination of theory, methods and philosophy the analyse the behaviour of systems over time. System dynamics acknowledge poor understanding of dynamic complex aspects and the existence of policy resistance. System dynamics consider ʼʼdynamic complex elementsʼʼ including causal loop diagrams, stock and flows, time delays and behaviour of systems over time. System dynamics could be adjusted to particular systems. Furthermore, overarching ʼʼschools of thoughtʼʼ were not identified. However, several approaches exist based on preferences of authors. In general these approaches could be reduced to the phases conceptualization, formulation, testing and implementation. The inclusion of client groups is also popularized last decades which led to the existence of ʼʼgroup model buildingʼʼ.

System Dynamics	
Definition	ʼʼA method for studying the world around usʼʼ while ʼʼlooking at the system as a wholeʼʼ by ʼʼunderstanding basic structure and interacting objects of a system, and represent and assess dynamic complexityʼʼ.
Features	- Theory, methods and philosophy to analyse behaviour of systems over time. - Learning about structures and dynamics of complex systems. - Tool to design policies for sustained improvement and to catalyze successful implementation and change. - Using computer models as advantage for dealing with greater complexity and carrying out multiple calculations at the same time. - Overcome ʼʼpolicy resistanceʼʼ by considering dynamic complexity. - Acknowledge the existence of bounded rationality and the human inability to think in complex systems. - Consider learning as a feedback process. - Representing feedback processes and other elements of complexity by using Causal Loop Diagrams (or Influence Diagrams). - Consider stocks and flows as a fundamental principle of dynamic complex systems. - Consider time delays as an important factor of dynamic complex systems. - Consider system ʼʼbehaviourʼʼ caused by the feedback loop, stocks and flows, delays. - Flexible tool, could be adjusted to system.
Schools of Thoughts	Not necessarily ʼʼSchools of thoughtʼʼ, rather varying approaches based on preferences.
Approaches	- Could in general by converted to shared steps: Conceptualization, Formulation, Testing , Implementation. - Group Model Building.

Table 7: System Dynamics Overview

2.3 Theory Comparison

In this part the theories will be compared and discussed. First the similarities and differences are addressed in terms of definitions, goals, features, schools of thought/ approaches, timeframe, tools and participants. Thereafter there will be discussed in which way system dynamics can complement scenario planning. The latter serves as input for theory development.

2.3.1 Similarities and Differences

For scenario planning a wide range of definitions exists, it has been found, throughout the literature scenario planning definition could be reduced to a method to create a product that describes some possible future state and/ or that tells the story of how such a state might come out. Broadly defined, the goal of scenario planning is understanding future environmental uncertainty, expanding people's thinking, surpass fixed future forecasts and create more robust competitive strategies. Scenario planning distinguishes itself as it addresses uncertainty rather than the risk in which uncertainty is referred to as a situation in which something is not known. On the other hand, system dynamics could be described as ''a method for studying the world around us, by looking at the system as a whole, understand the basic structure and interacting objects of a system, and represent and assess dynamic complexity''. System dynamics aims at helping people with understanding complex systems, design better policies and effectively guide change. So, whereas scenario planning focuses on increasing understanding of uncertain environments, system dynamics focuses on increasing understanding of complex systems. Both methods have different approaches and features. Whereas scenario planning describes future states by determining driving forces and trends, and map the system in a more intuitive way, system dynamics maps the system while implementing dynamic complex elements as feedback loops, stocks and flows, and time delays. Regarding approaches and schools of thought, scenario planning literature consists of a wide variety of methods while the system dynamics knows four basic phases which were present throughput multiple approaches (Luna-Reyes & Andersen, 2003). The steps in intuitive logics scenario planning as discussed by Wright et al. (2013) describe the approach in more detail. In general, there could be concluded, even if the approaches address different issues (uncertainty vs. complexity) and consists of different underlying principles, the scenario planning steps described could also be gathered under conceptualization and formulation. However, besides intuitive logic approaches, scenario planning also includes probabilistic trend modification and La Prospective methods. Similar to these approaches, system dynamics consider quantitative steps and parameters are used. System dynamics and probabilistic modified trends assume no outcome occurs in isolation but is influenced by other factors. However, rather than constructing a probability table, system dynamics map the causal system and add stocks and flows and time delays. So, in system dynamics besides the probability of occurrence, other sources of dynamic complexity as stocks and flows and time delays are mapped which results in a better method of dealing with complex environments. System dynamics maps a complex system in which a ''system'' could refer to any system, such as economic or financial systems. Therefore the scope of system dynamics varies depending on the system. For scenario planning, the scope could also range, varying from a world-view to a more focused perspective. In both methods knowledge of the participants are acquired and generic tools as brainstorming, stakeholder analysis, interviews, experiments are common in both approaches. In general, this is based on including experts in the field/ problem owners. In scenario planning the participants range from scenario planning experts, individuals or groups. In system dynamics normally two types of groups exist of which the first type is managed by one or more modellers who gain insights into the system and map and model the system self. On the other hand experts of the system and clients could be involved in the system. The differences regarding tools could be found in the quantitative part, as for scenario planning the La Prospective method includes tools as Micmac, Smic, and Mactor analysis, and probabilistic trends use tools as trends- and cross-impact analysis. On the other hand, system dynamics uses tools which supports mapping complex systems and complex dynamic elements such as causal loops, stock and flows, and delays. Tools which supports these elements are for example IThink, Vensim, and Anylogic. An overview of the theory comparison and similarities and differences could be found in the following tables.

Table 8: Scenario Planning and System Dynamics Theory Comparison

Scenario Planning and System Dynamics Theory Comparison		
	Scenario Planning	System Dynamics
Definition	Multiple, scenarios are broadly referred to as: ''product that describes some possible future state and/ or that tells the story about how such a state might come out''. So scenario planning is the method which lead to this outcome.	A method for studying the world around us, by looking at the system as whole, understand basic structure and interacting objects of a system, and represent and assess dynamic complexity.
Goal	Describe the future, assess future uncertainty, expand people thinking and respond to future uncertainty.	Describe the future, understand complexity, develop learning in complex systems, design better policies and effectively guide change.

Features	Describe future states; identifying driving forces; consider complex elements into coherent, systematic, comprehensive and plausible manner; flexible tool; address uncertainty; driving forces;.	Overcome policy resistance; related elements; consider dynamic complexity by using feedback structures, causal loop diagram, stocks & flows and time delays.
Approaches	Multiple: From abstract level: Intuitive Logics, Probabilistic Modification Trends, La Prospective. More practical: judgemental, baseline/ expected, elaboration of fixed scenarios, event sequences, backcasting, dimensions of uncertainty, cross-impact analysis, and modeling.	Several approaches but slightly varying phases, could be summarized to: conceptualization, formulation, testing and implementation. Discussion regarding focussing on qualitative or quantitative methods.
Scope	Wide variety of scope, varying from world-view to more focussed. In corporate planning business environment influencing factors are popularized.	Considered as medium problem scope. However, depends on system. System could be anything. Consideration of difficult complete systems or (possibly) incomplete systems.
Timeframe	In general long-term perspective e.g. 3 – 20 years	Flexible, depending on system.
Tools	Varying per school of thought: Intuitive Logics: Generic tools like brainstorming, STEEP analysis and stakeholder analysis. La Prospective: Proprietary and structural tools like Micmac, Smic, Mactor analysis etc. Probabilistic Modified Trends: Proprietary tools like trends- and cross-impact analysis.	Qualitative tools as: Interviews, focus and Delphi groups, content analysis, oral history, grounded theory, experimental approaches. Quantitative tools consists of software such as ITHink, Vensim, AnyLogic which supports system dynamics modelling.
Participants	Ranging from scenario planning expert, individual, or group activity.	In general two types of projects: first type, managed by one or more modellers. Second type, introducing experts/ clients involved in system.

