2014 Proceedings of PICMET '14: Infrastructure and Service Integration.

Front End Project Planning for the Power Sector in Africa: A Conceptual System Dynamics Model

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Abstract--**Developing countries offer abundant opportunities for high return and high growth potential investments, such as in critical energy sector infrastructure projects. In Africa, major projects are presently in progress to upgrade and refurbish the infrastructure in the energy sector, and especially in the electricity energy sub sector. However, many of these projects run into delays, quality problems and cost overruns which amongst other causes, are attributed to inadequate time and resources spent in the initial pre-planning and planning phases of these projects. This research focuses on electricity infrastructure projects in Africa using system dynamics approach. From the literature, the paper explores and discusses theories, methods and models previously developed to better manage projects, including how these models are to be used to derive a model beneficial to energy sector projects in Africa. The results of the research will help in reducing uncertainty in projects in the Africa and other developing countries, and will be beneficial to energy sector players, including investors in the energy sector. This paper presents results of literature review in this area as well as the initial systems thinking in model building. The research uses a system dynamics approach employing vensim software in model building and analysis.**

I. INTRODUCTION

Economies in Africa are currently registering impressive economic growth and this has resulted into the need for expansion of the electricity supply infrastructure in this region. This expansion takes the form of new generation plants needed to boost the electricity generation capacity, transmission grids and electricity distribution lines together with the needed substations. The new infrastructure is mostly procured and executed as projects awarded by government agencies to winning bidders. However, many such projects have run into delays, quality problems and cost overruns which, amongst other causes, are attributed to inadequate time and resources spent in the conceptual phase of these projects. Several researchers have advanced possible remedies that could help in better project management of infrastructure projects so as to deliver the desired results. Nguyen et al [17] noted that engaging stakeholders in the engineering and construction industry early during the concept and pre-planning stages of a project is important in managing uncertainty in the projects in the industry. Similarly, Li et al [10] stated that numerous public infrastructure and construction project failures resulted from insufficiently addressing the stakeholders' concerns, and conclude that where stakeholders fail to reach a consensus during the participation process in the early planning stage of a project, it may not be worthwhile to continue with the project as this would likely increase the chance of failure. These sentiments emphasize the importance of stakeholders in the front end planning stage of public infrastructure projects.

This research therefore aims at developing a method that will help evaluate and reduce risks in projects in the electricity industry in Africa, and that would lead to better project delivery in terms of cost and schedule management. The objectives of the research are to design a system dynamics model that will be useful in analyzing project risk behavior, to document the learning from the studies, and to design system structures and policies that result in improved system behavior for projects in the electricity industry in Africa.

II. RESEARCH METHOD

Fig. 1 gives the system dynamics modeling process [28]. Problem articulation deals with finding what problem there is and the key variables. The dynamic hypothesis lists the current theories of the problematic behavior with causal maps created, while in formulation, a simulation model is created specifying structure and decision rules. In testing, the model is checked if it reproduces the problematic behavior while in policy formulation and evaluation, future conditions that may arise are articulated, and the effects of a policy or strategy are analyzed. Project performance is typically measured in terms of schedule, cost, quality, and scope. The modeling process by Sterman [28] has been applied and used successfully to model various and diverse problems before; it was found suitable and is therefore used for this research.

Previous project management models ([5], [34]) were used as the basis for generating the conceptual model developed in this research paper. The risks incorporated were identified by holding discussions with practitioners in the power sector in Kenya through focus group meetings that included representatives from the government, clients in the power industry and representatives from contracting firms active in the power industry in Kenya.

System dynamics was chosen as the modeling and simulation tool in this research largely due to insights from the literature review. The nature of projects in the electricity industry can be framed as complex dynamic systems ([27], [23]) because these projects are formed by multiple interdependent and dynamic components, and include multiple feedback processes and non-linear relationships. Engineering projects also generally involve both "hard" and "soft" data [27]. Project risks can interact with each other to produce effects and impacts that are non-linear, with reinforcing feedback loops that usually result into policy resistance [34]. Despite efforts implemented to correct the effects that cause delays, quality problems and overruns in projects in the electricity sector, these effects persist, and therefore system dynamics may be useful for analyzing these risks, and to develop new policies that would guide successful project deliveries.

