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Frameworks for developing risks interaction models in complex systems

Rilwan Shuaib Abdulrahman[1]*, Ahmed Doko Ibrahim[1], Baba Adama Kolo[1], Hassan Adaviriku Ahmadu[1], Abdulrasheed Madugu Abdullahi[2] and Khairat Mamman Hassan[3]

[1]Department of Quantity Surveying, Ahmadu Bello University, Zaria, Kaduna, Nigeria
[2]Department of Quantity Surveying, Universiti, Teknologi, Johor Bahru, Malaysia
[3]Department of Quantity Surveying, Federal University of Technology, Minna, Niger, Nigeria
**- Corresponding author email: ridwanshuayb1@gmail.com*

Abstract

Over the years, the lack of understanding of the dynamic interrelationships and interactions among several risks in large projects has remained a huge problem in the field of risk management and a major determining factor for project failure till date. Although several studies have attempted to address this issue by modelling the causalities amongst several risks at various stages of the risk management process, they are yet to model the systemicity of risks, which certainly goes beyond modelling of causality. Hence, this study proposes a conceptual framework for developing risk interaction models. A qualitative research approach was used through extensive review and content analysis of related literature on risk interactions and systems theory. The study introduced the risk management system (RMS) which provides better understand to the dynamics within and across components of risks management process. Furthermore, the study found that complex systems theory offers deeper understanding to risk interactions than systems theory. Lastly, the frameworks developed will aid and improve understanding of the systemicity of risks as well as serve as a clear path to developing risks interactions models. This study recommends further studies to develop frameworks that will capture the risk response, monitoring and controlling phases of the risk management process.

Keywords: Risk management, Large Projects, System, Risk Management System, Risk Interactions.

Introduction

Construction projects are becoming more complex and riskier, particularly amongst large projects, which leads to increasing difficulties in project management and delivery, and eventually bad performance or even failure (He, et al., 2015). It is apparent that large projects management presents a major challenge worldwide (Hu, et al., 2015a), and the nature and characteristics of large projects distinguish them from normal construction projects and therefore require a new approach to ensuring success (Flyvbjerg, 2014). Erol, et al. (2018) stated that large project, megaproject, complex program, and major project have all been used interchangeably in literature, as a result many definitions have been reported with varieties of definitional boundaries for such project. Despite the lack of generally acceptable cost boundary, the difficulties in managing large projects are as a result of the complexities of such projects.

Large projects are complex projects where the effects of risks are difficult to understand without proper analysis. According to Simon (1982) complex projects are projects in which the behaviour of the whole is difficult to deduce from understanding the inputs to the system. Thus, in a complex project, understanding what is likely to impact the project does not lead simply to an understanding of what that impact might be. Studies has led to the realisation that the consideration of risk before a project starts and particularly the common practices in project risk analysis, are woefully inadequate for large projects (Williams, 2017). Furthermore, the interrelations and interactions between risks challenge the fundamental rationale underlying conventional project risk management models treating risks as independent. As stated by Fang, Marle and Bocque (2012), risks interrelate and negligence in entertaining such interrelationships causes either underestimation or overestimation of risk effects and consequently limits the effectiveness of risk management.

Consequently, recent endeavours have attempted to understand the complexities of risks in large projects through development of risks interaction models, which are expected to provide clarity into the dynamics that leads to the occurrence of risks as well as the interactions and interdependencies amongst several risks during risk management (Qazi, Dikemen & Birgonul, 2020; Guan, et al., 2020; Xie, Han & Skitmore, 2019; Boateng, 2017).

However, it has been observed that existing studies on risks interactions focused on identifying the causal relationships amongst several risks and/or risk factors to mean risks interactions, when what constitute interactions goes beyond the causal relationships. Furthermore, several studies (Boateng et al., 2015; Xu, et al., 2017; Abdulrahman, et al., 2019) have used risks and risk factors interchangeably which will rather invalidate some of their findings. Although, the causal relationship is the foundation upon which subsequent interactions are developed. So far, there has been a shortage of research endeavours that have constructed a framework for comprehending how risks interact with each other, beyond merely examining causal relationships. Therefore, this study developed theoretical and conceptual frameworks for understanding and developing risks interactions in large projects.