Table 9: Scenario Planning and System Dynamics Similarities and Differences

Similarities	Differences
• Both theories describe a ''state'' or how such a state could evolve. • Both theories expands people's thinking • Both theories helps guiding in strategic decisions. • Both theories considers a ''system'' or ''environment'' in which relating factors exists. • Intuitive logics and system dynamics approach have relating phases. • Both theories have flexible scopes depending on the relevant system. • Both theories have flexible time frames depending on the relevant system. • Both theories have similar qualitative tools which could be used like interviews, brainstorming etc. • Both theories could vary in participants ranging from specialist only to group work.	• Scenario planning is method to describe possible futures or how to reach such a future; while system dynamics studies the world around us by looking at system as a while and implement dynamic complex systems. • Scenario planning focusses on uncertainty; while system dynamics focusses on complexity. • System dynamics better structure the system and behaviour of the system over time by considering complex dynamic features. • Scenario planning has multiple schools of thought and approaches while system dynamics has slightly varying phases based on author's preferences. • Mainly quantitative tools used in theories differ. Quantitative scenario planning methods consists of Micmac Smic, Mactor etc.; while system dynamics software consists of IThink, Vensim, AnyLogic etc.

2.4 Complementary Factors

It has been stated the strength of scenario planning is being able to present all complex elements together into a coherent, systematic, comprehensive and plausible manner (Coates, 2000). However, in general, these stories are created without considering complex dynamic factors. Results of Sweeney and Sterman (2000) suggest high educated subjects have a poor understanding of system dynamics concepts as feedback, stocks, and flows, and time delays. This complicates behaving and thinking in complex systems. The implementation of system dynamics helps in structuring the system which is used to develop scenarios while dynamic complexity is taken into consideration. System dynamic theories stress people tend to interpret experiences as series of events which is addressed as the event-oriented view of the world (J. Sterman, 2002), in which x leads to y without considering feedback returning to x. In generating scenarios, people risk following the event-based worldview when considering relations between factors which could eventually lead to policy resistance. It has been stressed that in the real world feedback exists, so one's actions or decisions does not only lead to a change in the environment but also a change in the environment by actions of others and side-effects. System dynamics could complement scenario planning by introducing feedback loops in terms of causal loops. This will provide a more extensive view of the system and users will be better able to truly learning in the system. Furthermore, the system is influenced by stocks and flows and time delays as dynamic complex elements. These factors could further increase understanding of the complex system. In stock and flow structure, the stock could be filled or drained by the flow. This introduces state and flow variables and nonlinear behavior. Furthermore, a decision causes feedback but this does not always happen in the same timeframe. Delays in the process make systems more complex, so introducing this aspect in the system also leads to a better understanding of complexity. By introducing complex dynamic elements in scenario planning, the system is not only considered as complex and dynamic, but it could also be investigated in which ways possible scenarios could behave. So, the output of system dynamics-based scenario planning is more consistent scenarios considering dynamic complexity. System dynamics principles could complement scenario planning in such a way, the complex and dynamic system is better assessed and decisions could be better tuned based on the system.

Scenario planning considers dealing with uncertainty rather than risk by mapping the environment and develop multiple possible stories of the future. Providing possible outcomes of the future in terms of stories expands people thinking and choosing robust actions. So rather than assuming one future, multiple futures could be addressed. In system dynamics, different scenarios could be considered by experimenting with different parameters. When changing values of parameters in system dynamics models, the system could react differently and so provide different outcomes of the system. So, for factors of which uncertainty is high different scenarios could be developed. This addresses the strength of scenario planning which is considered as developing multiple possible stories of the future while addressing uncertainty. In this way, decisions could be assessed which are robust in multiple futures. Describing the stories based while using system dynamics leverages the strengths of both approaches. The output of the method considers complex elements together into a coherent, systematic, comprehensive and plausible manner while considering complexity, uncertainty and learning in complex and uncertain environments.

3 Theory Development

This part describes the rationale behind constructing an approach of scenario planning and system dynamics and the approach itself. In general, both approaches have differences and similarities in fundaments and approaches. To develop a combined approach, the goal of the combined method will be considered and elaborated. Based on the goal, applicable concepts from system dynamics and scenario planning theory will be considered and theory will be built.

As earlier mentioned, this study elaborates on researches which are focussed on improving management tools regarding aligning internal company strategies with long-term developments in the external market by providing robust approaches while maintaining communicative strengths. This is done by using management tools as business roadmapping and scenario planning. However, the former tools aim at working in groups while involving client groups and maintaining communicative strengths. This will also be the case for system dynamics-based scenario planning. In system dynamics working in groups is considered as important by authors (e.g. Rouwette and Vennix (2006)) as actual understanding and implementation increases when clients are involved. Scenario planning is considered as business-friendly method (Schoemaker, 1993), however, it is argued highly educated subjects have a poor understanding of basic principles of system dynamics (Sweeney & Sterman, 2000). Therefore, in order to create an approach which could be used in client groups and maintain communicative characters, a clear procedure must be developed and clients need an understanding of basic principles of system dynamics. Keeping this aspect in mind, this study elaborates on overarching research by developing a technique based on existing theories, in order to deal with scenario planning in complex systems. It extends the line of providing techniques which could be used to consider strategy while involving the client.

Scenario planning consists of three general schools of thought within literature: intuitive logics, probabilistic modified trends and La Prospective. It has been argued Intuitive Logics received the most attention in the literature of scenario planning (Amer et al., 2013). Furthermore, intuitive logics assume business decisions are based on a complex set of relationships among economic, political, technological, social, resource, and environmental factors (Amer et al., 2013). This fits within system dynamics as it considers the structure of systems which consists of relating and interacting objects. So the complex set of relationships could be mapped by the use of system dynamics. Furthermore, system dynamics adds an extra layer of understanding by considering complex dynamic factors as feedback loops, stocks and flows, and delays. Furthermore, the qualitative and business-friendly character of intuitive logics creates better possibilities to combine with a technique as system dynamics. As described intuitive logics scenario planning steps have overlapping factors with system dynamics. Furthermore, the group model building aspect, which increased in popularity last decades, fits within the process of using tools while involving clients. The literature of system dynamics, Luna-Reyes and Andersen (2003) identified steps which are similar for various approaches: conceptualization, formulation, testing, and implementation. Furthermore, based on research of Andersen et al. (1997), besides a process dimensions also a structural dimension exist in group model building. This structural dimension considers of group structure and a logistic component in which the first refers to participant and composition of the groups, and the latter refers to location, fitting and equipment of the room. Considering intuitive logics, a range of similar steps was identified by Wright et al. (2013): setting the agenda, determining driving forces, clustering driving forces, defining cluster outcomes, impact/ uncertainty matrix, framing scenarios, scoping scenarios, and developing scenarios. In iterative experimenting with combing both methods while maintaining strengths of both theories, the following phases are proposed: preparation, definition, conceptualization, scenario definition, formulation, testing, scenario development and validation and evaluation & strategic decision making. These steps will be further described in the following part.

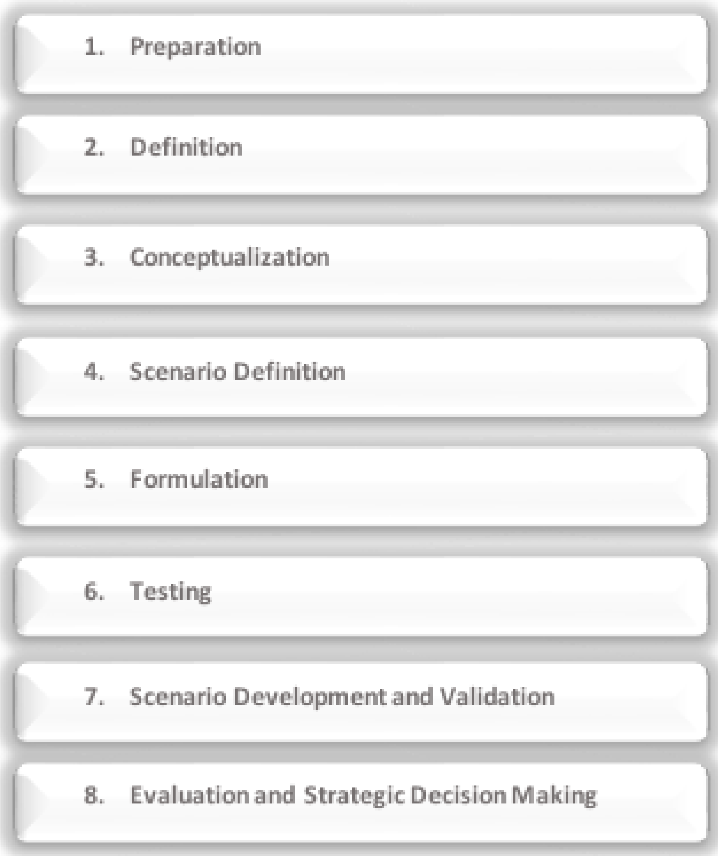


Figure 10: System Dynamics-based Scenario Planning

3.1 System Dynamics-based Scenario Planning

1. Preparation

The first phase in the process of system based-scenario planning consists of a preparation phase in which activities involves up front the group session. It is recommended to include a specialist in the field of strategic management tools regarding system dynamics and scenario planning. Furthermore, participants of the process must be carefully considered up front, participants must be prepared for the session and the setting of the session must be considered.