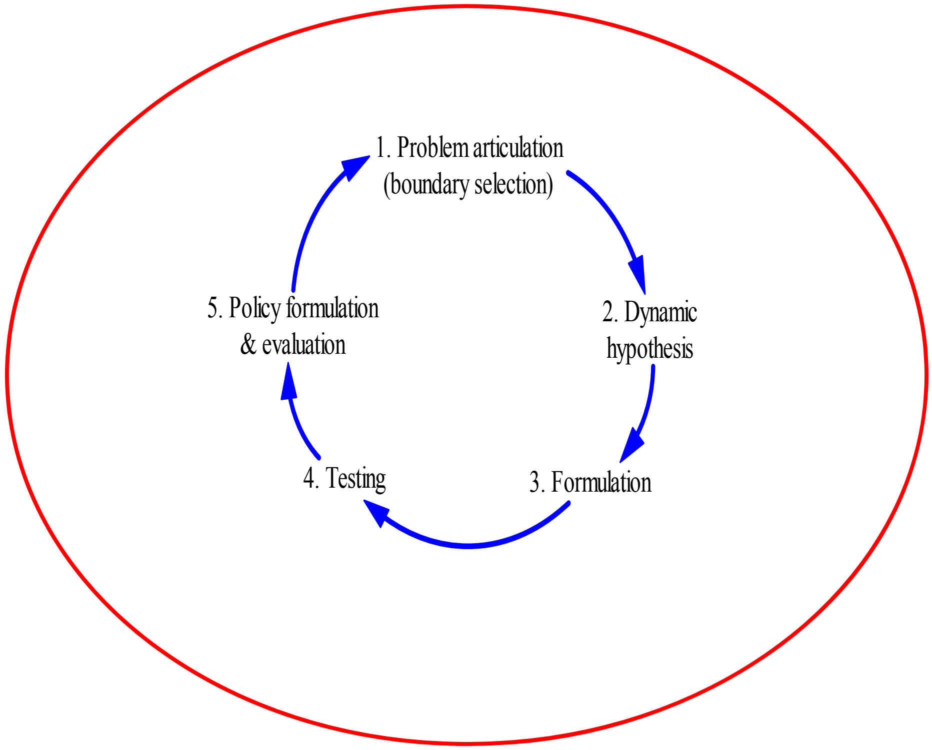

Fig. 1: The modeling process [28]

III. FRONT END PLANNING AND PROJECT RISK MANAGEMENT

Gibson et al [9] define front end planning, also referred to as pre-project planning, as the process for developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. The purpose of front-end management is to produce thorough and credible project concepts for evaluation before a final decision to finance the project or not is made.

In the recent past, differing opinions have emerged that explore new paradigms in project management. Williams [35] distinguishes between "the planning approach" to projects, in which a well-defined path to predetermined goals is assumed and "the learning approach," which "sees the project as an ambiguous task with changing objectives as the project proceeds". He however adds that project risk management lends itself to conventional structured planning as the project manager tries to avoid deviations from the predefined project plan. Shenhar [25] advocates that the project management style used should be dependent on the type of project, so that projects with lower technological uncertainty are managed in a formal style, while those with higher technological uncertainty should employ a more flexible attitude and tolerance for change and tradeoff between project requirements. Meyer et al [15] state that the challenge in managing uncertainty to whatever degree, is to find the balance between planning and learning. Planning provides discipline and a concrete set of activities and contingencies that can be codified, communicated and monitored. The two require different management styles and project infrastructure. They conclude that projects in which foreseen uncertainty dominate allow more planning, whereas projects with high levels of unforeseen uncertainty and chaos require a greater emphasis on learning. Similarly and while reporting on a paper on the changing paradigms of project management, Pollack [18] states that in many complex projects, it is impossible to foresee the actions which will be needed in the future and therefore through consultation and facilitation, the project manager defines what needs to be done as the project progresses, adapting as the project unfolds.

