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A System Dynamics Model for Risk Assessment of Strategic Customer Performance Perspective in Power Plants

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Abstract:

The energy sector is a dynamic business environment, power plants have to deal with several complex risks, including both technical and non-technical risks. Thus, unexpected risks can disrupt the energy generation processes, with a negative long-term impact. Furthermore, these risks are not isolated, as their impact may affect a series of interrelated risks. To add to this complexity, the assessment of those risks may change with time in a dynamic business environment. This situation makes strategic decision making less effective regarding the successful design of a risk management system. Understanding the dynamic behaviour of a complex system of interrelated risks in the energy sector is very important to achieve a more sustainable overall performance of the power plants. This paper presents a System Dynamics (SD) approach to capture the interdependencies of strategic non-technical risks associated to the customer performance perspective in a risk management system for the energy sector. Several approaches for risk assessment focus on technical risks related to equipment but fail to consider the complex interactions with other risks and neither consider the dynamic nature of the business environment. A system dynamics model with 15 risk factors was built to assist decision makers in understanding the behaviour for such risks affecting the customer performance perspective. The model was validated in a power plant in the Middle East. The model allowed to highlight the impact of mitigating the risk of policy and regulations on the availability risk of the power plant and on the risk factor related to operational and maintenance cost.

Keywords:

System Dynamics, Risk Assessment, Simulation, and Modelling.

1. Introduction:

In the energy sector, there are several risks that must be considered in order to carry out a more effective risk assessment (ALMashaqbeh et al., 2018). These risks can interrupt the energy generation process and cause a long-term negative effect on the performance of the power plant. These risks may emerge from processes such as failures of equipment, natural disasters, accidents, intentional acts to disrupt energy supply, political, economic or environmental concerns, etc. (Achebe, 2011). Different approaches have been proposed to manage these risks and mitigate their impact. In the energy sector, the importance of the risk assessment process arises from the crucial role of power plants for supplying energy to society and industry (ALMashaqbeh et al., 2018). Energy is a significant factor for socio-economic strength of a nation. Environmental, economic, and social aspects of the performance of an energy organization can have an important impact on local society and even at the national level (Azadeh and Vafa Arani, 2016).

In the current global business environment, competition has increased and become more complex as trade barriers have been reduced or even eliminated. In this context, the importance of assessing risks that could affect the efficient and effective deployment of organizational strategies has become paramount not only for industry but also for governments (Radivojević and Gajović, 2014). This is also the case of the energy sector. Manners-bell (2014) affirms that reliable energy sources are critical to also support the supply chain and logistics sector. For that reason, the power grid is critical for the local and national economy and society. Kovacevic et al. (2013) also confirm that the energy sector plays a crucial role in modern economies and people life.

This paper develops a model to understand the interactions of key risk indicators related to the performance of the strategic customer perspective (customer risks at the strategic level) in the context of the energy sector, specifically for power plants. The model is constructed applying a System Dynamics (SD) approach. This approach will allow to understand the behaviour of this system of interrelated risk indicators within a dynamic business environment and defining the boundary of the system. In this way, policymakers and managers can be assisted in decision making to develop more effective and sustainable strategies. Different scenarios can be simulated to understand the behaviour of the system in a long-term timeframe and the impact on key risk indicators, specifically with a focus on the performance of the strategic customer perspective. The paper reviews relevant literature related to the philosophy of Systems Thinking, the related System Dynamics modelling technique and the importance of risk management to support strategic decisions. The paper continues with the selection of key risks relevant to the strategic customer perspective, analysis and development of Causal Loop Diagrams (CLDs) and Cause and Effect Diagrams of risks and the construction of the System Dynamics model. Finally, the paper presents the application of the model and simulation of a scenario in which the impact of mitigating the risk of policy and regulations on the availability risk of the power plant and on the risk factor related to operational and maintenance costs is highlighted. The model is simulated based on data collected from one power plant in the Middle East and other assumptions based on the literature review.