As first, it is recommended to include a specialist in the field of strategic management tools such as system dynamics and scenario planning. Therefore, contact should be set up with a facilitator of the process. Up front the group session, conversations must take place between the expert in the field of system dynamics and scenario planning, and key problem owners within the company. Andersen et al. (1997) stress the importance of involving key problem owners in the introductory phases and labeled the key role of a company's contact person as a gatekeeper. The gatekeeper must identify the (broad) purpose of the system dynamics-based scenario planning, select the right people within the organization who will participate in the session and consider logistic activities. The literature supports early involvement in the process by conducting interviews with the key problem owners (Luna-Reyes & Andersen, 2003). By interviews conducted up front the session, the facilitator gets an understanding of the problem and could identify key variables and constructs. Discussions up front may be short in nature, however, these are important to planning the group sessions.

System dynamics-based scenario planning is based on group model building principles. So, it is important the right persons are involved in the process. The gatekeeper is responsible for identifying the right participants for the session. The group must consist of stakeholders and/ or experts in the system or part of the system (Bérard, 2010). Besides the participants in the group session, two to five persons should take the role of facilitator, gatekeeper, and modeller (Andersen & Richardson, 1997). The structure and size of the group depend on the context of the purpose and the system. A diversity of the group can have favourable outcomes, however communication is more difficult when more participants are involved and opinions are too widespread. This is aspect should be considered up front the process.

When participants are determined, hand-outs could be supplied with information of the session in terms of subject, goal and problem statement. When the right participants are included, the chance is high they are familiar with the issue and there could be further elaborated in the group session to better specify the problem, goal, and scope. The hand-out aims at informing the participant about the purpose of the session and the techniques used. It is recommended to let the participants think about important driving forces and identify trends. These driving forces could be derived from a PESTEL analysis.

When the group session is conducted, considering the logistics component increases the communicative efficiency of the session. The logistics component is scarce in literature, but a decent room set up regarding layout and technical setup could facilitate communication and the execution of tasks (Andersen & Richardson, 1997). These authors describe the chairs must be placed in a semicircle and consists of swivel chairs to foster communication with different members of the group. Furthermore, it is useful to use technical supports as digital whiteboards to project and simulate models.

2. Definition

The definition phase will define the boundaries of the session. In this phase, the problem, goal, scope, timeframe, and variables will be discussed. The goal is to create a shared understanding of the problem and what is relevant to address this problem in terms of goal, scope, timeframe and variables. As this phase states the boundaries, it is important to determine what factors will be included and so, what will not be included as the process of system dynamics-based scenario planning could be an infinitely ongoing process.

The first step of the group session is defining the problem. The problem will set the objective and scope of the session. In the preparation, the problem is discussed between the facilitator and key problem owners and presented to the participants to think about the problem and identify drivers. When the problem is not clearly defined, techniques as brainstorming could be used to increase the number of ideas regarding the problem and understanding the setting of the problem. It could be hard to derive consensus within the group, especially with messy problems. A facilitator is crucial to creating consensus and commitment in the group in which it is important to talk and listen reflectively to problem owners (Bérard, 2010; Martinez-Moyano & Richardson, 2013).

Based on defining the problem, a goal must be set. This goal must address the question what the team wants to achieve with the scenario based- scenario planning session. The tool allows flexibility in addressing the goal, which could vary from achieving an understanding of possible dynamic futures, considering strategies, determine focus areas of interest or assess real options throughout multiple futures. Furthermore, the combination of scenario planning and group model building allows flexibility in the outcome product itself. The full potential of this technique is to provide complex dynamic scenarios in which the behaviour of the system over time could be monitored. However, among other things products could also include stock and flow diagrams, a causal map diagram or running model (Andersen & Richardson, 1997).

When the problem, goal, and outcome is defined, the scope of the session is set in terms of products, market, geographic areas and technologies (Schoemaker, 1995). As Schnaars (1987) discuss, in corporate planning managers are usually created on more focused outputs. The scope will be adjusted to aspect within the environment which directly affect the products and markets of the company. However, this brings the risk of a scope which is too narrow. Therefore, it appears a trade-off exists between the feasibility of considering a large number of factors and the validity of considering only a few variables (Schnaars, 1987). The timeframe set depends on several factors such as rate of technology change, product life-cycles, political elections, competitors' planning horizons etc. (Schoemaker, 1995).

Furthermore, relevant drivers must be identified which are influencing the system. The scope will be adjusted to aspects which directly influences the business environments. Upfront the session it was recommended to determine relevant factors and trends. In this phase, the drivers and trends will be discussed aiming at achieving consensus to include the right factors. Each driver and trend must be explained briefly including how and why it's influencing the business environment (Martinez-Moyano & Richardson, 2013). It is recommended to list the factors in an influence diagram and assess the factor in terms of positive, negative or uncertain to business' strategy (Schoemaker, 1995). The group must reach a consensus on which factors must be included. When no consensus is reached, the factors could be assessed while using DELPHI or relative importance techniques.

3. Conceptualization

It has been found difficult to get the client team to think in detail about causal linkages which forms the key feedback loops which control the system (Andersen & Richardson, 1997). Based on the desired outcomes this phase includes the conceptualization of the model. Best practices in this phase are recognizing that conceptualization is creative, a dialogue must be generated with the participants to address their mental models, and the start of the process is identifying major stock variables to describe the system and drew their reference modes (Martinez-Moyano & Richardson, 2013). The use of dynamic hypothesis in the conceptualization phase of the dynamic complex model is popularized in the system dynamic literature. This stage further describes the conceptualization process.

When the problem is defined and characterized as described in step 2, theories of the system must be developed. J. D. Sterman (2000) proposes to start developing these theories by formulating a dynamic hypothesis to account for problematic behaviour. He describes dynamic hypothesis as dynamic because it provides an explanation of dynamics characterizing the problem in terms of underlying feedback and stock and flow structure of the system, and it is a hypothesis as it is always provisional and subject to revision or abandonment as you learn from the process and real world (J. D. Sterman, 2000).

During this phase, a discussion will take place within the group to discuss problems and theories about causes of the problem. The mental models of the team must be tapped, so team members must share their theory regarding the elements involved in the system and the source of the ''problem''. All theories and mental models of participants must be captured by the facilitator. This facilitating role has an increased importance as opinions of team members could conflict and members advocate own opinions. First, the facilitator must capture mental models of participants without criticizing or filtering them. When mental models are discussed the group must move towards a more specified model.

In an earlier phase, participants have discussed elements or driving forces influencing the system, and the scope had been set. During this phase in which the model will get an appearance, the boundary of the model will be set. This could be done by using a model boundary chart. A model boundary chart creates a summary of the scope by structuring key variables which are endogenous, exogenous, and excluded. Endogenous variables generate system dynamics through interacting variables and agents in the model. By the specification of the system structure and rules of interaction between variables, patterns of behaviour could be explored and changes in behaviour could be explored when structure and rules are altered. Exogenous variables, arising from without, explains dynamics of variables which is cared about in terms of other variables assumed. System dynamics is based on an endogenous view and exogenous variables must be limited. (J. D. Sterman, 2000)

In the following step, it is case to actually map the system. The model boundary chart decides which variables are exogenous, endogenous and excluded but it does not the relation between the variables. A causal loop diagram, as discussed in the literature review, will be used to map the feedback structure of systems by showing causal links between variables with arrows of cause and effect. Besides the feedback structure, stock and flow diagrams emphasize the underlying physical structure and track accumulations. As mentioned the stock variables describe a certain state as inventory, population, financial account etc. A flow variable consists of the rates which influence the stock variable by altering the rate of inflow or outflow (J. D. Sterman, 2000). As last delays in the system must be identified.

