

A CONCEPTUAL SYSTEM DYNAMIC MODEL TO DESCRIBE THE IMPACTS OF CRITICAL WEATHER CONDITIONS IN MEGAPROJECT CONSTRUCTION

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Abstract

In Africa, critical weather conditions (CWCs) such as snow, heat waves, harmattan and storms are increasing in frequency and severity. The ability of players in the construction industry to plan against such CWCs and cope with their immediate impact on construction activities is critical to the contractor, client and the community that is affected. As part of a funded research scheme by the Heriot Watt University in Edinburgh, UK and the European Cooperation in Science and Technology (ECOST), this paper aims to introduce a system dynamic (SD) model to describe the impacts of critical weather conditions in megaproject construction for more accurate construction planning against project delays and cost overrun at the strategic level of megaproject management. The SD methods have been used extensively over the last 35 years on complex projects and have proven track records of project management performance in project lifecycle. The SD approach to megaprojects construction planning is first based on extensive literature review into current research practice in mega construction projects in Africa in incorporation with authors' experience related to megaproject management and research across the world. An experimental SD model is then illustrated for the OR Tambo International Airport (ORTIA) project in South Africa. The paper further discusses the use of such a SD model for better understanding of the impacts of critical weather conditions and to improve accuracy of construction planning in megaprojects management in Africa.

Keywords: Weather, delay, cost overrun, complexity, system dynamic, megaprojects

INTRODUCTION

Construction, like many other industries, has complex and sizeable risks built into its structure and process from the initiation to the closing stages (Ashley, 1977). For example, megaprojects are characterised by a number of uncertainties such Social, Technical, Economical, Environmental and

Political (STEER) (Chen, et al. 2011) risks that exist throughout the life cycle of megaprojects. Delays and cost overruns have become common occurrences in many of their delivery (Flyvbjerg, 2007) especially against interrelated STEER variables. Pan (2004) in a study commensurate these as having many implications on both the construction organisations and the client organisations which commission them

One of the challenges faced by contractors of megaproject construction with regard to project environment is the planning and management of critical weather conditions against delays and cost overruns at the strategic megaproject management level. With respect to impacts caused by severe weather, contractors can usually recover extra time but not extra money. In other words, even if the contract allows for the recovery of extra time because of delays caused by critical weather conditions, contractors as advised by Molenaar (2005) must still be sure to document the impact to their performance properly or risk to losing any right to recover.

For large construction projects (megaprojects), leading project engineers and contractors often seek for advice from environmental consultants to help them precisely determine any possible inclement weather risk that may delay the project and cause cost overruns (NOAA, 2011). However in oftentimes, delay and cost overruns continue to dominate the news globally during megaproject development. Cohenca and Laufer (1990) believed that the poor capability of the traditional project management approaches to plan and manage severe weather conditions contributes in decreasing project performance. Therefore, megaproject construction as a complex system (Flyvbjerg, et al. 2003), requires tools and techniques that can holistically aid Project managers at the strategic level to plan effectively ahead against the trends of critical weather conditions during megaproject delivery.

In view of the above, the SD approach is used in this study as a tool to conceptually model the impacts of critical weather conditions on megaproject construction. The SD models have been used extensively over the last 35 years on complex projects and have proven track records of project management performance in project lifecycle. However, its use for unforeseen and unpredictable situations such as critical weather conditions was not captured

enough in literature. For this reason, the paper aims to introduce a system dynamic (SD) model to describe the impacts of critical weather conditions to construction projects for more accurate construction planning against project delays and cost overrun at the strategic level of megaproject management. The results of this study are expected to provide better understanding of the impacts of critical weather conditions and to improve accuracy of construction planning in megaprojects management in Africa

BACKGROUND

System dynamic in megaproject management research

System dynamics (SD) is both a methodological approach and set of tools based on systems thinking developed in the year 1950 for the analysis of industrial systems (Forrester, 1961). Its approach to project management is based on a holistic view of the project management process (Rodrigues, 1996) and focuses on feedback processes that take place within the project system (Rodrigues, 2001). Consequently, the SD approach has three important features of psychoanalysis, connectivity and new view of process (Darmon, 2000). It shows clearly a hierarchy of interacting routes to build a process model and the ability to using mathematical equations to represent a system, and then solving those equations simultaneously to find feasible solutions (Brockmann, 2007). As far as the relationship between systems elements are relatively known, this technique coupled with the power of computer could solve problems of any degree of complexity. It has been successfully used in construction project related research (Nasirzadeh et al., 2008) as summarised in Table 1.