Literature Review

Approaches to Risk Management

Generally, two approaches have been used by researchers and practitioners of risk management namely; the reductionist and the systems approach. On the one hand, the reductionist believes that the best approach in understanding a new phenomenon is to study the properties of its individual parts (Cornell & Jude, 2015). For instance, the best way to understand building construction is by fragmenting the construction process into elements (substructure, frames, upper floor etc.) and to study the properties of each element. On the other hand, systems approach concentrates on the interactions and interrelations between individual parts (elements) and how they fit and work together as a whole (Cornell & Jude, 2015). The manner at which individual parts connect and interrelate with one another will determine the output of a system.

Risk management studies generally revolves around decomposition into components (risk planning, identification, assessment, response and monitoring and controlling), which according to Williams (2017) is inadequate for complex projects such as large projects. However, a holistic approach of systems thinking, particularly modelling risk interactions for the entire risk management process may be too elaborate to the point of losing its true essence (Sterman, 1992). According to Sterman (1992) a model should represent a system (a group of functionally interrelated elements forming a complex whole) that must address a specific problem and must simplify rather than attempt to mirror an entire system in detail. That is, any attempt to model a comprehensive system may result to complex and not readily understood models. Also, a model need not be oversimplified, otherwise it will lack the capacity of producing significant effects. Although, even with the decomposition of risk management, the lens of complex systems can be used to understand the fragmented parts as subsystems within the larger system. Thus, this study used the lens of complex system in understanding the systemicity of risk in large projects.

Large projects are complex systems because they exhibit certain properties of complex systems (Marle, 2015). Complex systems are systems in which the behaviour of the whole is difficult to deduce from understanding the inputs to the system (Williams, 2017). Risks set up causal chains, often involving human motivational reactions to events and decision making by the project parties. The risks are significantly exacerbated when these chains lead to positive feedback loops. As a result, understanding the behaviour of large projects becomes very difficult, and taking away the rational basis for decision making (Williams, 2017).

Risks Systemicity

According to Walker (2015) systems theory is "essentially a way of thinking about complex processes so that the interrelationships of the parts and their influence upon the effectiveness of the total process can be better understood, analyzed and improved.

The literature discussed above have used the systems theory in understanding and describing the problem of risks interactions in their various sub-system levels but even within the systems theory, there exist several classifications which can be used to describe risk systemicity. Boulding's classification of systems by their level of complexity is summarized by Scott (1992b) in Walker (2015) below:

- Frameworks: systems comprising of static structures, such as the arrangements of atoms in a crystal or the anatomy of an animal.
- Clockworks: simple dynamic with predetermined motions, such as the clock and the solar system.
- Cybernetic Systems: systems capable of self-regulation in terms of some externally prescribed target or criterion, such as a thermostat.
- Open system: systems capable of self-maintenance based on a throughput of resources from its environment, such as a living cell.
- Blueprinted-growth System: systems that reproduce not by duplication but by the production of seeds or eggs containing preprogramed instructions for development, such as the acorn-oak system or the egg-chicken system.
- Internal Image System: Systems capable of a detailed awareness of the environment in which information is received and organized into an image or knowledge structure of the environment as whole, a level at which animals' function.
- Symbol-processing Systems: systems that possess self-consciousness and so can use language. Humans function at this level.
- Social Systems: multi-cephalous systems comprising actors functioning at level 7 who share a common social order and culture. Social organisations operate at this level.
- Transcendental Systems: systems composed of the absolutes and inescapable unknowable

The above-mentioned hierarchy of systems are not mutually exclusive, in that a higher-level system incorporates the features of those below it. Therefore, it is possible to analyse a level 7 using levels lower than 7. It was the believe of Boulding (1956) that much valuable information could be obtained using lower-level systems to understand higher level subject matter as well as a higher-level system to understand a lower-level subject matter.

On the one hand systems theory refers to a holistic approach to understanding and analysing complex phenomena by examining the relationships and interactions among various components or elements within a system. It involves considering the interconnections, feedback loops, and dynamic behaviour of a system, rather than focusing solely on individual parts in isolation. On the other hand, complex systems refer to systems that are characterized by many interconnected components or agents, where the interactions among these components give rise to emergent properties and behaviors that cannot be explained solely by analyzing the individual parts. Complex systems are often characterized by nonlinearity, feedback loops, self-organization, adaptation, etc. These concepts shall further be discussed during the result section.