Projects in the energy sector, specifically in the electricity utility sector can be categorized as formal in the sense that they either use existing technologies or adopt new technologies to an existing infrastructure. However, the projects are increasingly being outsourced as Design-Build, or EPC-Turnkey projects, and many of the projects are large in magnitude and budget. Complexities therefore arise from the interactions between the client, contractors, various project risks, and the assembly of equipment from different sources which have to be connected to an existing network. According to Love et al [11], methods used in a risk management approach, as given in [26], can be successfully applied in a dynamic approach. For example, risk identification techniques can be applied to identify unattended dynamics. Therefore system dynamics modeling is relevant for managing risks of projects in the energy sector in Africa.

Risk management is defined as a procedure to control the level of risk and to mitigate its effects. The conceptual phase of a new construction project is most important, since decisions taken in this phase tend to have a significant impact on the final cost. It is also the phase at which the greatest degree of uncertainty about the future is encountered. In response to this type of situation, risk management can play an important role in controlling the level of risks and mitigating their effects. However, its adoption by industry has been rather slow, and the construction industry in particular has been slow to realize the potential benefits of risk management [33]. According to Prasanta [19], large-scale construction projects are exposed to uncertain environments because of factors such as planning and design complexity; presence of various interest groups like project owner, owner's project group, consultants, contractors and vendors, resource issues; climatic; environmental; the political environment and statutory regulations. This is illustrated in table 1.

IV. SYSTEM THINKING AND SYSTEM DYNAMICS

Systems thinking involve holistic consideration of our actions and is needed to deal with the complexity of our world, whose elements are interrelated [24]. Everything people know about the world is a model, and these models usually have a strong congruence with the world [14]. Systems thinking is not one thing but a set of habits or practices within a framework that is based on the belief that the component parts of a system can best be understood in the context of relationships with each other and with other systems, rather than in isolation. Systems thinking takes the principles of systemic behavior that system dynamics discovered and applies them in practical ways to common problems in organizational life [21]. Successful systems thinking is about being able to see the whole picture or context of a situation and its interconnections to its environment. Forrester [7] warns that system dynamics models have little impact unless they change the way people perceive a situation. A model must help to organize information in a more understandable way, link the past to the present by showing how present conditions arose, and extend the present into persuasive alternative futures under a variety of scenarios determined by policy alternatives. In other words, a system dynamics model, if it is to be effective, must communicate with and modify the prior mental models. Only people's beliefs, that is, their mental models, will determine action [7]. This research employs the method as given in Fig. 1 by holding discussions and focus group meetings with stakeholders in the energy sector, and using the system dynamics approach to formulate a conceptual model.

Sterman [29] states that policy resistance, the ability of a system to perpetuate unintended consequences, arises because we do not understand the full range of feedbacks operating in the system and so we persistently react to the symptoms of difficulty, intervening at low leverage points and triggering delayed and distant, but powerful feedbacks [30]. Policy resistance breeds a sense of futility about our ability to make a difference, a creeping cynicism about the possibility of changing our world for the better. The structure of a model comprising different types of variables, the links between them, and the feedback loops they form, together with their underlying equations and values, determines the behavior of the system. In order to fundamentally change the behavior of a model, one therefore needs to change the feedback and/or stock-flow structure, equations, and/or parameter values. It is often assumed that, if the model and the real-world system correspond closely, the changes required to change the model behavior would normally also change the real-world system behavior [20]. Important objectives of most system dynamics studies are to enable virtual experimentation, to learn from these experiments and to design system structures and policies that result in improved system behavior. Using the research method as given in Fig. 1, a system dynamics model is to be developed that will allow us virtual experimentation based on the data gathered from the stakeholders.