4. Scenario Definition

In previous phase, the system was conceptualized by a model boundary, stocks and flows, and causal loop diagrams. Before assigning values to variables, scenario themes will be defined. In the literature, a range of options is proposed varying from one till multiple scenario themes. The purpose of this phase is to provide guidance, rather than providing the ''right'' amount of themes. Among other things, the decent number of themes depending on the major uncertainties within the system. However, system dynamics reflects the system is it is or could be. So, first, this paper proposes to provide a ''surprise-free'' scenario to understand the dynamics of the current system. A surprise-free scenario is based on the assumption no unexpected changes happen, which could or not could be the most likely (Schnaars, 1987). To further determine the scenario themes, the variables and related trends/ events which significantly affect the issues must be considered. The identification of trends, events, and uncertainties are the main ingredients to develop scenarios (Schoemaker, 1995). As mentioned the number of scenarios could vary heavily. The literature review of Amer et al. (2013) reveals the standard approach considers 3 – 8 number of uncertain factors and usually generate a range from 3 – 6 scenarios. A great number of scenarios tends to be confusing while one scenario is a point estimate forecast (Schnaars, 1987). When uncertainties are determined, a theme must be specified in which a possible scenario is described based on certain criteria. Possible themes could be best-case, worst-case, economic crisis, environmental concern, technologic transition etc. The process of identifying themes is to a large extent creative and judgemental, and depending on the experiences of the group (Coates, 2000). So, the selection of themes could depend per particular case.

5. Formulation

This phase considers the quantification of the model. Bérard (2010) describes the model formulation involves the process of knowledge elicitation to design a level-rate diagram, decision rules, the quantification and calibration of the model. On the one hand, the author mentions providing values to variables is based on individual meetings or on small nominal groups, as well as using structured and systemized group activities. This study focuses on conducting the session while using client groups. Luna-Reyes and Andersen (2003) describe the most common way is to elicit parameters and non-linear relations from problem owners by using interviews and group session. The facilitator could ask individual estimates for unknown parameters and provide a summary of the acquired values. Upper and lower limits, and a central tendency as mean or median could be used. Multiple rounds could be conducted, so a certain degree of consensus will be reached. Best practices in this phase found by Martinez-Moyano and Richardson (2013) is to start small and simple and to build the model out by adding complexity while later quantifying the structure a bit at a time. Furthermore, the equations must also make sense, as all parameters must have real-life meaning. The model could be simulated as early as possible even if models are simple. The model and simulations outcomes could be discussed with the group to consider viability. The assigned values depend on the chosen scenario themes. E.g. in an economic recession theme, economic values as the gross domestic product could be adjusted to change the system and investigate the model during the recession. The determined values and outputs per theme must be provided for later use.

6. Testing

Before creating scenarios based on the system dynamics model, the model must be validated. This will increase the credibility of the method and check for errors in the system. The technique proposed in this research is focussed on group sessions. It must be noticed advanced statistical techniques exists which could be used in isolation to calibrate system dynamics models and their potential use to estimate unknown parameters. However, although these techniques are considered as powerful aids to assess models, the system dynamics model has a qualitative nature and so, methods could not stand by themselves. Furthermore, the system is based on judgemental data. So, the modeller could involve the client team and ask the experts to assess the model structure and behaviour through the group session. The facilitator could ask specific questions about causal relationships and behaviour of the model. Individuals within the groups are asked to discuss his/ her level of agreement and explain the reasons why he or she agrees or disagrees on the statements. Furthermore, the facilitator could focus on specific parts of the model and challenge participants to criticize the model and suggest alternative theories.

7. Scenario Development and Validation

Until this phase the variables are determined, the themes are selected, the model is created, values are provided for the themes and the system is validated. In this phase, the actual scenarios will be constructed based on the simulated models. Members could consider the themes and matching outcomes and go down through each variable to judge which is plausible for the variable. Scenarios are based on uncertain factors which influence the system, but members might find some variables are not relevant for certain themes and could be eliminated for the scenario theme. The irrelevant factors could be determined based on the outcomes of the modelling process. Some variables might not influence other relevant factors significantly. When relevant variables are selected the team members could start writing the scenarios. Depending on the number of scenarios and number of participants, the scenarios could be divided. Important in scenario planning based on system dynamics, is that behaviour is not particularly linear but rather non-linear. This increases complexity in scenario development and must be carefully considered. This extra complex element, however, does increase understanding of the system. When scenarios are written, the team will come together to present and evaluate the scenarios (Coates, 2000). The author further addresses the questions whether the written scenarios are interesting and well written, whether all points have been made adequately, and whether a point can be made more incisively. These steps could be taken until scenarios are satisfactory. To further validate the scenarios Amer et al. (2013) identified shared stages of validating scenarios. The identified scenarios must be tested for plausibility, consistency, utility/ relevance, novelty, and differentiation. Scenarios respectively must be capable of happening (plausible), must ensure that no built-in inconsistency and contradiction exists (consistency), must contribute insights into to future which help to make decisions (utility/ relevance), must challenge the organization's wisdom about the future (challenge), and must be structurally different (Amer et al., 2013).

8. Evaluation & Strategic Decision Making

Up to this phase scenarios, the system is mapped and scenarios are created based on the system. Furthermore, scenarios are validated and discussed. At the beginning of the process, the modelling team set goals and outcomes of the session. This phase addresses whether the outcomes are reached and useful for further evaluation. This phase also considers identifying further research needs as discussed by Schoemaker (1995). The author discusses the team might need to do further research to increase understanding of uncertainties and trends. In this case, system dynamics principles are introduced in the scenario planning process to get a better understanding of the system in which the company is behaving. The group session could formulate the model, but could be further specified to improve the model. The model might provide new perspectives which could be interesting to study further. Finally, when the potential of the output is discussed, the team could move towards making decisions to solve the problem stated in the beginning. Possible actions could be discussed and compared to the behaviour of the model. An overview of the system dynamics-based scenario planning method is provided in Table 10.

System Dynamics-based Scenario Planning	
1. Preparation	**Includes stages up front the session:** define team, upfront conversation with facilitator, develop hand-out, determine logistics.
2. Definition	**Defines the boundary of the session:** define problem, define goal, define expected outcome, define scope/ timeframe, identify drivers and trends.
3. Conceptualization	**Conceptualization of the model:** formulate ''dynamic hypothesis'', discussion of problems and theories, capture mental models of participants, set boundary of the system, map the system: causal loop diagram, stocks and flows, time delays.
4. Scenario Definition	**Set the themes of the scenarios:** determine main uncertainties/ trends, determine the themes, determine amount of scenarios.
5. Formulation	**Quantification of the model:** ask individual estimates for parameters, repeat the process based on acquired information, derive consensus, adjust parameters for scenario themes, provide model output per theme.
6. Testing	**Validation of the model:** ask questions about causal relationships and behaviour, determine level of agreement, challenge participants.
7. Scenario Development & Validation	**Actual scenario development and validation:** consider theme and outcome, determine relevance/ plausibility of variables, start scenario development, present and evaluate scenarios, test scenarios for plausibility, consistency, utility, novelty, differentiation.
8. Evaluation & Strategic Decision Making	**Assess outcome and further evaluation:** evaluate realized outcomes, identify further research needs, further strategic decision making.