The applications of the SD models in project management research summarised in Table 1, were developed by various researchers to inform practitioners how to tackle problems of complexity, uncertainty, conflict and scale in construction and engineering fields (Nasirzadeh et al., 2008). It has also been used for studying and managing dynamically complex systems through the application of simulation models (Ford, Anderson and Darmon, 2002) to build on the reliable part of understanding systems while compensating for the unreliable part. The procedure untangled several threads that can cause confusion in ordinary debate and can be useful for managing and simulating processes with fundamental systems thinking, concepts,

assumptions, and tools (Forrester 1961, 1971; Richardson 1986; Senge 1990; Darmon, 2000; and Toole, 2005).

Table 1: Applications of system dynamics in research into construction project management

Researchers	Year	Summary
De-Marco, A. & Rafele, C	2009	A feedback process to understand construction project performance
Nasirzadeh, Afshar and Khanzadi	2008	An approach for construction risk analysis
Mugeni-Balyejusa, B.	2006	Modelling changes in construction projects.
Long, D. and Ogunlana, S.	2005	Modelling the dynamics of an infrastructure project
Howick, S.	2003	Disruption and delay in complex projects for litigation
Ogunlana, Sukhera and Li,	2003	Performance enhancement in a construction organization.
Love, Holt, Shen, Li and Ira ni.	2002	The need for understanding of how particular dynamics can hinder the performance of a project management system.
Park, M.	2002	Change management for fast-tracking construction projects
Chritamara. S and Ogunlana. S.	2002	Modelling of design and build construction projects
Rodrigues, A. and Bowers, J.	1996	A comparative analysis between two approaches to project management.
Darmon, J.S.	1989	Misperceptions of feedback in dynamic decision making
Jessen, S. A.	1988	Systems approach in the analysis and improvement of project performance.

Construction planning concerning critical weather conditions

Construction planning is a fundamental and challenging activity in the management and execution of construction projects (Baracco-Miller, 1987). It is a necessity for managing complexity and involves the choice of technology, the definition of work tasks, the estimation of the required resources and durations for individual tasks, and the identification of any interactions among the different work tasks. Although, it is difficult forming a good construction plan, its development will allow Project Managers to adapt to changes brought by both external and internal macro environment (Civil Engineers link, 2011) over time as construction proceeds.

Though, many various planning techniques are used to analyse delays caused by severe weather events in a construction project, these techniques however, depend on factors such as project complexities, contract requirement, and quality of contractor's programmes among the lot to select appropriate techniques to apply. The techniques can either be prospective or retrospective.

The prospective delay analysis are those that predict the likely impact on the progress of the works while the retrospective delay analysis are those that seek to demonstrate the actual impacts on the work. The former include names such as the As-planned Method, the As-planned vs. as-built Schedule Analysis, the Modified as-built Method, the Impact as-planned Method, the Collapsed as-built Method and the Global Impact Method (AACE, 2009). Each of which can be used both before and after the delay effect has taken place. While these techniques and past experience are good guides to construction planning against delays, each project is likely to have special problems or opportunities that may require considerable ingenuity and creativity to overcome or exploit.

It is essential to understand that the above techniques have their own advantages and disadvantages and can produce different results in the hands of two different delay analysts. Evidence suggests that these techniques deliver unsatisfactory results (Carnell, 2000). Instead, in McDonald (2000), the location of the project, the type of work, and the time of the year in which the work is to be executed must be considered holistically as role importance in quantifying the allowance to be made for weather in contracts.

Unfortunately, it is quite difficult to provide direct guidance concerning general procedures or strategies to form good plans in all weather related circumstances. There are some recommendations or issues that can be addressed to describe the characteristics of good plans, but this does not necessarily tell a planner how to discover a good plan. These therefore make project management one of the most important but poorly understood areas for severe weather management. For large projects such as megaprojects, planning and managing complexities especially when it comes to critical weather conditions can be very difficult. Such projects have systems that are extremely complex, highly dynamic and involve multiple inter dependencies components and feedback processes (Ogunlana, et al. 2003).