2. Literature Review:

Risk management helps to identify and assess relevant risk factors that may affect the successful deployment of strategic plans and decisions. In this way, risk management can assist policymakers, strategic planners, and managers in analyzing and taking countermeasures to ensure effective deployment of strategies. Power plants have to deal with several complex risks, including both technical and non-technical risks. Thus, unexpected risks can make interruption to the energy generation processes, with a negative long-term impact. Risk management can be considered as a key activity to support strategic decision making (Zhou et al., 2008). By analyzing the key risks that could jeopardize the successful implementation of long-term strategies, organizations could be better prepared to achieve the expected targets of performance objectives. However, in traditional approaches to risk management and assessment, the interrelationships among different risks are not considered. Furthermore, these approaches do not consider the dynamics of business environments in which the assessment of risk may change. Therefore, policy makers and managers need to consider risk management approaches that could help them to understand the interrelationships of risks and their effect of the strategy and performance of the organization. Thus, the risk management and assessment process can play a very important role in strategic decision-making processes for different functions or perspectives of the organization, e.g. financial, internal business processes and operations, supply chain operations, customer, learning (innovation) and growth, sustainability, etc. ((Zhou et al., 2008); (Jonkman et al., 2003); (Ergu et al., 2014)). The first steps in the risk management process are risk identification and the weighting of risk. The risk weighting will be used as inputs for the constant factors. Fundamentally parameters and their values generating from a pre-developed FMEA methodology which is clarified in detail in (ALMashaqbeh et al., 2018). After that, it is important to understand the interrelationships among those risk by applying tools like cause and effect tree diagrams and causal loop diagrams. A modelling technique like system dynamics could be applied to simulate the effect of such interrelationships of risks and considering changes in the weighting of those risks along time. Such analysis could help organizations to understand the impact of risks with a long-term strategic perspective, that could support taking better decisions and avoid poor organizational performance due to ineffective countermeasures (Ambrosio et al., 2011). Different scenarios could be tested to improve this approach to manage and assess risks (Sprague, 1980).

To improve the service of generating electricity and minimize important risks of supply interruption or poor performance of the service, an integral approach for identification of existing and potential risks in power plants should be developed and implemented. Pan et al. (2016) show that the potential risks along the operation of the business can disrupt the operation and cause significant losses, either these risks are catastrophic events like fire or flood or other smaller events like failures and breakdowns. All these risks will cause revenue losses, dropped production rates, inability to meet planned production goals, and these lead to reduce the reliability and hit the reputation of the company. In the same context, Liu and Arthanari (2016) clarify that risks present in each stage of life cycle, from the planning stage to the decommissioning stage of power plants and risks in one stage may affect other stages due to the integrity in the supply chain.

Electricity demand has increased by 3.5% annually. Decision-making process regarding the successful design of a risk management system in the electricity sector has become a challenge for investors and policymakers due to uncertainties of this sector and to retain in a reliable and affordable of supplying electricity ((Ahmad et al., 2016); (Foley et al., 2010)). Uncertainties in demand and fuel price, are different factors that affect long-term planning. However, for analyse long-term uncertainties, a dynamic model turns to be essential (Alishahi et al., 2012). Decision-making regarding risks is very complex thus, SD approach will be applied (Jonkman et al., 2003).

Systems thinking is a methodological approach (considered also as a philosophy) that considers the different factors that could affect the performance of an activity under study, analysing that activity as a system of interrelated factors. This approach can be applied to analyse different problems or situations in different fields of study, such as economics, biology, business studies, health care, etc. The aim of the application of systems thinking is to enhance the understanding of how the performance of the activity under study is linked to and affected by different internal and external factors (Sterman, 2000). Thus, systems thinking is a process to understand how factors in a system affect each other, influencing the overall performance of that system. This approach can be considered a problem-solving technique where the problem is considered as a system integrated by different interrelated parts or factors (Aslani et al., 2014). In the same context, Forrester (1968) and Rowitz (2013) emphasized that the systems thinking approach can also be applied to study social systems and public health problems. A modelling technique developed to apply the principles of systems thinking is System Dynamics, which allow simulating models of systems as their behaviour changes along time.

System Dynamics is a modelling technique that was originally used to capture the complexity of socio-economic and biophysical systems (Guo and Guo, 2015). These systems are represented by Stock and Flow Diagrams (SFD) which show how inputs are transformed into outputs along time. A series of parameters (constants) and variables are included to represent factors affecting the flow rates of those inputs in the system. This modelling technique, with the support and development of IT technologies, allows simulating those models to understand how the behaviour of the system changes with time. Thus, SD can be considered an analytical method which combines qualitative and quantitative analyses to understand the underlying behaviour of these complex systems over time (Liu and Zeng, 2017). In the same context,((Forrester, 1961) ; (Wei et al., 2012)) define the SD as the theory of system approach to represent a complex system and analyse the dynamic behaviour. On the other hand, ((Kotir et al., 2016); (Sterman, 2000)) assert that SD is a useful analytical tool help decision makers and scientists to understand the changes in system variables over time. Similarly, (Park et al., 2004) asserts that SD has been applied to analyse various systems economic, social, and environmental systems. On the other hand, (Coyle, 1996) affirms that SD focuses on the policies and dynamic behaviour of the system which is the crucial strategic feature of the top management. The aim of SD is identifying how the model structure and decision policies help in producing the observable behaviour of a system to implement decision policies (Qudrat-Ullah and Seong, 2010).