Research Methodology

A qualitative research approach was adopted for the study through review of related literature on risk interactions, systems, and complex systems. Content analysis was subsequently used to synthesize the articles reviewed and subsequently developing the theoretical and the conceptual frameworks. Furthermore, literature has revealed that multiple techniques and approaches could be used in modelling risks interactions, however, Sterman (1992) reported that, of all the formal modelling techniques, the system dynamic (SD) has better guidelines in terms of presentation, analysis, and explanation of the dynamics

Table 1: The system dynamic modelling processes across literature

Randers (1980)	Richardson and Pugh (1999)	Roberts et al. (1983)	Wolstenholme (1990)	Sterman (2000)	Boateng (2014)
Conceptualization	Problem Definition System Conceptualization	Problem Definition System Conceptualization	Diagram Construction & Analysis.	Problem Articulation Dynamic Hypothesis	Problem identification & Definition
Formulation	Model Formulation	Model Representation		Formulation	Initial Model Development
	Analysis of Model Behaviour	Model Behaviour	Simulation Phase (stage 1)		Model Verification
Testing	Model Evaluation	Model Evaluation		Testing	Final Model Development & Simulation
	Policy Analysis	Model Evaluation			Model Validation
Implementation	Model Use	Policy Analysis & Model Use	Simulation Phase (stage 2)	Policy Formulation & Evaluation	Policy Analysis, Model Use or Implementation

(Source: Luna-Reyes and Anderson, 2004)

Table 1 shows the different modelling processes that have been used by various authors in literature, though different in terms of the number of steps, the activities remain fairly the same across all processes. Furthermore, modelling is dependent on the nature of the problem and the style of the modeller. Hence, this study adopted the modelling process by Boateng (2014).

Findings and Discussion

Application of System Theory to Risk Management and Complex Systems

Looking at risk management as a system, it is made up of three essential components of causation, risks, and consequences. This can be fitted into the input, process, and output structure of a system. In this case, the causation (risk factors or sources of risk) being the input, the risks (risk management process) being the process and lastly, the consequences (effects) being the output. Figure 1 below depicts the risk management system (RMS).

Figure 1: Risk Management System

In the RMS, interactions are dynamic starting from the causations to the risks, its management, and eventual consequences. Once risk analysis is carried out and responded to, this further generate risks which is commonly known as risks propagation. These interactions complicate analysis beyond the capabilities of mental model because a change in one part of the system may have implications in other remote parts (Sterman, 1992).

While studies in this domain have generally focused on the risk factors, risks, and their consequences (input, process, and output) on large projects, they have been considered separately and in isolation within the RMS. For instance, the interactions amongst risk factors within the system which have been modelled through identification of the causal relationships (Boateng, Ogunlana, Chen & Ikediashi, 2012; Wan & Liu, 2014). This is an important aspect within the entire RMS because subsequent analysis is built upon this stage and as reported by Wan & Liu (2014) this initial interaction will provide a good starting point for further analysis. However, the causal relationships amongst risk factors does not provide enough description and understanding of the risk systemicity.

Likewise, studies by Boateng, et al. (2015) modelled economic risk in megaproject construction; a systemic approach. Their study attempted to connect risk factors and consequences (input and output), thereby either neglecting the risks or considering risk and risk factors to be same. It was noted that risk factors and risks were used interchangeably in their study, a clear indication that, at best the researchers merged both risks and risk factors together, which of course are different. Risk factors causes risks and so causes of risks cannot and should not be considered as risks. A number of studies (Abdulrahman, et al., 2019; Maina, & Mbabazize, 2016; Boateng & Chen, 2012) in this domain are guilty of this problem, using risk factors and risks interchangeably. In any case it becomes difficult attributing the cause of risks as having high impact (to the tune of 22%) on construction projects.