Therefore, megaprojects need a capable planning technique such as the SD approach to represent the complexities of the systems and be properly managed against the change and impacts of critical weather conditions on various productivity tasks.

RESEARCH METHODOLOGY

The methodologies adopted in this research are literature review, case study, SD modelling and interview with experts involved in megaprojects.

Literature review

To obtain relevant information which fit into the purpose and direction of this research, keyword search was conducted through online databases including ASCE Civil Engineering Database, ICE Virtual Library, IEEE Xplore Digital Library, Elsevier SciSverse, Wiley Online Library, and Springer Link. Keywords used include ‘Inclement weather and construction planning’, ‘System dynamics and construction planning’. Besides searching into those online databases, relevant articles published in the construction project and weather related journals were also collected, and those journals are International Journal for Project Management, Journal of Construction Engineering and Management, Journal of Management in Engineering, Engineering, Construction and Architectural Management, Construction Management and Economics, Disaster Prevention and Management. As a result, 218 journals, 31 conference papers and 20 articles were identified.

Case study method

To understand the subject of this research and ensuring accurate and unbiased, systematic gathering of empirical data on OR Tambo International Airport (ORTIA) expansion project was carried out. The choice of ORTIA was based on the fact that almost all the weather conditions to be considered critical to megaproject construction in Africa can be traced in South Africa except the harmattan which normally occurs in South Saharan Africa that the case project location does not experience. However, the harmattan has similar characteristics comparable to some of the weather conditions researched upon in this study. The results obtained were used to describe and justify in the first place, the methodology adopted in this research, and also provided descriptive features beyond studying surround context.

The method further elaborated on detail findings, and made accurate observation and rigorous collection of evidence on the impacts of critical weather conditions on the case project. The results were used to explain why delays and cost overruns occur in megaprojects development by determining causes and effects.

SD method

Consequently, the SD method used in this research contained both the quantitative and qualitative elements of the critical weather condition impacts revealed during the literature review and interviews with experts involved in megaprojects planning and construction. The method offered an approach to model initially, each of the weather conditions identified and then review them for consistency to capture the major feedback processes responsible for the system behaviour. The variables used to develop the initial SD models are summarised in Table 3 and defined the boundary of the model development in this research. The variables include those for the critical weather conditions which impacts on the ORTIA expansion project and site workers.

CASE STUDY

To evaluate the effectiveness of the proposed methodology, the consequences of identified classified risks from a wider external macro (supra) environment were quantified on the extension and upgrading of OR Tambo International Airport (ORTIA) in South Africa. The profile of this project is presented in Table 2. All the projects were expected to be completed by 2009.

In addition to the above details of the case study project, also included a mass rapid transit railway system station called Gautrain which is integrated and built within the airport complex. The Gautrain links Sandton (a business area) and Pretoria, the administrative capital of South Africa

Table 2: Details of the ORTIA project

Projects	Duration (completed year)	Cost (billion Rand)
Central Terminal Building	2009	1,800
International Pier	2008	0.512
Echo Apron	2008	0.218
Terminal A departure upgrade	2007	0.081
Multi storey parkade	2007	0.475
Total		3.086

Source: Airport Company, South Africa. Equals to USD 3.88 million

On average, four major critical weather conditions in Table 3 with their various impacts on ORTIA project during construction were identified. The identified weather conditions were as a result of three major risk categories revealed and classified in Table 4. These risk categories were based on the research methodology adopted and interviews carried out with experts involved in similar megaprojects and through network groups such as Project ‘Manager’s discussion forum’, ‘Chartered Institute of Building (CIOB)’, ‘Project Manager Network Groups’ on LinkedIn.

However due to space limitations, only one of the ecological/force majeure sub factors under the context specific risks namely “severe weather condition” has been selected for detail consideration.