Due to the ability of SD in linking between the behaviour of a system to micro-level structure and decision-making processes, it is popular in the analysis of energy policies, the possible future scenarios, and management purposes (Qudrat-Ullah and Seong, 2010). The traditional approaches to risk assessment focusing more on the technical risks area and ignoring the interdependency among risks. Thus, this paper seeks to develop a risk assessment model depends on various data (literature review, experts, questionnaire, interviews and numerical data). The developed approach will consider the correlations among various risks in the customer risks perspective.

The research on this paper focuses on the analysis of key risks affecting the strategic performance perspective of the customer viewpoint. This is a very critical perspective as customer satisfaction will be strongly related to the flow of cash into the energy organization (e.g. a power plant). Furthermore, this perspective is important to ensure that customer needs are fully covered and to secure strengthening the relationship with customers with a long-term and sustainable view. Various risks factors (economic, social and demand risks) are identified to show how are interrelated with each other. Section 3 will cover these risks and the building of the SD model.

3. Building a System Dynamics Model for Risk Assessment

The System Dynamics (SD) model for risk assessment was started with the conceptualization and development of Causal Loop Diagrams (CLD) to represent the different risk factors affecting the strategic Customer Performance Perspective in the context of the energy sector. Then, the CLD will be translated into the form of an SFD and the relationships between the different factors will be quantified to be able to simulate the model using an SD software (Sterman, 2000). A Causal Loop Diagram (CLD) is a graphics tool represents for a better understanding of the internal relationships among variables and parameters (constants) that represent factors affecting the performance of the system ((Nabavi et al., 2017); (Aslani et al., 2014); (Park et al., 2014)) .CLDs are beneficial and flexible tools to emphasize the feedback structure of systems. The CLD and the SFD presented in this paper represent the interaction of 15 risk factors that may affect the performance of the Customer Performance Perspective (see Figure 1). These stages of the modelling methodology allow confirming the interrelationships among risk factors and they also help to identify feedback loops that may intensify (reinforcing loop) or reduce (balancing loop) the impact of certain risks on the performance of the system.

The systematic methodology followed to develop the SD model for risk assessment of the customer perspective considers 6 stages: (1) define the problem; (2) determine the system boundaries; (3) create the Causal Loop Diagrams (CLD) for each sub-models by considering the interrelations between factors; (4) construct the Stock and Flow Diagram (SFD) and quantify interrelations by defining mathematical relationships equations; (5) check, test and validate the model; (6) and finally simulate a scenario to understand the behavior of the model (system). This methodology can be applied to develop SD models to analyse the risks affecting other strategic performance perspectives (e.g. sustainability).

15 key risk factors have been identified which are strongly related to that customer perspective (see Table 1). These risks are selected through conducted focused groups and questionnaires survey at a large power plant in the Middle East and also from literature review accordingly, these risks have been assessed and evaluated using an improved failure mode and effect analysis and using analytic hierarchy process. At this stage, it is important to identify whether these risk factors will be considered to be controlled or influenced internally somehow within the system (endogenous risk factors) or whether these risk factors are external to the system and therefore the system has no control on them (exogenous risk factors). This helps to define the boundary of the system to be considered for the model (Dastkhan and Owlia, 2014). The weighting and influence of endogenous risk factors may be subjected to changes with time as the performance of the system also changes (e.g. due to the dynamics of the system).