Similarly, studies on risk interactions have modelled within the process phase of the RMS (Ongkowijo & Doloi, 2018; Xu, meng & Cao, 2017; Marle, 2015; Fang, et al., 2012; Nasirzadeh, Afshar & Kanzadi, 2008). Although, effort by these researchers have resulted in modelling risk interactions, they were unable to linkup the process and output phase of the RMS. Attempts by researchers (Ongkowijo & Doloi, 2018; Xu, Meng & Cao, 2017; Marle, 2015) have yielded limited results such as; connecting input and output and/or within the process phase alone. Modelling risk interactions within the process phase would entail; interactions within the identified risks, interactions having analysed the risks and interactions when response strategies are used.

Furthermore, Wang & Yuan (2016) attempted to provide connections between the process and output phases through assessing the effects of dynamic risk interactions on a schedule delay in infrastructure projects. Their study simulated the effect of each individual risk on the project schedule without considering risk interactions and found only a delay of 1week whereas simulating the effect of risk on the project schedule considering risk interactions showed a delay of 77weeks, indicating a collapse of the project in practice. They concluded; it is critical to consider the dynamic risk interactions when evaluating infrastructure project risks. While these studies have modelled at the input, process, and output phases of the RMS, very few studies have attempted to provide interactions between these phases (Xu, et al., 2017; Wang and Yuan, 2016; Boateng, et al., 2015). Moreover, some of the effort towards these interactions are somewhat questionable, in that, the interactions were between input and output, rather than the more logical input-process, process-output or input-process-output system. Contrary to Xu, et al. (2017) and Boateng, et al. (2015), Wang and Yuan (2016) linked up the process-output system through effects of dynamic risk interactions on a schedule delay in infrastructure projects which was discussed earlier. Consequently, from the literature reviewed, there are no indications of studies that have connected the input-process (risk factors-risks), process-output (risk and consequences) or the input-process-output (risk factors-risk-consequences) of the RMS. Although, Wang and Yuan (2016) reported that of process-output (risk and consequences) of the RMS.

The essence of the risk management system presented in figure 1 is to document what exist in literature and properly situate this research. However, for deeper understanding of risks interactions, the lens of systems theory is used to understand a complex system (large projects) as discussed subsequently.

Several models explaining the properties of complex systems exists. Popular among these are those of Lucas (2002) and Sterman (1992). The Lucas model outlines sixteen (16) generic properties while the Sterman's model outlines five (5) specific properties. Sterman's model is chosen for its aptness to relate with properties of construction projects. These properties are highlighted below:

- Extremely complex consisting of multiple interdependent components
- Highly dynamic
- Multiple feedback relationships
- Nonlinear relationships
- Hard and soft data
- Extremely complex, consisting of multiple interdependent components

A system is said to be complex when it is difficult to understand, describe or control both the system itself, as well as its dynamic behaviour. These difficulties stem from the interdependencies of components within a system. Because a change in one part of the system can have implications in other, distant parts, interdependencies complicate analysis beyond the capabilities of mental models. For instance, a change in position of an internal door may cause subsequent changes in the position of windows, electrical socket, switches, etc. The implication of this change will necessitate rework far beyond the initial change that was made. Because of this change, workers may have to be rescheduled and so delaying other aspects of work that should have been completed. Thus, using this property of complex system as a lens to view risk systemicity will help in understanding the complexity of risks.

o **Highly dynamic**

Being highly dynamic means the system is in a state of constant change, activity, or progress.

Project management inherently involves constant change. Processes like recruitment and training unfold gradually over time. Various time delays come into play when implementing programs, including the detection and correction of errors and responses to unexpected shifts in project scope or specifications. These dynamic elements lead to a distinction between the immediate response of a system to a disturbance and its long-term response. For instance, hiring additional personnel enhances an organization's capacity over the long haul, but in the short term, experienced staff members must allocate time to train new hires, leading to a temporary decrease in productivity. System Dynamics (SD) was specifically developed to address these dynamic complexities. Among all modelling techniques, SD boasts the most advanced guidelines for accurately representing and explaining the intricate dynamics of complex technical and managerial systems.