Table 10: System Dynamics-Based Scenario Planning

4 Case Study

In this part a short case study will be conducted. This short case study will be conducted to illustrate and test the technique in order to assess the technique in an iterative way and draw conclusions about the usability. The case study will follow the steps created in the theory development phase in chapter three and will be based on the oil and gas industry. The steps followed are preparation, definition, conceptualization, scenario definition, formulation, testing, scenario development & validation, and evaluation. This case will be adjusted to particular goals of this case: illustrating and testing the technique which is developed. As mentioned the case study will be connected to the overarching research as explained in chapter 1.4 and will address the oil and gas industry. The preparation phase of the case study addresses the variables which are discussed up front the experiment which is conducted by the researchers as addressed in chapter 1.4. The researchers who conducted the experiment determined the drivers in collaboration with the company involved in the oil and gas industry. In the definition phase, the problem, goal, outcomes, scope, and timeframe will be provided. In the same step, a further investigation of drivers and trends will be conducted. As mentioned, the author is not exclusively involved in the oil and gas industry, therefore academic articles will be addressed to further identify drivers and structures to develop the system in order to create a better understanding of the system structure. So existing drivers from phase one will be complemented by drivers derived from literature to strengthen the system. A final list of drivers and corresponding definition will be provided. Based on the definition phase, the third phase includes the conceptualization of the model. In this phase dynamic hypothesises and mental models are processed in a discussion. This phase also shows which variables are treated as endogenous and exogenous, and which variables will be excluded from the model. This leads to a system which will be provided while using the AnyLogic software. The scenario definition phase sets the themes of the scenarios in part four of the case study. Because this case study aims at illustrating the technique, this phase will show the possibility of creating multiple other scenarios in part 4.1 and 5.1 of the case study. The themes methodology will be used in which per theme two variables are included per axis. This will result in four scenarios per themes, as could be seen in Figure 11: Theme 1. Based on the direction of the variable, the system will behave in a certain way: e.g. economic decline could lead to less energy demand. Therefore, other variables could be increased (+) or decreased (-). Further behaviour of the system will be presented in a table in which the direction of variables or provided based on the direction of

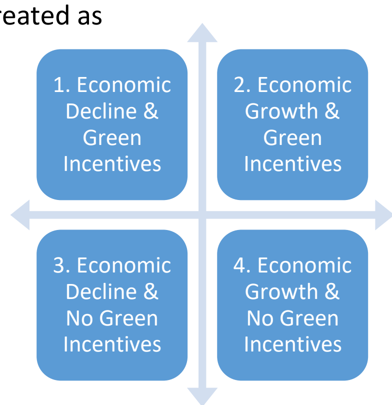


Figure 11: Theme 1

the variable which leads to various scenario outcomes. A scenario outcome consists of variables which tends to behave to a certain direction based on the direction of the input variables. Controlling the input variables will lead to different scenario outcomes. The creation of the axis will be provided in the scenario definition phase, in which part four describes the scenario which is worked out in more detail and part 4.1 describes other possible scenarios in terms of scenarios. The actual output will be further provided in the formulation phase. Part five of the case study describes the scenario theme which is worked out in more detail and part 5.1 describes the other possible outcomes. Besides the various theme and scenarios described in 4.1 and 5.1, the theme described in part four and five is further used to develop scenarios in part seven to illustrate the approach. The last step of the experiment will provide an evaluation.

1. Preparation

This part is intentionally left out for confidentiallity reasons.

2. Definition

Problem: The oil and gas industry could be characterized as dynamic and uncertain. The dynamics in the system involves the linkages between agents in the system, system linkages, and behaviour. Besides complexity, uncertainty drives this industry which means that factors are not predetermined in the future. The dynamic and uncertain market makes it more difficult to guide strategic direction in the long term. Therefore, the system must be understood to develop a robust strategy in order to survive in the industry.

Goal: The goal of this particular session is to map and understand the system and develop scenarios based on the system. The dynamic scenarios could act as input for strategic decision making.

Outputs: The system dynamics model will involve stocks and flows, causal diagrams and time delays to map the system. The output of the model will consist of multiple dynamic scenarios based on the system dynamics model to create an understanding of the system and possible future outcomes. The behaviour is estimated by data but the model will be mainly qualitative in nature because of the long-term timeframe.

Define scope: The goal of this session is to map and understand the general system of the energy industry. General links will be identified and processed in the causal loop diagram. General links are derived from literature: e.g. the supply/ demand loop is often mentioned. The timeframe will be set in the long term. To create an understanding on long-term dynamics only main constructs and loops of the industry will be considered, i.e. factors which are highly related to the industry. A focus on long-term increases the use of qualitative methods as discussed in Amer et al. (2013).

This part is intentionally left out due for confidentiality reasons.

3. Conceptualization:

This part is intentionally left out due for confidentiality reasons.

Figure 12: Variables and Relations

Figure 13: Causal Loop Model Energy Market

4. Scenario definition

This part is intentionally left out due for confidentiality reasons.

5. Formulation

This part is intentionally left out due for confidentiality reasons.

6. Testing

This part is intentionally left out due for confidentiality reasons.

7. Scenario Development & Validation

This part is intentionally left out due for confidentiality reasons.

8. Evaluation & Strategic Decision Making

This part is intentionally left out due for confidentiality reasons.

5 Conclusion and Discussion

5.1 Conclusion

This research aimed at creating a new technique to address dynamic complexity in scenario planning by combining scenario planning and system dynamics in order to increase understanding in dynamic complex environments and possible futures of such environments. To fulfil the need of the research goal, the report was structured by three central research questions. The first question refers to the features of scenario planning and system dynamics, and which features could be combined in order to address dynamic complexity. The second question refers to how these features practically will be combined to create a credible approach. As last, the third question refers to the actual use of the approach to develop complex dynamic scenarios.

The literature provided in chapter 2 presented both theories in terms of definitions, features, schools of thought and approaches. The scenario planning theory was more dispersed in terms of definitions, schools of thought and approaches. An overview is provided to structure the literature of scenario planning. In general scenario planning schools of thought follows the intuitive logics, probabilistic modified trends, or La Prospective school of thought. Most popular and user-friendly was the use of intuitive logics theory. For system dynamics, the theory was less widespread regarding schools of thought, but differences exists because of differences in opinions. Main point was the use of qualitative and/ or quantitative modelling. In last decades system dynamics evolved from method which was used in isolation by a modeller, to involvement of the client group which resulted in ''group model building''. When comparing both theories, scenario planning aims at describing the future and assess future uncertainties to expand people's thinking and respond to future to future uncertainty whereas system dynamics describes a complex dynamic system and how such a system behaves to develop learning in complex systems, design better policies and effectively guide change. Both theories consider systems, in which scenario planning addresses uncertainty and system dynamics dynamic complexity. It is expected both theories could complement each other by mapping complex environments while considering dynamic complexity, and addressing uncertainty on the other hand.

Based on the literature review and comparison of theories, an approach is designed. The approach is based on a combination of system dynamic approach and features, and intuitive logics features of scenario planning. The designed approach consists of structured steps, but allows flexibility so the tool can be adjust to specific cases. Furthermore, the approach is designed to be applied in a group setting with the help of a facilitator. The designed approach was applied in a case to illustrate the approach and assess the approach. The case clarified the approach was able to produce scenarios based on the system dynamics model. To illustrate this further, besides the written scenario, eighty-eight scenarios were created of based on twenty-two themes. The scenarios showed how variables behaved based on the system when two variables behaves in a certain way. The process of creating a certain amount of scenarios while using the model made clear it was possible to create consistent scnenarios based on the system dynamics model. Pre-specified relations were followed which increased consistency between scenarios. The modelling process might not deliver a ''perfect'' model from the beginning, but the modelling process must include iterations to improve the model. With help of a facilitator viable models could be constructed based on the knowledge of the participants (experts). The linkages in the case were carefully specified by using existing literature about the oil and gas industry. The linkages are based on literature, but danger lies in wrong or changing linkages. When a wrong relation is considered in the model, it has effect on scenarios. Therefore, linkages must carefully be studied and assessed over time to avoid fundamentally wrong models. The created model with specified positive or negative linkages allows creating consistent scenarios, however there is still room for intuition. Multiple variables which influence the system could influence a single variable. The scenario developers must think about which variables puts a heavier weight on the variable, and so determine the direction of this variable. Quantification of the model could reduce the intuitive reasoning. The case illustrated in this report is rather based on a qualitative approach to develop scenarios. The qualitative approach was able to provide a causal loop model including delays and increase understanding of the system. A quantitative model could better map how systems behave and show how the structure of the system leads to complex dynamic behaviour. The creation of a quantitative model demands time and expertise which increases the complexity of the approach. A qualitative approach, however, still made it possible to construct a system dynamics model and create scenarios while considering complexity and uncertainty. However, the proposed approach does allow for flexibility and provides a basis for scenario based-scenario planning to address dynamic complexity in scenario planning, in which users could adjust steps within the model to fit their need.