Table 1: Risk Factors (Endogenous and Exogenous) affecting the strategic Customer Performance Perspective and define the system boundaries

Code	**Endogenous Risk Factors**
CR1	Demand uncertainties
CR2	Demand certainties
CR3	Availability risk
CR4	Outage hours
CR5	Power plants efficiency risk
CR6	Technical risks
CR7	Risk of operational and maintenance cost
CR8	Aggravation of operational and maintenance cost
CR9	Supplier price risk
CR10	Labour strike
CR11	Labour risk cost
CR12	Cost of policy and regulations
Code	**Exogenous Risk Factors**
CR13	Inflation rate
CR14	Policy and regulations
CR15	Global economic recession

To develop the risk assessment sub-models, the previously mentioned steps (1-6) should be followed. Accordingly, the system boundaries are determined as shown in Table 1 for the customer risk sub-model. Through the long term, the dynamic behaviour of the system can be detected which will help the decision makers in their policies. The causal loop diagrams are constructed with VENSIM®.

In the CLD in Figure 1, it is possible to see how uncertainties for the Demand for energy are affected by policy and regulations; technical risks; supply chain risks; global economic recession. The CLD also allows to highlight that Operational and Maintenance Cost is affected by labour strike; policy and regulations; power plant efficiency; and technical risks.

Then, the CLD can be created depending on the determined system boundaries. The CLD for the customer risks sub-model is depicted in Figure (1).

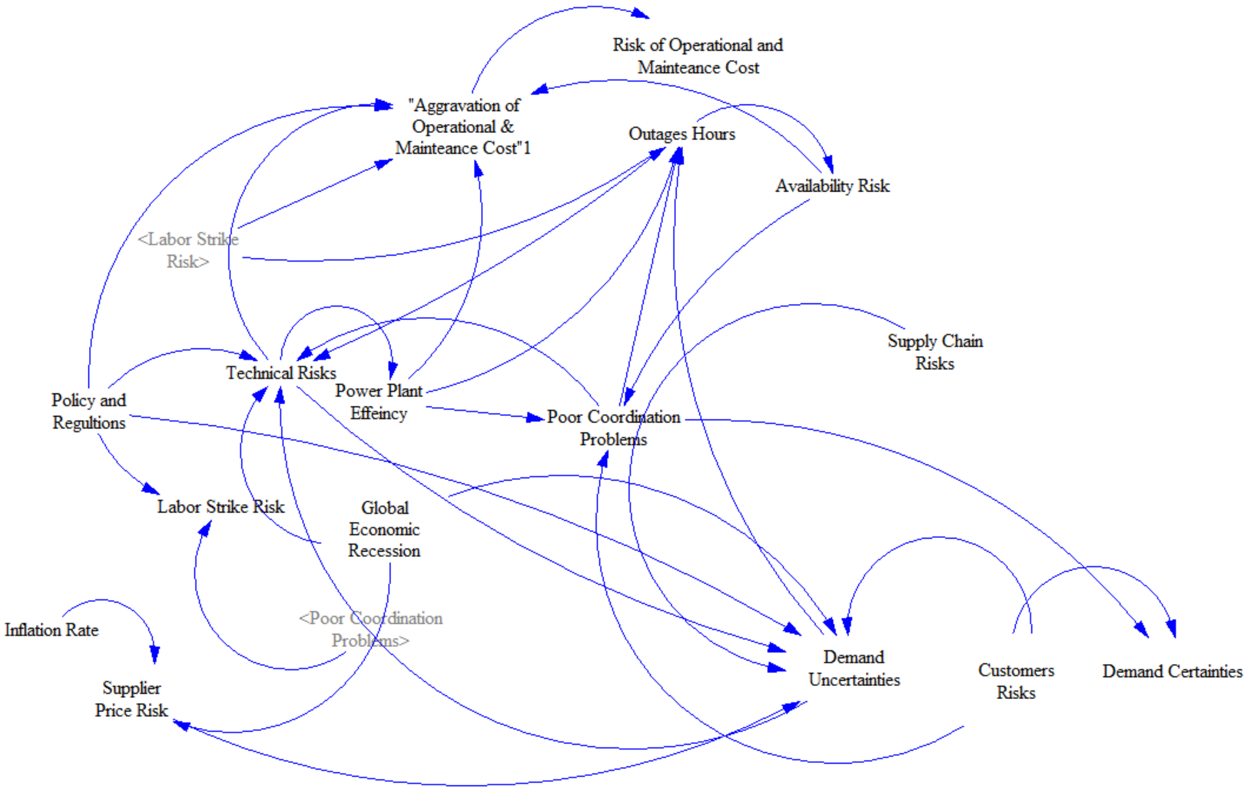


Figure 1: Causal Loop Diagram (CLD) representing risk factors affecting the strategic Customer Performance Perspective

From the created CLD in Figure 1, two cause and effect tree diagrams can be constructed. The first trees show the variable in question and include all the variables that influence it (as shown in Figure 2). The second tree has the entity in question and represents all other variables influenced by it (as shown in figure 3). For example, Figures 2 and,3 show cause and effect tree diagrams for demand uncertainties.