The goal of the conceptualization phase of the modeling process is to capture the feedback structure that can offer a largely endogenous explanation of the problem [28]. The steps of the model conceptualization phase are to determine the purpose or objective of the model, define the model boundaries and identify the most important variables, construct a conceptual model of important mechanisms and feedbacks in the system and formulate a causal theory or dynamic hypothesis on how problematic behavior is generated by the model structure. This causal theory, like all theories, exists to be tested and is constantly subject to

TABLE 1: RISKS IN LARGE SCALE CONSTRUCTION PROJECTS [19]

Technical Risks	Scope change, technology selection, implementation methodology selection, equipment risk, materials risk and engineering and design change
Acts of God	Normal natural calamities and abnormal natural calamities
Financial, Economic and Political Risk	Inflation risk; fund risk; changes of local law; changes in government policy and improper estimation
Organizational Risk	Capability risk of owner's project group; contractor's failure; vendor's failure and consultant's failure
Statutory Clearance Risk	Environmental clearance; land acquisition; And other clearance from government Authorities

change or abandonment. Reference [16] carried out research aimed at determining best practices in system dynamics modeling and their key findings on what is important in the system conceptualization phase included the need to incorporate views from different perspectives, establish the client's mental models and identify important stocks. Table 2 gives their findings on what is key in system conceptualization phase. In the conceptualization phase, causal loop diagrams are usually created to elicit the assumed feedback structure of a system or issue. This approach has been used in this research, and in formulating the conceptual model presented in the paper. Focus group interviews with key stakeholders was used to get the variables that contribute most to delays and quality problems in the sector. Documentation was also used to get a history of the projects previously completed, together with the challenges faced in each project.

V. SIMULATION IN SYSTEM DYNAMICS MODELING

While acknowledging the importance of qualitative system models in [30], qualitative modeling exposes us to one of the most fundamental bounds on human cognition: our inability to simulate mentally the dynamics of complex nonlinear systems. Formal models, grounded in data and subjected to a wide range of tests, lead to more reliable inferences about dynamics and uncover errors in our mental simulations, he states. There is an even more fundamental reason why simulation is essential. There is no learning without feedback, without knowledge of the results of our actions. Normally, scientists generate that feedback through experimentation. But physical experiments are impossible in many of the most important systems. When experimentation is too slow, too costly, unethical, or just plain impossible, when the consequences of our decisions take months, years, or centuries to manifest, that is, for most of the important issues we face, simulation becomes the main, perhaps the only way we can discover for ourselves how complex systems work, where the high leverage points may lie [30].

Therefore using the research method as indicated in Fig. 1, a conceptual model has been developed that is qualitative at this point, with the intention of progressing this model in the next phase of research to the simulation phase, where experimentation with different types of variables will take place with the aim of understanding those variables that give the greatest leverage to beneficial behaviors. The next stage of research therefore will focus on developing this model into a dynamic model with stocks, flows, and feedback loops that will be simulated and analyzed to get the leverage points that can be used to come up with new policies beneficial to project management in Africa at large.

VI. THEORETICAL FRAMEWORK AND CONCEPTUAL MODEL FORMULATION

A. The rework cycle structure

The majority of system dynamics studies that focus on project dynamics include a simulation model of project evolution and the core feature of these models is the rework cycle [2]. While most of the original work is usually finished early in the project, delays are usually caused by the need to rework that original work. The rework cycle is illustrated in Fig. 2. Reference [5] report that it was first developed by Pugh-Roberts Associates and refined over many subsequent applications ([2], [3], [4], [21], [6], [31], and [32]). By considering defects, quality and testing through rework cycle; many path-dependent reinforcing loops are generated that critically impact the fate of projects. Almost all dynamic project models have a rework cycle in some form [13]. Thus the rework cycle is central to understanding project delays and disruptions [12], and the conceptual model developed in this paper uses the rework cycle, essentially because many projects in the power industry in Africa suffer from rework, that results into project delays.

TABLE 2: BEST-PRACTICE STATEMENTS IN SYSTEM CONCEPTUALIZATION [16]

Importance	Summarized statements
Highest	Approach system conceptualization creatively, from different perspectives Elicit clients' mental models to help develop the building blocks of the dynamic hypothesis Identify important accumulations (stocks) early in conceptualization
High	Strive for an endogenous dynamic hypothesis Make sure the boundary of the dynamic hypothesis is large enough to enable the endogenous point of view Identify key variables representing problematic behavior