o **Involve multiple feedback relationships**

This property occurs when the output of a system is routed back as inputs as part of a chain of cause and effect that forms a loop. Feedback refers to the self-correcting or self-reinforcing side effects of decisions (Sterman, 1992). Example; a good response to a project that is behind schedule is increase in overtime. This means workers would have to put in more hours to get the project back on schedule but of course with additional pay. This type of feedback process is self-correcting. However, should the overtime be extended over certain period, the workers may become fatigued and will result to a decrease in their productivity, a higher rate of errors amongst other effects, thus delaying the project further. This type of feedback process is self- reinforcing. Tightly coupled systems such as large construction projects contain large numbers of important feedback relationships (Sterman, 1992).

o **Involve nonlinear relationships**

The nonlinear relationships that exist in complex system refers to a situation in which a change in the output is not proportional to the change of the input. This means that causes and effects do not have simple and proportional relationships. For example; increasing the workweek of a worker from 40hours/week to 50hours/week may increase the productivity of the worker by 20%. But over time this may no longer be proportionate because increase in workweek will cause fatigue, errors and other effects which were previously unimportant.

o **Involve both hard and soft data**

Hard and soft data refers to the technical and non-technical data requirements in understanding complex systems. According to Sterman (1992) complex system such as large projects cannot be understood completely based on architectural and engineering drawings alone, in fact most of the important data needed to understand the dynamics of large projects will include managerial decision making and other so-called soft variables. Majority of data required in understanding complex systems are descriptive, qualitative, and usually have never been written before, yet they are crucial for understanding complex systems (Sterman, 1992). Imagine managing risks on large projects using solely the standard risk management process (planning, identification, assessment, response, monitoring and controlling) without taking into cognisance the risk appetite of key project participants, their risk management maturity amongst other soft variables. Risk on such project will become more difficult to manage should the project participants' appetite and maturity be unknown.

The above discussed characteristics of complex systems is therefore used subsequently to x-ray the interactions within and across components of the RMS. Explicit illustrations are made on how these characteristics relate within and across components of the RMS as illustrated in Figure 2 below:

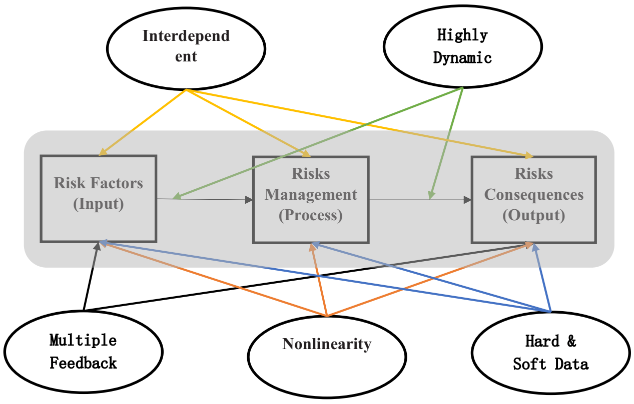

Figure 2: Theoretical Framework for understanding risks interactions in large projects

Firstly, as illustrated in Figure 2 above, the interdependent feature of a complex system occurs in the RMS at the components (risk factors, risk, and consequences) level but does not occur at the system level. The yellow arrows from Figure 2 signifies the interdependences that exist within each category of the RMS. Risks depend on the risk factors while risk factors do not depend on risks. Likewise, the consequences depend on the risk but risk do not depend on the consequences. However, within each component of the RMS several interdependencies occur. For instance, exchange rate and economy fluctuation, cash flow problems and conflict and so many others. For cash flow problems and conflict; both factors have a symbiotic relationship, in that they both depend on one another. For instance, a situation where Cash flow problem is caused by a different factor, a consequence of cash flow could be conflict likewise conflict being caused by different factor, a consequence could be cash flow problem.

Secondly, the highly dynamic feature of a complex system like large building projects occurs only at the system level (RMS). The green arrows from Figure 2 shows that the dynamism is in the relationships between the components of the RMS, rather than within each component. A good justification for the dynamism being within the RMS is the human component that has not been captured in the system. According to Stermann (1992), wondrous as it is, the capability of human mind is bounded by various limitations of attention, incomplete information, dated or biased and time available to weigh alternatives insufficient. In practice the bounded rationality of human judgement means that the best-intentioned mental analysis of a problem as complex as large construction project cannot hope to account accurately for the myriad interactions which jointly determine the outcome of the program. For this reason, the dynamism within the RMS becomes inevitable, as people have differing understanding and interpretation of any given situation which subsequently leads to different outcomes.