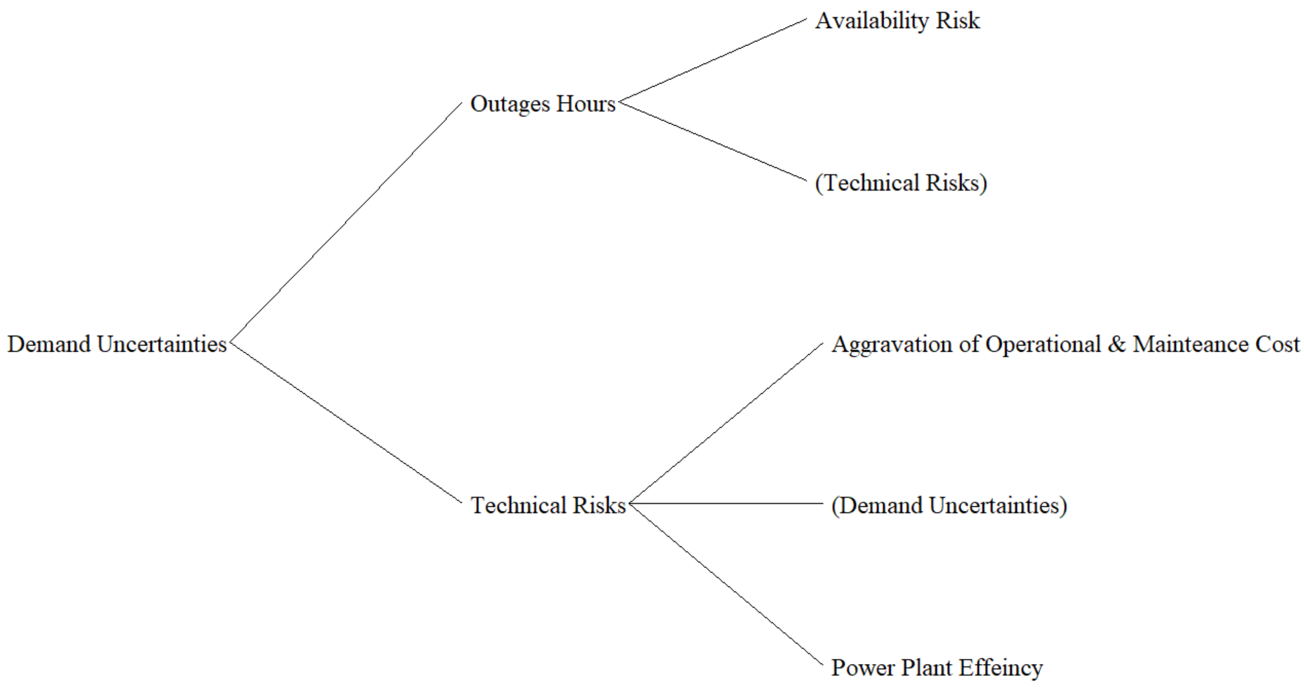


Figure 2: Cause and Effect Tree Diagram representing the effect of the Demand Uncertainties variable on other risks (related to the Customer Perspective)