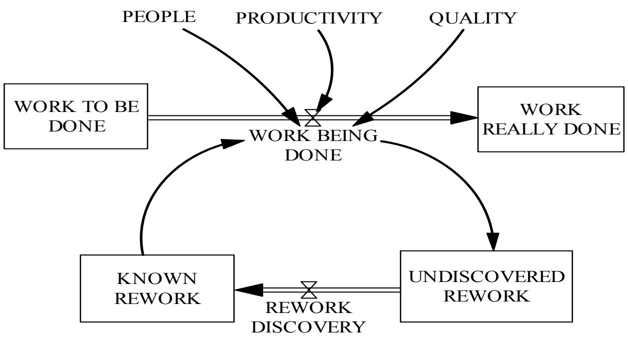

Fig. 2: The rework cycle structure. (Adapted from [2])

As shown in Fig. 2, the rework cycle represents four pools of work or stocks. At the start of a project or project stage, all work resides in the pool 'WorkTo Be Done'. As the project progresses, changing levels of staff working at varying rates of 'Productivity' determine the pace of 'Work Being Done'. 'Work Being Done' depletes the pool of 'Work to be Done'. This work is executed at varying, but usually less than perfect, 'Quality'. 'Quality' represents the fraction of the work being done at any point in time that will enter the pool 'Work Really Done' and which will never need re-doing. The rework cycle has been applied in the following model on changes and their effects on project dynamics.

VII. CONCEPTUAL MODEL OF FEEDBACK STRUCTURE FOR INTERACTING PROJECT RISKS IN THE POWER SECTOR IN AFRICA

The causal loop diagram in Fig. 5a and Fig. 5b has been developed by incorporating the risks perceived to be prevalent in the electricity industry in Africa into earlier models in [5], [34]. The risks incorporated were identified through discussions with practitioners in the power sector in Kenya through focus group meetings that included representatives from the government, clients in the power industry and representatives from contracting firms active in the power industry in Kenya. Reflections from the literature review have also been included ([24], [7], [29], [30], [20], [28], and [16]).

A. Logic used in developing the conceptual model

In the causal loop diagram in figure 5a, political risk has been modeled as a stock influenced by positive or negative political events, directly impacted in the model by the variations in the probability of achieving business objectives. Political risk refers to the complications businesses and governments may face as a result of what are commonly referred to as political decisions or any political change that alters the expected outcome and value of a given economic action by changing the probability of achieving business objectives. During focus group meetings and in discussions with the players in the power sector in Kenya, political risk came out as an important risk that affects projects in the sector. Discussions with representatives of contracting firms in the power sector also mentioned political risk as a major factor that affects project delivery in the entire sub-Saharan region where they operate. Political risk often results into schedule slippage, and so affects the planned schedule for projects, leading to delays.