Thirdly, multiple feedback feature occurs at the RMS level but only between the "consequences" and the "risk factor", where parts of an output has been returned to the input for corrective actions as shown in Figure 2 above. A good illustration of this feature is the example given above of project falling behind schedule and responding to that by increasing the use of overtime. This most certainly can correct the problem of time overrun but if over used could result into other multiple problems which were not envisaged or planned for.

Fourthly, the nonlinearity feature of a complex system occurs in the RMS at both components (risk factors, risk, and consequences) and the system levels. The example of the relationship between workweek and productivity given above is a perfect illustration of how nonlinearity occurs within the RMS. Furthermore, at the components level, a risk factor such as, "lack of competence" or "fatigue" or "poor project relationship" could interact to generate "errors in design" or "conflict" amongst other factors. Similarly, for risk, "errors in design" could interact with "increase in material prizes" to generate "rework" as a risk emanating from several interactions. For consequences, "clients' dissatisfaction" could interact with "cost overrun" which may lead to "reputational damage" or "project failure" among others. The fact that several interactions may not lead to predetermined outcome makes it disproportionate. Therefore, a small change in one part of the system may lead to a big or small change in other parts of the system.

Lastly, the hard and soft data, which are the technical and social aspects of projects. These occurs within and between the components of the RMS as shown in Figure 2 using blue arrows. The technical and social aspects of projects interact extensively throughout a project life cycle. For instance, resources as an aspect of a project requires a collaborative effort from both technical and social aspect for it to be utilised optimally. On the one hand, the technical aspect analyses the resources required, the number required, and when it is required through a series of mathematical computations. Any default can be addressed using a variety of methods such as resource levelling. On the other hand, which is the social aspect, several things could happen to derail the objective which has nothing to do with technicalities but rather social aspects. Remember the planner of this technicalities have no authority regarding these resources required by the project. Hence, the planner must use his /her peoples' skills to obtain commitment of the resources. Another example is the competencies and personalities of parties in projects. Technically, the questions of what technical abilities are required, how to acquire these abilities for the project, and when they are required on the project are all technical questions with technical solutions. But socially, what if these technical people cannot get along together or there are not enough technical people. These discussions sum up the systemicity of complex projects. Although, this complexity seems unsurmountable, Stermann (1992) opined that these complexities can be managed by developing models that can represent a system with these characteristics and it must be understandable and usable.

Conceptual Framework Development

The essence of developing theoretical and conceptual frameworks is to provide structure, guidance, and a coherent framework for understanding, explaining, and conducting research. Both frameworks (theoretical and conceptual) are tools that researchers use to anchor their work in established knowledge, structure their research inquiries, and provide a basis for interpreting and extending the understanding of their chosen topic (Grant and Osanloo, 2014).

o Problem Identification and Definition (Purpose)

This is the first and most important stage in the modelling process. It requires a clear problem definition as well as a clear purpose of the model through cutting off the less important components. According to Sterman (1992) the art of modelling is knowing what to cut out and the purpose of the model acts as the logical knife. Every model is a representation of a system (a group of functionally interrelated elements forming a complex whole). But for a model to be useful, it must address a specific problem and must simplify rather than attempt to mirror an entire system in detail (Sterman, 1992). Of course, even models with well-defined purposes can be too large. Always model a specific problem, never model an entire system. This study seeks to model the dynamic interactions of risk factors and risks in large building projects. Hence, this stage of modelling requires information on risk factors and risks associated with large building projects. This objective was achieved using literature review and questionnaire surveys to specifically identify risk factors and risks as well as ascertaining the occurrence and magnitude of risks.

o Initial Model Development and Verification

Causal loop diagrams will be used to describe the conceptual model structure derived from a modeler's understanding of system and show the dynamics of the variables or components within the system (Park et al., 2004). These causal loops diagrams indicate how these components or variables relate with one another within the system. The causal links can be determined in many ways such as; observation, reliance on accepted theories, hypotheses or assumptions and statistical data (Coyle, 2000, cited in Park and Pena-Mora 2004).

The data required at this stage was collected using the following procedures.