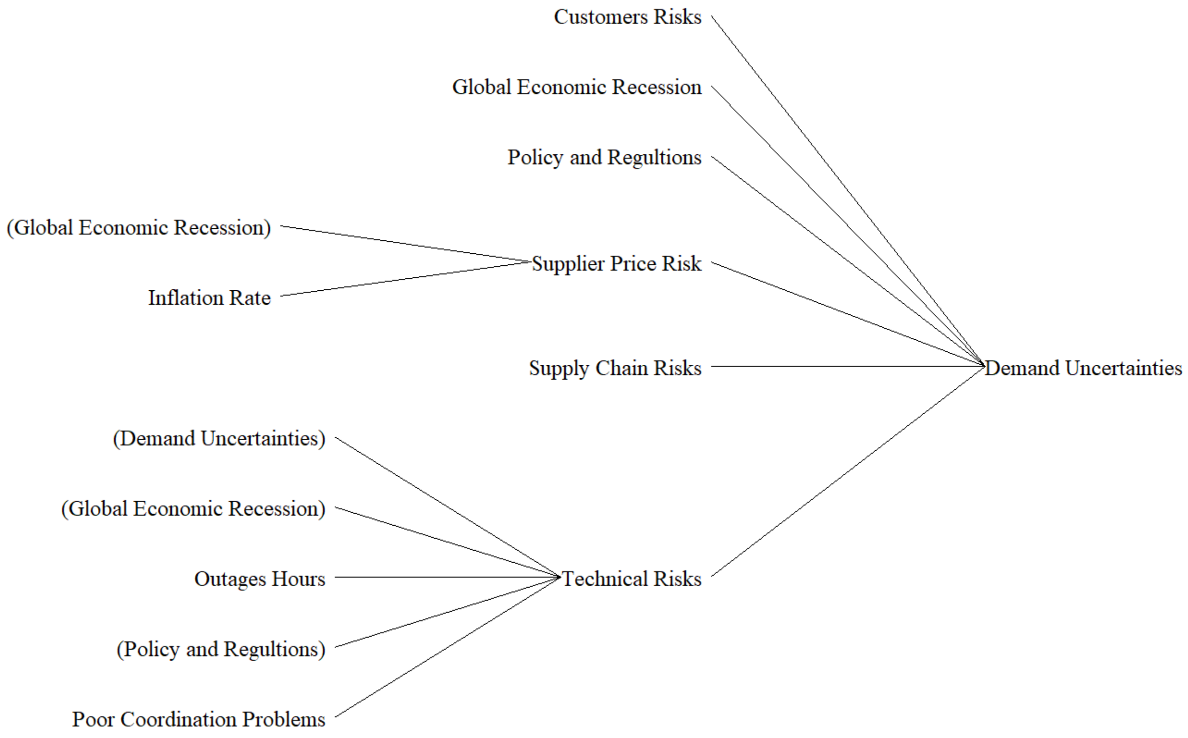


Figure 3: Cause and Effect Tree Diagram representing the effect of other risks (related to the Customer Perspective) on the Demand Uncertainties variable

For example, from Figure 3 it can be seen that the demand uncertainties are affected by many factors either within or out the system such as customer risks, global economic recession, policy and regulation, supplier price risk, supply chain risks, and technical risks. Furthermore, it's clear that the supplier price risk is influenced by the inflation rate and the global economic recession. In addition, the demand uncertainties, global economic recession, outages hours, policy and regulations, and poor coordination problems cause more technical risks.

The tree shown in Fig. 10 illustrates the relationship between the demand uncertainties and various risks. This tree reveals the importance of the demand uncertainties as the major challenge in risk assessment.

Depending on the CLD, the SFD can be constructed for the customer risks sub-model. Mathematical equations that quantified the cause-affect relations and feedback are note covered in this paper). The risk assessment model simulated for a long term over a 10 years period (2018-2028) for large power plants in the Middle East. The complete simulation is implemented with Anylogic®.

The developed SFD is shown in Figure (4). From the SFD, the customer risks have affected by economic variables such as supplier price risk, inflation rate, global economic recession additionally, it has affected by social risks like the labour strike risk which leads to making a disruption the demand of electricity.

From Figure 4, it's clear that the model of customer risk assessment includes 4 stocks: customer risk, availability risk, power plant efficiency risk, and risk of operational and maintenance cost. Which are the key elements to measure the performance of power plants with time? These stock are interacted to each other and affected by other variables like supplier price risk, labour strike, and poor coordination problems. The flows of the customer risk are the demand certainties and uncertainties which change over time. The next section will simulate one scenario by mitigating the effect of the policy and regulation risk.