5.2 Contributions

The report could contribute in theoretical and practical way. Theoretically seen, first a literature review is conducted in the theories of scenario planning and system dynamics. It became clear, especially the literature of scenario planning was widely dispersed. To develop a combined approach, it was necessary to develop a clear overview of both theories. This study structures both theories by providing an overview of definitions, features/ characteristics and literature schools of thought. Furthermore, the developed approach provides a basis of the combination of scenario planning and system dynamics. This could be used to deal with dynamic complexity in scenario planning. The research provides a structured approach to deal with both dynamic complexity and uncertainty in complex systems.

In practice, the proposed approach helps in understanding complex system while developing scenarios. Therefore, the approach could be used as great learning experience in complex and uncertain systems. Understanding dynamic complex principles as feedback loops, stock an flows, and time delays helps individuals to better understand behaviour in complex systems and increases effective decisions making. In combination with scenario planning, people will be able to identify uncertainty in dynamic systems. Furthermore, this research developed an approach which companies can use as management approach to address both dynamic complexity and uncertainty. So, besides learning about complex systems in scenario planning, the approach could help companies to develop dynamic complex scenarios which could help to develop robust strategies based on future uncertainty and complexity.

5.3 Limitations

Although the research proposed a structured approach provides a way to address dynamic complexity in scenario planning and so addresses complexity and uncertainty, the author is aware of limitations of this research.

As first, a limitation is the application of the approach in a qualitative way. Although, qualitative modelling helps to understand the system and allows for scenario planning, system dynamics has its roots in engineering and applied mathematics. System dynamics has been applied within many disciplines such as physics, engineering, economics, management. The author approached the research with a business perspective, so these aspects are taken into consideration. Therefore, it was hard to construct a quantitative model. However, quantification of the model could lead to better modelling of the system in order to see how the structure of the system leads to dynamic complex behaviour.

Second, the approach is developed and tested in isolation. So, the practical feasibility in a group setting is not tested. As theory and practice differ, it is case to test whether the approach is feasible in practice. Including system dynamics adds an extra layer of complexity to scenario planning. It is argued in literature people have difficulties in coping with dynamic complex elements which might increase complexity of the approach. Furthermore, the approach itself is based on literature and a theoretical case application. So, the approach is based on theory rather than practice. Conducting the approach in practice might lead to new insights to fine-tune the approach.

5.4 Future Research

This research provides a basis to combine both scenario planning and system dynamics to address complexity in scenario planning. Addressing the main limitation of not testing the approach in a quantitative setting, a future step would be researching the application of a quantitative system dynamics model in the system dynamics-based scenario planning approach. A quantitative model increases complexity but it shows how the system behaves based on its structure, i.e.: different relations within the model will lead to different kinds of behaviour as explained in the theory part. When a quantitative model is produced, the applicability to scenario development must be assessed. In this case, scenarios are created based on a causal loop model. When producing a quantitative model, there must be assessed in which way scenarios could be developed and assess to which extent this increases the usefulness of the approach.

Furthermore, future research could focus on improving the method by conducting the approach in practice and eventually conduct experiments to compare conventional scenario planning/ system dynamic outcomes with a combined method. Practical research could improve the approach to reach its full potential. The approach is based on best practices in the field of system dynamics and scenario planning, but practical insights could assess practical best-practices and fine-tune the approach.

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Appendix A: Scenario Planning Techniques & Features

Comparison of the principal scenario development techniques

Scenario characteristics	Intuitive logics methodology	La prospective methodology	Probabilistic modified trends (PMT) methodology
Purpose	Multiple, from a one-time activity to make sense of situations and developing strategy, to an ongoing learning activity	Usually a onetime activity associated with developing more effective policy and strategic decisions	A onetime activity to make extrapolative prediction and policy evaluation
Scenario type/perspective	Descriptive or normative	Generally descriptive	Descriptive
Scope	Can be either broad or narrow, ranging from global, regional, country, industry to a specific issue	Generally a narrow scope but examines a broad range of factors within that scope	Scope is narrowly focused on the probability and impact of specific events
Time frame	Varies: 3–20 years	Varies: 3–20 years	Varies: 3–20 years
Methodology type	Process oriented approach, essentially subjective and qualitative	Outcome oriented approach, which is directed, objective, quantitative and analytical relying on complex computer based analysis and modeling	Outcome oriented approach, very directed, objective, quantitative and analytical using computer based extrapolative simulation models
Nature of scenario team	Usually an internal team from the organization for developing scenarios	Combination of some members from client organization led by an expert (external consultant)	External teams, scenario developed by experts (external consultants)
Role of external experts	Experienced scenario practitioner to design and facilitate the process. External experts are used to obtain their views for new ideas	Leading role of external expert using an array of proprietary tools for comprehensive analysis	Leading role of external expert using proprietary tools and expert judgments to identify high impact unprecedented events
Tools	Generic tools like brainstorming, STEEP analysis, and stakeholder analysis	Proprietary and structural tools like Micmac, SMIC and Mactor analysis etc.	Proprietary tools like trends impact and cross impact analysis etc.
Starting point	A particular management decision, issue or general concern	A specific important phenomenon of concern	Decisions/issues for which detailed and reliable time series data exists
Identifying key driving forces	Intuition, STEEP analysis, research, brainstorming techniques, and expert opinion	Interviews with stakeholders and comprehensive structural analysis using sophisticated computer tools	Curve fitting to past time series data to identify trends and use expert judgment to create database of unprecedented events
Developing scenario set	Defining the scenario logics as organizing themes or principles	Matrices of sets of possible assumptions based on the key variables for future	Monte Carlo simulations to create an envelope of uncertainty around base forecasts
Output of scenario exercise	Qualitative set of equally plausible scenarios in narrative form with strategic options, implications, and early warning signals	Multiple quantitative and qualitative scenarios supported by comprehensive analysis, implications and possible actions	Quantitative baseline case plus upper and lower quartiles of adjusted time series forecasts
Use of probabilities	No, all scenarios are equally probable	Yes, probability of the evolution of variables under assumption sets of actors' behavior	Yes, conditional probability of occurrence of unprecedented and disruptive events
No. of scenarios	Generally 2–4	Multiple	Usually 3–6 depends on the no. of simulations
Evaluation criteria	Coherence, comprehensiveness, internal consistency, novelty, supported by rigorous structural analysis and logics	Coherence, comprehensiveness, internal consistency tested by rigorous analysis; plausible and verifiable in retrospect	Plausible and verifiable in retrospect

[redacted] Comparing starting points, process and products of the scenario techniques

Technique	*Starting point*	*Process*	*Products*
1. Judgment			
Genius	Personal information	Thinking, imagining	One or more scenarios
Visualization	Personal information, unconscious ideas, values	Relaxation, stimulation of imagination	One or more scenarios
Role playing	Personal information, unconscious ideas, values	Act out one or more pre-arranged conditions	One or more scenarios
Coates and Jarratt	Personal or team information	Define domain and time horizon, identify conditions or variables of interest, develop scenario themes, estimate values of conditions and variables under each scenario theme, write the scenarios	Four to six scenarios
2. Baseline			
Manoa	Dominant trends	Implications, cross-impacts, elaboration	Elaborated baseline scenario
3. Elaboration of fixed scenarios			
Incasting	Multiple scenario logics	Elaboration on specific domains	Elaboration of multiple scenarios
SRI	Multiple scenario logics	Specific domains in rows	Elaboration of multiple scenarios in specific domains
4. Event sequences			
Probability trees	Branching uncertainty or choice points	Sequence, assign probabilities	Probability of end states
Sociovision	Branching uncertainty or choice points	Cluster similar alternatives into macro themes	Multiple scenarios
Divergence mapping	Multiple potential events	Place on one of four time horizons, link events in sequence	Multiple future histories
Future mapping	Multiple end states, many potential events	Sequence events to create end state	Future history
5. Backcasting			
Backcasting, horizon mission methodology	One or more end states, can even be fantastical	Steps that could lead to that end-state	Ideas for near-term work or investment
Impact of future technologies	Technology themes	Highly capable scenarios, signposts leading to scenario, cost/benefit	Contingent strategies to pursue given the occurrence of signposts