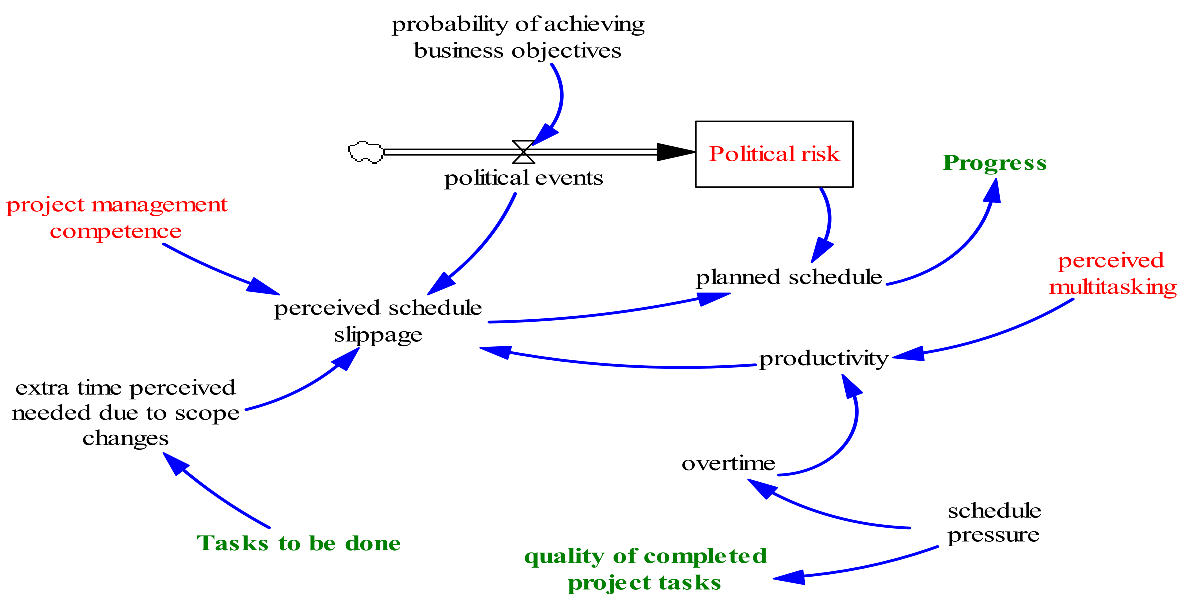

Fig. 5a: Conceptual model, portion incorporating political risk, perceived multitasking and project management competence

The other risks which were mentioned highly in the focus group meetings with the stakeholders in the power sector were project management competence, perceived to be low amongst utility companies as well as within the contracting firms operating in the region, and multitasking that is common amongst the key staff of contracting firms operating in the sector. Project management competence is key in contract management and administration, and the focus group meetings revealed that low project management competence often leads to schedule slippage, which then leads to adjustment of the planned schedule for project completion. During the discussions, it came out that contracting firms operating in the region often win and manage many projects concurrently, leading to multitasking amongst the key personnel such as those carrying out testing and commissioning parts of projects. This affects productivity, leading to schedule slippage. Schedule slippage and political risk therefore directly impacts the original planned project schedule, leading to delays in completion of projects.

Similarly, increase in multitasking impacts productivity negatively as the few highly skilled staff move from one project to another, meaning that subsequent tasks often have to wait for completion of key tasks performed by these skilled staff, resulting into instances of idle resource utilization, and hence leading to schedule slippage. This also causes schedule pressure, which on the one hand affects the quality of work as later stage processes are done in a hurry to try and catch up on lost time. Schedule pressure also leads to overtime work employed to catch up on lost time, but over reliance on overtime leads to fatigue that ultimately affects productivity negatively. During the focus group meetings, it emerged that the need for scope changes arises from problems related to competence of the project teams as well as due to political risks and preferences. This often leads to schedule slippage as the need for the changes are mostly discovered late in the project while the number of tasks to be performed also increases from the original number planned at the beginning of the project. In Fig. 5a, ‘tasks to be done’, ‘progress’ and ‘quality of completed project tasks’, marked in green, link to the conceptual model portion in Fig. 5b.

During the focus group meetings and discussions with stakeholders in the power sector, and partly as a result of the risks previously mentioned such as political risk, low project management competence, and multitasking, rework was mentioned as a common occurrence in many projects in the power sector in Kenya and the region. As indicated in figure 5b, poorly completed project tasks lead to undiscovered rework, which is later discovered through testing and the tasks that have to be re-done re-enter the ‘tasks to be done’ stock. Work progress is influenced by the productivity of project personnel, while undiscovered rework directly and negatively influences quality of completed project tasks. Progress is often influenced by the productivity of the project personnel, and either leads to proper completion of project tasks, which forms the stock of satisfactorily completed project tasks, or may lead to poor completion of project tasks, which feeds into the stock of undiscovered rework that later leads to detection of rework, feeding into the stock of tasks to be done. Completed project tasks done well would lead to high quality of completed project tasks, while undiscovered need for rework is a major source of poor quality of completed tasks.