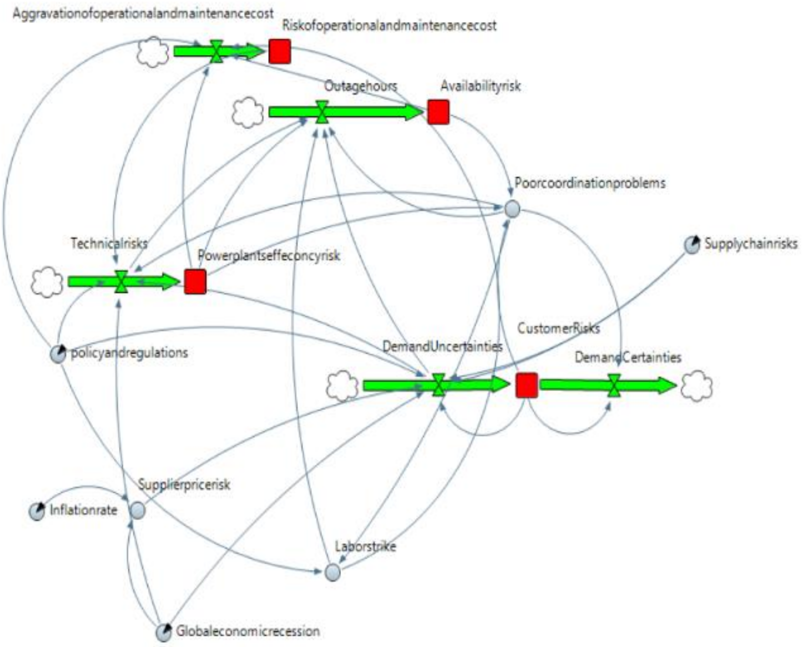


Figure 4: Stock and Flow Diagram representing the different risks affecting the strategic Customer Performance Perspective

4. Simulation of the System Dynamics model for Risk Assessment:

To run the simulation model firsly, the Problemn is formulated then constrcuting the conceptual (CLD) by collecting the reqired data. Then the model can be devloped and validated finally, the model can be simulated and the run results can be shown.

Customer risks are affected by economic risks like inflation rate, supplier price risks, and a global economic recession. Also, customer risks could be affected by social risks like the labour strike. From the CLD, the supplier price risk will increase the demand uncertainties which affects the load forecasting. This will increase customer demand risks. Accordingly, the power plants performance will be affected by these risks.

The simulation results of the effect of the customer risks on the power plants performance and how various risks interact with each other are shown in the below Figures (5-8).