6. Dimensions of uncertainty			
Morphological analysis, field anomaly relaxation	Dimensions of uncertainty	Multiple alternatives for each dimension, link one alternative from each dimension	Multiple end states as combinations of one alternative from each dimension
GBN	Driving forces, two dimensions of uncertainty	Select two most important and most uncertain, create 2×2 matrix, title and elaborate	Four mutually exclusive scenarios
Option development and evaluation	Dimensions of uncertainty	Multiple alternatives for each dimension, rate consistency of every alternative against every other alternative, perform nearest neighbour calculation	Ranking of combinations of alternatives from most to least consistent
MORPHOL	Dimensions of uncertainty	Multiple alternatives for each dimension, link one alternative from each dimension, excluding impossible combinations and rating more likely combinations more highly; can calculate probability of combination of probabilities of	Multiple end states as combinations of one alternative from each dimension, based on exclusions and likelihood of pairs of alternatives; can calculate probability of combination of probabilities of alternatives are known

Technique	*Starting point*	*Process*	*Products*
7. Cross-impact analysis			
Cross-impact analysis	Potential future events or end states	Initial probability of each, contingent probabilities of each given the occurrence of each other, Monte Carlo simulation	Final probabilities of each event or end state
IFS	Variables of future ends states	High, medium, low values of the variables, initial probability of each range, cross-impact of ranges from different variables on each other, Monte Carlo simulation	Final probabilities of each range of each variable
SMIC PROB-EXPERT	Potential future events or end states	Initial probability of each, contingent probabilities of each given the occurrence of each other, correction of contingent probabilities for consistency, Monte Carlo simulation	Final probabilities of each event or end state
8. Modelling			
Trend impact analysis	Trend, one or more potential future events	Estimate impact of event on trend – time of initial impact, max impact, time of max impact, time of final impact	Adjusted trend values
Sensitivity analysis	Systems model with boundary conditions	Enter multiple plausible values for each uncertain boundary condition, possibly Monte Carlo simulation	Range of plausible outcome variable
Dynamic scenarios	Dimensions of uncertainty	Build system model for each dimension, combine into one overall model	Dynamic behavior associated with each scenario

Attributes of the scenario techniques

Technique	*Basis*	*Perspective*	*Group*	*Computer*	*Difficulty 1-4 (4 hardest)*
Genius	Judgment	Forward	No	No	1.2
Visualization	Judgment	Forward	Optional	No	2.3
Role playing	Judgment	Forward	Required	No	2.2
Coates	Judgment	Forward	Optional	No	2.3
Manoa	Judgment	Forward	Optional	No	2.2
Incasting	Judgment	Forward	Recommended	No	2.5
SRI	Judgment	Forward	Optional	No	2.3
Probability trees	Quantification	Forward	Optional	Optional	2.5
Sociovision	Judgment	Forward	Optional	No	2.6
Divergence mapping	Judgment	Forward	Optional	No	2.2
Future mapping	Judgment	Backward	Optional	No	2.6
Impact of future technologies	Judgment	Backward	Optional	No	2.8
Backcasting, horizon mission methodology	Judgment	Backward	Optional	No	2.3
Morphological analysis, field anomaly relaxation	Judgment	Forward	Optional	No	2.3
GBN	Judgment	Forward	Optional	No	2.6
Option development and evaluation	Quantification	Forward	Optional	Required	3.0
MORPHOL	Quantification	Forward	Optional	Required	2.5
Cross-impact analysis	Quantification	Forward	Optional	No	2.5
IFS	Quantification	Forward	Optional	No	2.8
SMIC PROB-EXPERT	Quantification	Forward	Optional	No	2.3
Trend impact analysis	Quantification	Forward	Optional	Optional	2.5
Sensitivity analysis	Quantification	Forward	Optional	Required	3.3
Dynamic scenarios	Judgment	Forward	Optional	Optional	2.8

Advantages and disadvantages of the scenario techniques

Technique	*Advantages*	*Disadvantages*
1. Judgment (Genius, visualization, sociodrama, Coates and Jarratt)	Easy to do Taps into intuitive understanding of the future Genius, Coates and Jarratt – requires no special training or preparation Visualization, sociodrama – can lead to novel insights and revelations	Difficult to do well Opaque, not transparent Genius, Coates and Jarratt – relies on the credibility of the individual Visualization, sociodrama – requires some training and experience to do well; clients may resist relaxation or dramatic techniques
2. Baseline (Trend extrapolation, Manoa, systems scenarios, trend impact analysis)	Easiest for client/audience to accept because generally expected already Manoa – highly elaborated, creative, lots of detail Systems scenarios – shows dynamic relationships among scenario elements Trend impact – links events with trends	No alternative scenarios proposed Manoa, systems scenarios – futures wheel, cross-impact, and causal models require some training and experience to do well Trend impact – requires judgment to estimate impacts, best done with group of experts, perhaps using Delphi
3. Elaboration of fixed scenarios (Incasting, SRI matrix)	Easiest for client/audience participation because scenario kernels/logics are done for them Provides in-depth elaboration of alternative scenarios	Generic scenario kernels/logics might not be relevant to client/audience; therefore less buy-in SRI Matrix – many have an intuitive sense of the best-case and worst-case scenarios already; filling in the cells of the matrix with many rows (domains) might become tedious
4. Event sequences (Probability trees, sociovision, divergence mapping, future mapping)	Tells the story in the usual way, as a series of events If probabilities at each branch point are known, can calculate the probability of end-states	Probability trees, sociovision – events/branch points usually do not follow each other in a fixed sequence Divergence mapping – events are not always easy to classify according to time horizon Future mapping – pre-defined end-states and events might not be relevant to the client/audience
5. Backcasting (Horizon mission methodology, impact of future technologies)	Creative because it decreases the tendency to extrapolate the future based on the past and the present; therefore can provide new insights Also results in a sequence of events or breakthroughs	Fantastical nature of the mission or end-state might reduce buy-in for client/audience Impact of Future Technologies – process for developing signposts and recommendations still opaque

6. Dimensions of uncertainty (Morphological analysis, field anomaly relaxation, GBN, option development and option evaluation, MORPHOL)	Best for considering alternative futures as a function of known uncertainties GBN –the right mix of technical sophistication and ease of use for a professional audience OD/OE – allows for the calculation of consistency among different combinations of alternatives (scenarios) MORPHOL – allows for the reduction of scenario combinations by the exclusion and likelihood of some pairs of alternatives; also allows for calculating the probabilities of different scenarios if the probabilities of the alternatives are known	Less creative because may not consider some novel developments that are not currently considered uncertain GBN – almost impossible to fully characterize the uncertainties of the future with just two dimensions OD/OE, MORPHOL – almost impossible to make valid estimates of the compatibility or influence of all alternatives against all other alternatives
7. Cross-impact analysis (IFS, SMIC-PROB-EXPERT)	Calculates the final probabilities of alternatives or end-states based on rigorous mathematical procedure SMIC – adjusts the matrix of conditional probabilities for consistency with the laws of probability IFS – allows for quantitative analysis of alternative future values of important variables	Almost impossible to validly estimate the conditional probabilities or impacts of all alternatives against the others
8. Systems modeling (Sensitivity analysis, dynamic scenarios)	Creates the best quantitative representation of continuous variables that describe the future state	Difficult to validate the models without complete historical data

Appendix B: Relation Numbers & Sources

This part is intentionally left out due for confidentiality reasons.