- A detailed literature review was conducted to gather information and insights into risk factors and risks in large building projects
- Questionnaires were administered to project managers to retrieve information relating to the likelihood of occurrence and magnitude of impact of the risks identified from literature. This was done because the researcher was unable to access the projects' risk registers.
- Interviews were conducted to establish the CLDs as well as their verification by experts from academia and industry.

- **Final Model Development and Simulation**

  Once the causal loop diagrams have been formulated, the stock and flow diagram known as a simulation model will be created. According to Coyle (1996) a simulation model is a different version of a mental model or causal loop diagrams, only that, it is written in equation computer codes. Computer simulation were used to determine how all the components within the system behaves over time. This simulation was carried out using Vensim software, which is a graphical system dynamic modelling software, developed by Ventana Systems. Once the model structure is defined, the underlying equations were entered to create the simulation model and the model is tested for consistency with their purpose and boundary.

- **Model Validation Using Software Tools and a Case Study**

  Validation is the process of establishing confidence in the soundness and usefulness of a model. It is a gradual process of building confidence rather than either accept or reject a model. Although, a model is a simplified representation of a real system that should capture the system's behaviour, no model is expected to capture the exact system behaviour but to predict the system behaviour with relative accuracy. Sterman (1992) stated that model validation has been one of the key issues in system dynamics. Similarly, report (Boateng, 2014) shows that dynamic model validation is problematic, just as in scientific theories in general and that correctness of a model cannot be proven, though, it is an important phase in the modelling process. However, the difficulties in a model validation is the objective of SD model validation, which is to establish confidence in the model structure and behaviour (Sterman, 1992). Furthermore, it is pointless to test the behaviour of a model when structural validity has not been tested or passed.

The third phase in system dynamic model testing is the test of policy implications which is carried out after both the structural and behavioural tests have been successfully passed. The test of policy implications is highlighted below:

- Changed Behaviour Prediction Test: this test shows how well the model predicts the behaviour of the system if a policy is changed. The test is carried out by changing specific policies in a model and examining the resulting behaviour changes. Similarly, one can examine the response of the policy already pursued to see how well model response agrees with the real system response. The test will essentially show the impact of exogenous variables on a model behaviour.
- Policy Sensitivity Test: once all other tests have been carried out and passed successfully the next and last tests is the policy sensitivity. To carry out this test, the question of policy sensitivity arises, although not recognised as such (Bala, et al, 2017). The questions are as follows:
- What kind of researchers should be involved?
- What mechanisms should be included or left out of formal and mental models?
- For which relationships and parameters should one seek better data and higher-quality estimates?

These questions are best answered by policy sensitivity analysis. The traditional and frequently used form of sensitivity analysis in system dynamics is to vary model assumptions and to observe how behaviour changes. In the branch of operations research using optimisation, sensitivity analysis is to vary model assumptions and to observe how optimal policies change (Bala, et al., 2017). In other to avoid confusion between the sensitivity analysis, the terms behaviour sensitivity and policy sensitivity are used, of which the latter is the focus here. According to Sterman (2000), policy sensitivity exists when a change in assumptions reverses the impacts or desirability of a proposed policy. For instance; when a set of assumptions causes low productivity and another does not, then it can be said that the model exhibits policy sensitivity. Whereas if a policy change produces improvement regardless of changes in a sensitive parameter, then the policy recommendation is not affected. That is, when both sets of policies produces improvement to low productivity, then the model is set to exhibit policy insensitivity. Policy sensitivity test depicts the robustness of a model behaviour and policy recommendations. This test shows the uncertainty in the values of the variables and in some cases, change in the values of the variables can invalidate the recommendations proffered.

v. Policy Analysis, Model Use, or Implementation

Once the model is tested, it will be experimented for various practical consequences. The sole purpose of the experiment is to outline the weaknesses in the existing risk management process and therefore recommend new policies.

Conclusions & Recommendations

Over the years, the lack of understanding of the dynamic interrelationships and interactions among several risks in large projects has remained a huge problem in the field of risk management and a major determining factor for project failure till date. Hence, this research has constructed theoretical and conceptual frameworks with the intention of enhancing comprehension regarding the systemic nature of risks. These frameworks serve the purpose of cataloguing previous studies that employ system theory and provide a well-defined roadmap for comprehending and advancing the understanding of risk interactions. Nonetheless, it is important to note that the framework's applicability is limited in scope. It currently addresses only the risk identification and assessment phases within the risk management process. The inclusion of how the risk response strategies, monitoring, and control stages will be incorporated into the framework remains unresolved.