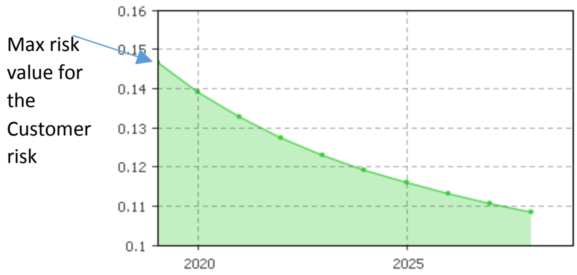


Figure 5: Dynamic simulation behaviour Graph for Customer risks

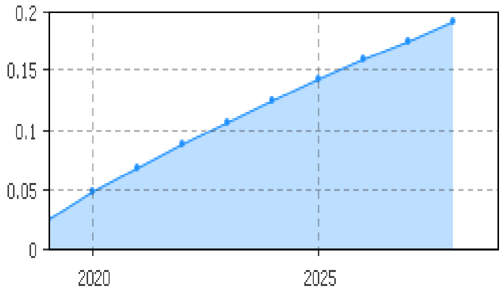


Figure 6: Dynamic simulation behaviour Graph for Availability risks

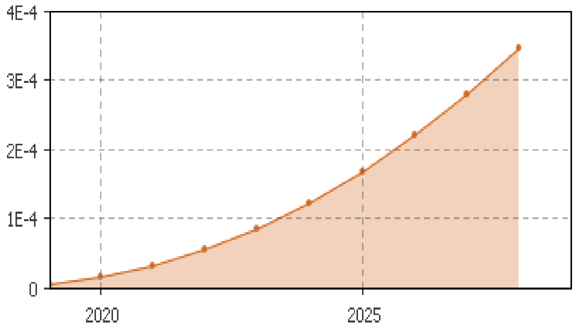


Figure 7: Dynamic simulation behaviour Graph for Power Plant Efficiency Risk

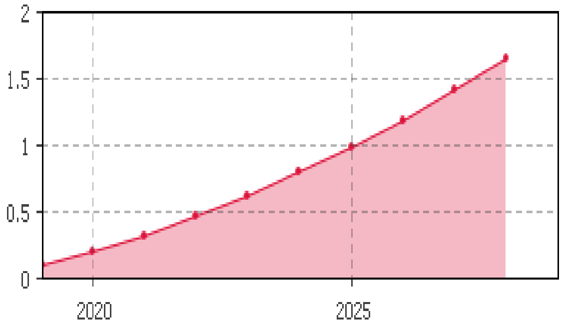
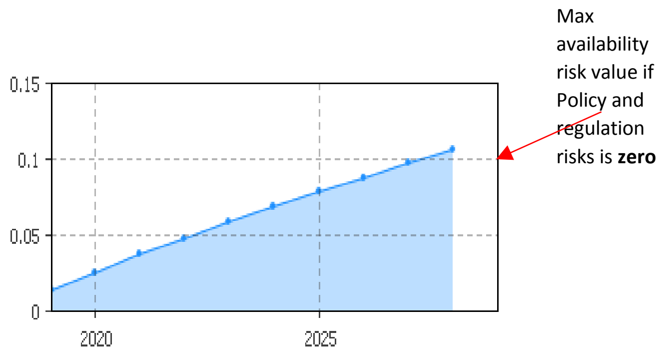


Figure 8: Dynamic simulation behaviour Graph for Risk of Operational and Maintenance Costs

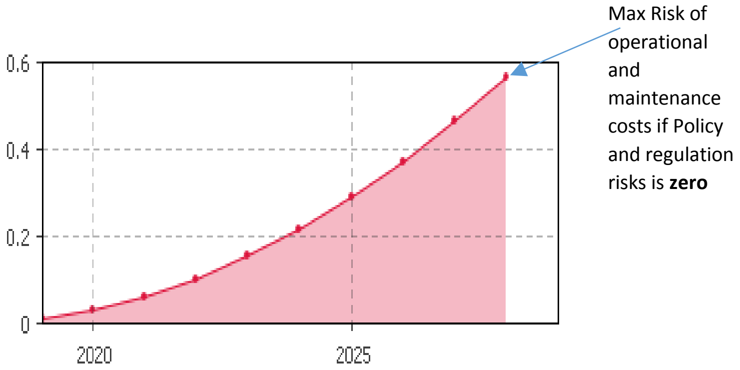
To validate the model, entire validation tests are done. One of these tests is the dimensional consistency test which is conducted through the Analogic software.

Scenarios and sensitivity analysis can be implemented by adjusting various parameters during policy making to understand risks levels affecting the power plant performance. The critical risk entity is the ‘policy and regulations; is switched off to zero, and simulating a scenario. The generating behaviour for availability risk and risk of operational and maintenance costs are illustrated in the below Figures (9 and 10). The results show that the availability risk will reduce from (20% to 10%) and the risk of operational and maintenance costs will reduce form (160% to 58%). This will reduce the operational and maintenance cost and reduce the unavailable time of power plants, which in turns lead to increase the revenue and enhance the performance of power plants for the long term.



Max availability risk value if Policy and regulation risks is **zero**

Figure 9: Scenario Simulation for Availability Risk



Max Risk of operational and maintenance costs if Policy and regulation risks is **zero**

Figure 10: Scenario Simulation for Risk of Operational and Maintenance Costs

5. Conclusion:

This paper describes the development of a system dynamic model capturing the interdependency between various risks. The aim of the paper is to develop a system dynamics risk assessment model and use it to help policymakers in understating the behaviour of systems for the long term. The developed model is used to simulate the output results of one scenario (mitigate the risk of policy and regulations).

This paper proposed a model for better understanding of the interactions of key risk indicators related to the performance of the strategic customer perspective in the context of the energy sector, specifically for power plants. The model is constructed applying a system dynamics approach. This approach assists to understand the behaviour of this system of interrelated risk indicators within a dynamic business environment and defining the boundary of the system. In this way, policymakers and managers can be assisted in decision making to develop more effective and sustainable strategies. Different scenarios can be simulated to help to understand the behaviour of the system in a long-term timeframe and the impact on key risk indicators, specifically with a focus on the performance of the strategic customer perspective. The contribution of this paper is in developing a risk assessment model to assist non-technical risks in power plants (ex. customer risks). Where the current research focusing more on the technical risks related to requirements. The developed dynamics risk assessment model help policy makers in understating the behaviour of systems for the long term and assist them in design a better strategy through understanding the interaction of various risks among the system.

Limitation of this study is its reliance on data related to non-technical risks which are very rare. Thus, determining the risk indicators and the interdependency between various risks and quantified these relations are a very difficult task.

Finally, the paper presents the application of the model and simulation of a scenario in which the impact of mitigating the risk of policy and regulations on the availability risk of the power plant and on the risk factor related to operational and maintenance costs is highlighted. The model is simulated based on data collected from one power plant in the Middle East and other assumptions based on the literature review.

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