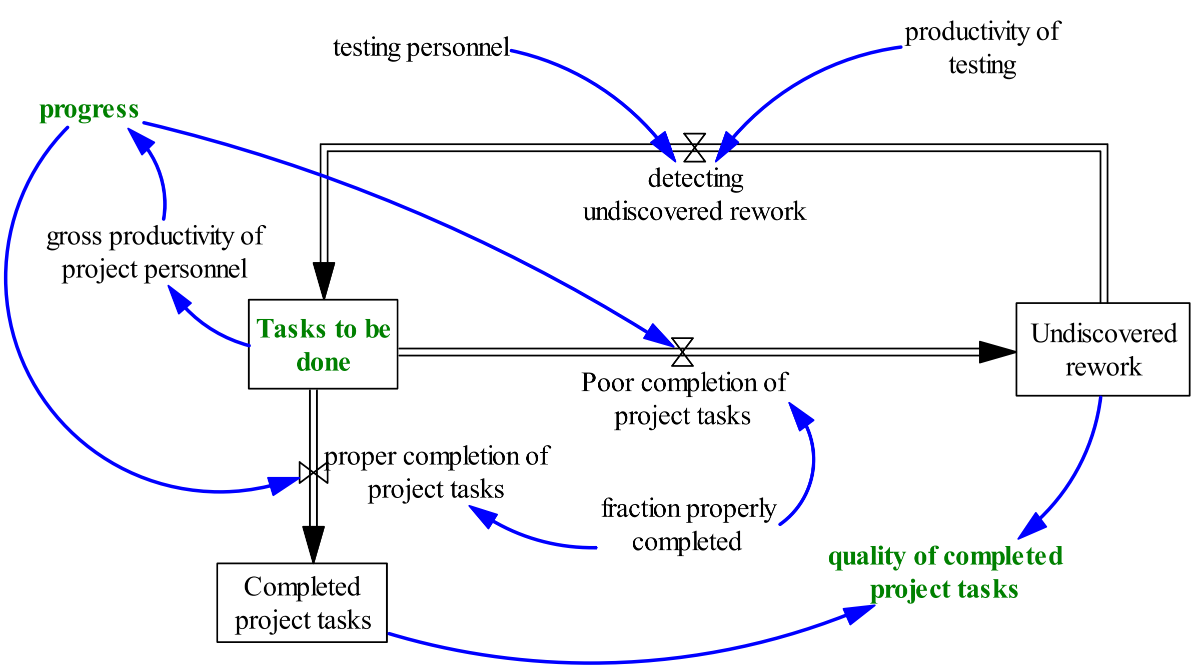

Fig. 5b: Conceptual model, portion incorporating the rework cycle

The productivity of testing personnel, especially commissioning engineers usually determines the speed at which rework is detected in energy sector projects. Similarly, productivity and competence of project personnel impact the fraction of properly completed project tasks. The resultant conceptual model developed is shown in Fig. 6. Auxiliaries in Fig. 5a such as project management competence, probability of achieving business objectives, and perceived multitasking, together with those from Fig. 5b such as productivity of testing, fraction properly completed, gross productivity of project personnel testing personnel can be varied dynamically during simulation to determine their effect on schedule slippage, productivity, planned schedule, proper completion of project tasks, quality of completed project tasks and rework detection. This will form the next phase of this research.

The proposed framework for applying system dynamics modeling to identify the interdependencies of project risk drivers is potentially applicable to other construction projects in other parts of the world, and will not be limited to developing countries. This paper highlights the conceptual framework that will be further enhanced in the next phase, where more stakeholders' views will be brought on board and a simulation model employing vensim software developed to analyze experiment and test the risks inherent in construction projects in the energy sector.

VIII. CONCLUSION

The paper brings out the importance of system thinking, which can be applied to common problems in organizations so as to see the holistic context of a situation together with its interconnections to its environment. Acknowledging the feedbacks of a problem in a holistic manner can help us avoid policy resistance, which perpetuates unintended consequences. With policy resistance at play, organizations often react to the symptoms of difficulty, and intervene at low leverage points, triggering delayed, distant but powerful feedbacks. While it helps us to conceptualize the problem, system thinking being qualitative in nature, faces the challenge that human beings are unable to simulate mentally the dynamics of complex non-linear systems. On the other hand, system dynamics takes the qualitative results and through dynamic simulation, helps us infer reliable information about the dynamics of the problem and uncover errors in the mental simulations. We also learn from the paper that simulation is quite useful in situations where experimentation may be too slow or costly, or when the consequences of our decisions take a long time to realize.