Table 3: Impacts of weather conditions on the ORTIA expansion project

Weather conditions	Criteria (NOAA, 2010)	Impacts of weather conditions	
		Project	Site workers
Snow fall	<ul style="list-style-type: none"> • Heavy snow \geq 2mm/hr or more accumulating to \geq15mm • Heavy/moderate snow with visibility near zero or \leq 200m accompanied by wind of 30m.p.h 	<ul style="list-style-type: none"> - Decreased productivity - Increased project cost - Damage to materials, tools & Equipment - Increase journey time on site - Minor accidents on site - Local route impassable - Increased maintenance/repairs - Earthworks instability - Landslides - Increased washout & flood - Drainage system problems - Signalling systems information problems - Work activities delays - Loss of power - Erosion - Loss of skilled/specialist workers - Call for overtime & rework 	<ul style="list-style-type: none"> - Frostbite - Loss of job - Nil pay for absence - Visibility problems - Accessibility problems - Confused behaviour - Heart attack - Respiration & skin infections - Vector born diseases

Based on desktop study and interview with experts involved in similar airport projects

Table 3: Impacts of weather conditions on the ORTIA expansion project

Weather conditions	Criteria	Impacts of weather conditions	
	(NOAA, 2010)	Project	Site workers
High temperature	<ul style="list-style-type: none"> Expectation of significantly higher than average temperatures in South Africa; thresholds are pre-determined via the Heat-Health Watch system. 	<ul style="list-style-type: none"> Rapid evaporation of water form concrete. Pre-mature setting of mortar Reduced resilient of seals & sealants Premature breakdown of machine filters in dusty conditions Lower compressive strength of concrete Heat curve Tram tracks buckling Twisting of tracks Expansion of tracks Breaking of tracks Signalling & system installation problems Increased incidents of glare Decreased productivity Damage to materials, tools & Equipment 	<ul style="list-style-type: none"> Weak Rapid pulse rate Heat stroke / stress Nauseated & Heart attack Very pale Dry & red skin Working difficulties Need for sunscreen & more water Increased resting time Skin cancer/cataract & sunburn Long term mental health Confused behaviour Respiration & skin infections Social cost
Rainfall	<ul style="list-style-type: none"> 2hrs rain to give 15mm within 3hrs period following 25mm/day of previous heavy rain event with thunderstorm warnings. 	<ul style="list-style-type: none"> Decreased productivity Increased project cost Damage to materials, tools & Equipment Increase journey time on site Minor accidents on site Power surge Local route impassable due to flood Increased maintenance/repairs Disturbed Earthwork Landslides & muddy sites Weak subgrade & Ballast Increased washout & flood. 	<ul style="list-style-type: none"> Nil pay for absence Visibility problems Accessibility problems Social cost

		- Drainage system effects - Erosion - Call for overtime & rework	
Wind	- Ave. Dangerous speed (>31mph) - Dangerous high speed (>46mph)	- Delay - Rework - Increase project cost	- Accident - Idleness - Injury due to flying debris

Based on desktop study and interview with experts involved in similar airport projects

Table 4: Identified risk categories in the ORTIA expansion project

Risk categories			
	Context specific risks	Project specific risks	Industry specific risks
Risk types	- Economic (macro) risks - Social risks - Ecological/force majeure (severe weather, earthquake, strike, war, crime, volcanic, etc.) - Political	- Delivery/operation risks - Technology risks - Financial risks - Procurement/contractual risks - Permits and licences	- Security - Operation/safety - Environmental

Based on desktop study and interview with experts involved in similar airport projects