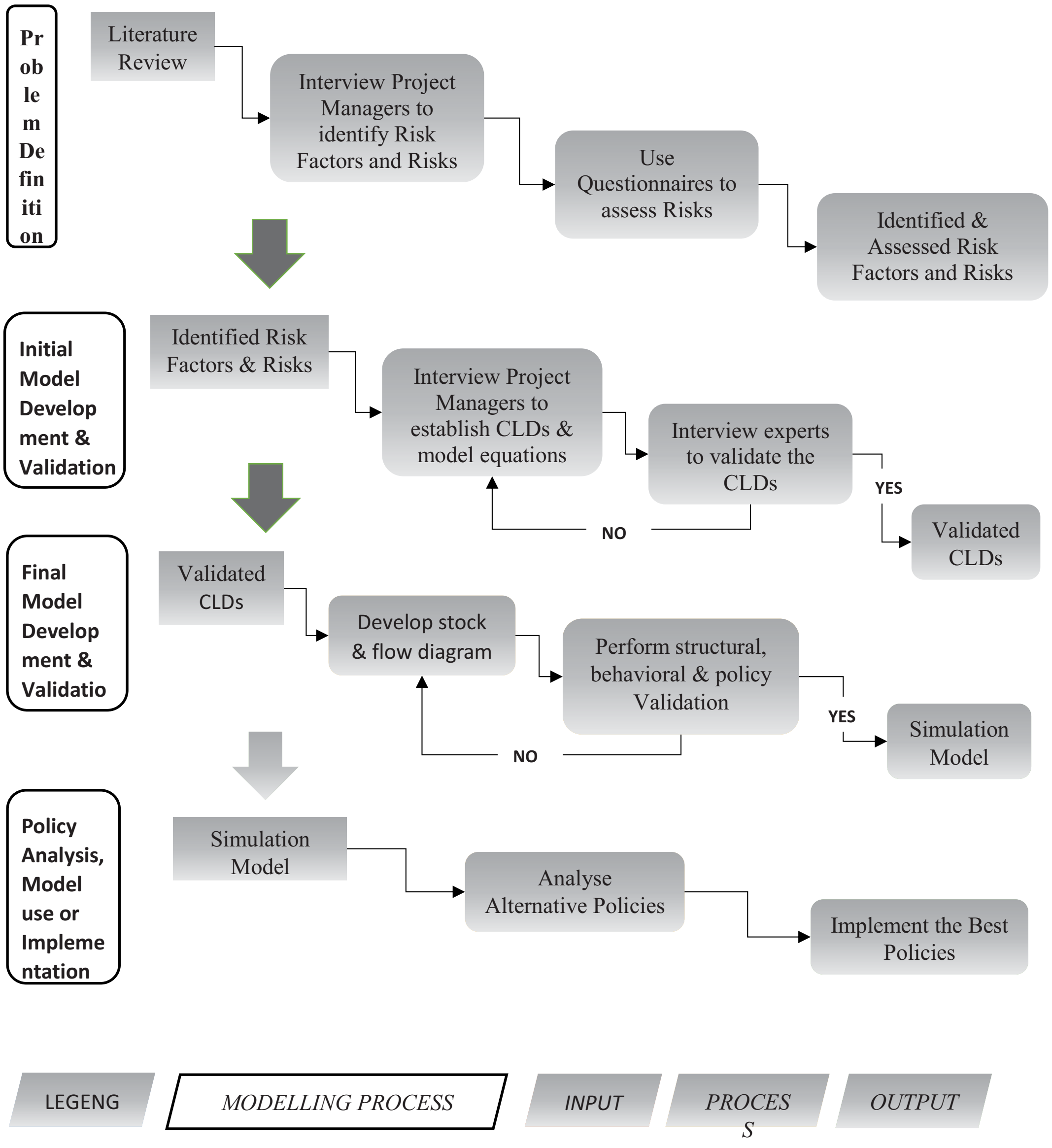

Figure 3: Framework for Developing Risk Interaction Models

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