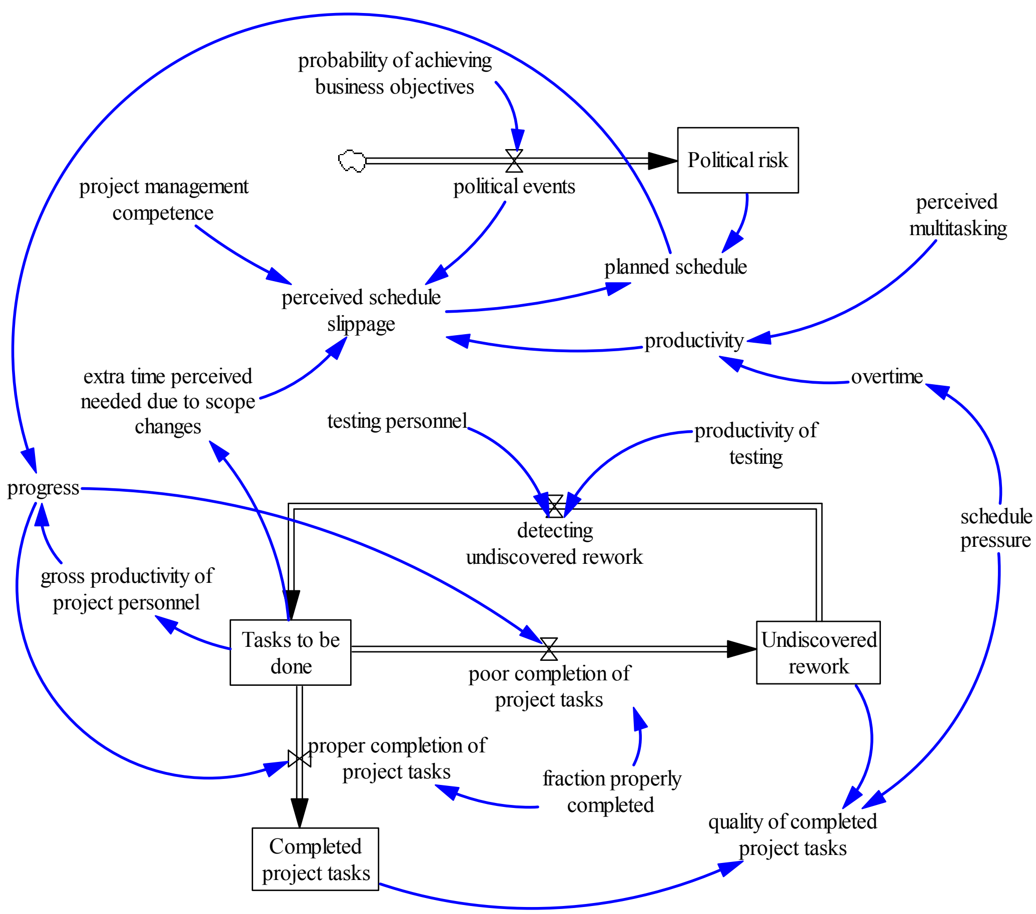

Fig. 6: Conceptual model of the interacting project risks in the power sector in Africa

For projects in the electricity energy sector in Kenya, common risks that afflict the projects include multitasking, which eats into project lead time and is due to shortage of skilled staff in the region, worker fatigue, political risk, and competence of project teams which tends to affect contract management and administration. The other risks that are at play are substandard work quality leading to rework, and frequent scope changes that interferes with the project schedule. Rework causes delays and disruptions in projects, and can be caused by shortage of skilled manpower for project delivery, as well as by lack of project management skills within the project team.

In this paper, a qualitative conceptual model of interacting project risks in the electricity industry in Sub-Saharan Africa has been developed and it brings out the feedback structure of how the risks influence one another and the project as a whole. Some of the risks at play in the region include political risk that can slow down projects or make them costly, multitasking that occurs as a result of contractors handling too many projects at the same time and in the process, being forced to share key technical personnel from one project to another. Inadequate competence of project staff is also noticeable, as it leads to poor contract management and administration. Through simulation, analysis and testing of the conceptual model developed here, new system structures and policies will be developed that hopefully will result in improved system behavior for projects in the electricity sector in Africa.

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