Model Linkages and Sources		
Number	Source	Relation
1	Morales-Acevedo (2014)	-
2	Hosseini, Shakouri G, Kiani, Pour, and Ghanbari (2014)	(-)
3		
4	Hosseini et al. (2014)	(-)
5		
6		
7		
8		
9		
10		
11		
12	Hosseini et al. (2014)	(-)
13		
14		
15		
16		
17	Hosseini et al. (2014)	-
18	RafieiSakhaei et al. (2016b) Rafieisakhaei et al. (2017)	+
19	RafieiSakhaei et al. (2016a) RafieiSakhaei et al. (2016b)	+
20		
21	Hosseini et al. (2014)	+
22		
23		
24	RafieiSakhaei et al. (2016b)	(+)RafieiSakhaei et al. (2016b)
25		
26		
27		
28	Qudrat-Ullah (2013) Hosseini, Ghaderi, and Shakouri (2012)	(+)
29	Aslani, Helo, and Naaranoja (2014)	+
30		
31	Qudrat-Ullah (2013)	(+)
32	FORD (2008)	(+)
33	Qudrat-Ullah (2013)	+
34	RafieiSakhaei et al. (2016b) Rafieisakhaei et al. (2017)	+
35	Qudrat-Ullah (2013) Kilanc and Or (2006) Hosseini et al. (2014)	+
36	Qudrat-Ullah (2013)	(-)
37		
38		

39	RafieiSakhaei et al. (2016b)	-
40		
41		
42		
43	Qudrat-Ullah (2013) Kilanc and Or (2006)	(+)
44		
45	Hosseini, Ghaderi, et al. (2012)	-
46	Qudrat-Ullah (2013)	(-)
47		
48	Qudrat-Ullah (2013) Kilanc and Or (2006)	+
49	Qudrat-Ullah (2013)	(-)
50	Qudrat-Ullah (2013)	-
51	Hosseini et al. (2014)	(+)
52		
53	RafieiSakhaei et al. (2016b) Ata (2013)	0
54		
55	Ata (2013)	(+)
56		
57	Qudrat-Ullah (2013) Ata (2013)	(+)
58	Ata (2013)	+
59	Ata (2013)	+
60	Qudrat-Ullah (2013)	+
61		+
62	Qudrat-Ullah (2013)	(-)
63	Qudrat-Ullah (2013)	(-)
64		
65		
66		
67		
68		
69		
70	Qudrat-Ullah (2013)	(+)
71		
72		
73	Qudrat-Ullah (2013)	(+)
74	FORD (2008)	(+)
75	Qudrat-Ullah (2013)	(-)
76	Hosseini et al. (2014)	+
77		
78		
79		
80		
81		
82	Qudrat-Ullah (2013)	(+)
83		
84		

85	Qudrat-Ullah (2013)	(+)
86	RafieiSakhaei et al. (2016a)	+
87	Qudrat-Ullah (2013)	+
88		
89		
90		
91		
92		
93	Hosseini et al. (2014)	(+)
94	Hosseini et al. (2014)	(+)
95		
96		
97		
98		
99	Aslani et al. (2014)	(+)
100		
101		
102		
103	Aslani et al. (2014) Ata (2013)	+
104	Aslani et al. (2014)	0
105	Aslani et al. (2014) Ata (2013)	+
106	Hosseini et al. (2014)	(+)
107	FORD (2008)	-
108	Aslani et al. (2014)	+
109		
110		
111		
112	Aslani et al. (2014); Qudrat-Ullah (2013) Ata (2013)	(+)
113	Aslani et al. (2014) Ata (2013)	(+)
114	Ata (2013)	(+)
115	Qudrat-Ullah (2013)	(+)
116	FORD (2008)	+
117	Qudrat-Ullah (2013)	(+)
118		
119		
120	Hosseini, Shakouri, and Akhlaghi (2012) Ata (2013)	-
121		
122	Hosseini, Shakouri, et al. (2012)	-
123		
124		
125		
126		
127		
128	Ata (2013)	(+)
129	Ata (2013)	(+)

130		
131		
132		
133	Ata (2013)	(+)
134	Aslani et al. (2014)	+
135	Ata (2013)	(+)
136		
137	FORD (2008)	+
138	Aslani et al. (2014)	(+)
139	Aslani et al. (2014)	0
140	Hosseini et al. (2014) Ata (2013)	+
141	Qudrat-Ullah (2013)	(-)
142	FORD (2008)	-
143	Qudrat-Ullah (2013)	(-)
144	Aslani et al. (2014)	(+)
145		
146		
147	Aslani et al. (2014)	(+)
148		
149	Speight, Banks, and Bansal (2008) Ata (2013)	-
150		
151		
152	Qudrat-Ullah (2013)	(-)
153	FORD (2008)	+
154	Hosseini et al. (2014)	(-)
155	Hosseini et al. (2014)	(+)
156	Rafieisakhaei et al. (2017) Qudrat-Ullah (2013)	-
157	Hosseini et al. (2014)	-
158	RafieiSakhaei et al. (2016b)	(+)
159	RafieiSakhaei et al. (2016a) RafieiSakhaei et al. (2016b) Rafieisakhaei et al. (2017) Qudrat-Ullah (2013)	-
160	Qudrat-Ullah (2013) Hosseini et al. (2014)	+
161	Qudrat-Ullah (2013)	(-)
162	Qudrat-Ullah (2013)	0
163	Qudrat-Ullah (2013)	+
164		
165		
166	Qudrat-Ullah (2013)	(+)
167		
168	Qudrat-Ullah (2013)	+
169		
170		
171		
172		

173	Hosseini et al. (2014)	+
174		
175		
176	Aslani et al. (2014)	(+)
177		
178		
179		
180	Aslani et al. (2014)	(-)
181		
182		
183	RafieiSakhaei et al. (2016a) RafieiSakhaei et al. (2016b) Rafieisakhaei et al. (2017) Morales-Acevedo (2014) Qudrat-Ullah (2013) Aslani et al. (2014) Ata (2013)	+
184	RafieiSakhaei et al. (2016b)	(+)
185	RafieiSakhaei et al. (2016b)	(+)
186	Qudrat-Ullah (2013)	(+)
187	Qudrat-Ullah (2013)	+
188		
189		
190		
191		
192		
193		
194		
195		
196		
197		
198		
199		
200	Ata (2013)	+
201		
202		
203		
204	Ata (2013)	(+)
205		
206		
207		
208		
209		
210	Morales-Acevedo (2014) Aslani et al. (2014) Ata (2013)	+
211		
212		
213		
214		

215		
216		
217	Aslani et al. (2014)	+
218		
219		
220		
221	Qudrat-Ullah (2013) Aslani et al. (2014)	0
222	Qudrat-Ullah (2013)	(-)
223		
224	Qudrat-Ullah (2013)	-
225	Qudrat-Ullah (2013)	-
226		
227	Aslani et al. (2014)	(+)
228	Aslani et al. (2014)	(+)
229	Hosseini, Shakouri, et al. (2012)	+
230	Ata (2013)	+
231		
232		
233	Aslani et al. (2014)	+
234		
235		
236		
237		
238		
239	Aslani et al. (2014)	+
240		
241		
242	Hosseini, Shakouri, et al. (2012)	(+)
243		
244	Aslani et al. (2014)	(+)
245		
246	Rafieisakhaei et al. (2017)	(-)
247	Rafieisakhaei et al. (2017)	(-)
248	Rafieisakhaei et al. (2017)	(-)
249	Rafieisakhaei et al. (2017)	(-)
250	Rafieisakhaei et al. (2017)	(-)
251		
252		
253	Aslani et al. (2014)	+
254		
255	Ata (2013)	+
256		
257	Speight et al. (2008)	+
258	Aslani et al. (2014)	-
259		
260	Qudrat-Ullah (2013)	-
261	Qudrat-Ullah (2013)	+
262		
263	Qudrat-Ullah (2013)	(-)

264	Qudrat-Ullah (2013)	(-)
265		
266		
267		
268		
269	Qudrat-Ullah (2013)	+
270		
271	Qudrat-Ullah (2013) Ata (2013)	+
272	Qudrat-Ullah (2013)	(-)
273	Ata (2013)	(+)
274		
275		
276		
277		
278		
279		
280		
281	Hosseini, Shakouri, et al. (2012)	(+)
282		
283		
284		
285		
286	FORD (2008) Ata (2013)	+
287	FORD (2008) Ata (2013)	+
288	FORD (2008) Ata (2013)	+
289		
290	Hosseini et al. (2014)	+
291	Qudrat-Ullah (2013)	(-)
292	Qudrat-Ullah (2013)	-)
293	Qudrat-Ullah (2013)	(+)
294	Qudrat-Ullah (2013)	+
295	Qudrat-Ullah (2013)	(-)
296		
297		
298		
299	Hosseini, Shakouri, et al. (2012)	+
300		
301		
302	Qudrat-Ullah (2013)	+
303	Aslani et al. (2014)	0
304		
305	Qudrat-Ullah (2013)	(+)
306		

Appendix C: Variables Matrix

This part is intentionally left out due for confidentiality reasons.

Appendix D: Scenario Themes

This part is intentionally left out due for confidentiality reasons.

Appendix E: Scenarios

This part is intentionally left out due for confidentiality reasons.