A CONCEPTUAL SD MODEL

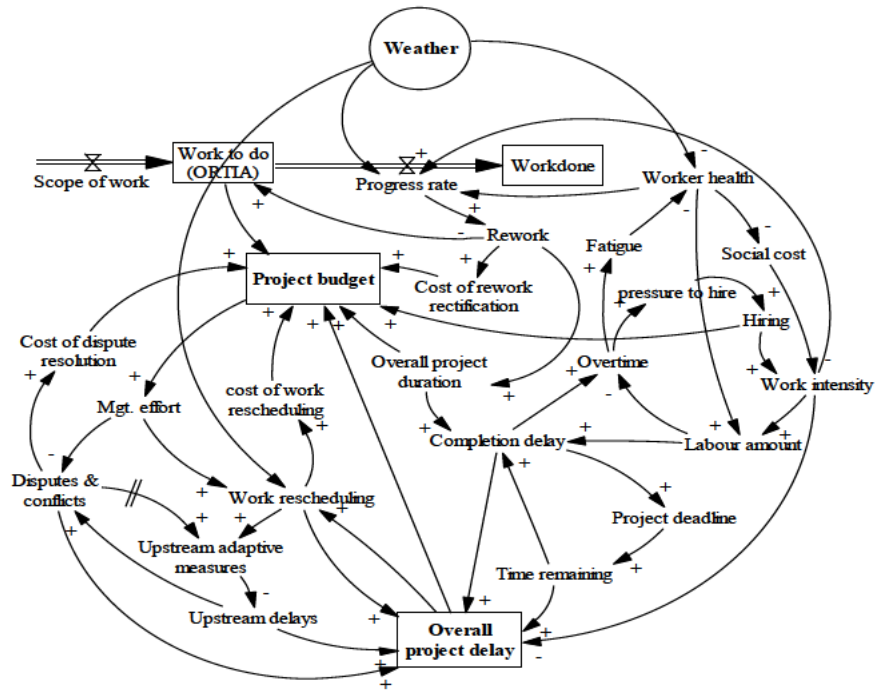
Further to the results obtained from the desktop study, the impacts of different type of weather conditions on ORTIA expansion project were described using the SD method. The impacts of four types of weather conditions including wind, rain, snow and temperature on the project have been individually illustrated at the beginning.

Those models were developed by placing the four types of weather events and their impacts on both human resource and the non-human resource aspect of the case project in logical and dynamic proceeding.

Findings from the four individual SD models were then transferred into one conceptual SD model (see Figure 1) to describe the overall weather impacts to project performance in terms of cost and duration. The structure of the model in Figure 1 demonstrates direct and indirect causative and effects relationship in the case project features and contains casual and feedback loops to indicate influences of one variable over the other and how changes in severe weather conditions affected progress in quantitative manner.

The model consists of five stocks (Weather, Work to do, Work done, Project Budget and Overall Project delay). The impacts caused by the weather conditions (Rain, Snow Wind and Temperature) have critical effects on the case project performance and target. These effects typically reduced progress rate through decreased in the human and non-human productivity by increasing rework, overall project duration, completion delay, project deadline, time remaining and the overall project delay. Cost of rectification and rescheduling of affected work packages by management in addressing the risks in the system further lead to increase in the project budget and delay.

Also, reduced progress rate, increased rework and the associated increased in completion delay, kept the amount of work remaining greater. Therefore, increase in overtime was needed to finish the work on time. The increase of overtime led to more fatigue and degradation of worker health. As a result, pressure to hire labour evolved to increase work intensity, and progress rate. Although, the effect of hiring increased the project budget, the process contributed to reduced completion delay, overtime and the overall project delay.



Legend:

→: A casual relationship

+ (-) signs at the arrowheads indicate that the effect is positively (negatively) related to the cause.

// signs on the arrows indicate the material and/or information delay

R denotes reinforcing loop and **B**, the balancing loop.

☁️ : Source or sink. X : Valve of ☁️→☁️ flow. ⚡ : Rate or flow

☐ : Accumulation of Tasks, project budget and overall project delays

◯ : Accumulation of weather events.

Figure 1: The conceptual SD model about the impacts of overall weather conditions on the ORTIA project.

Diagrammatically, the model structure well explains all leading factors into overall project delays and project budget increase. An arrow directed from one variable to another is referred to as a coupling.

If the sign associated with the coupling is positive, then the variable from which the coupling is directed is said to have an increase effect on the variable toward which the coupling is directed. The model conceptualised what project managers must expect from critical weather conditions during megaproject construction periods. The approach is to improve the understanding and accuracy of the management of critical weather events in mega construction projects in Africa and similar economies across the world.

CONCLUSIONS

Megaprojects involve lots of complexities due to their structural nature. This has necessitated the development of various tools to effectively manage changes in their lifecycle to ensure better project delivery. One way to do this is to reduce risks associated with achieving challenging and worthwhile goals of the project by gathering information about relevant issues and model their impacts on the project to lower the level of uncertainty. This will assist megaproject managers to also reduce probabilities of failures or to reduce their consequences.

This paper addressed the impact of the change of weather conditions on mega project construction in Africa using OR Tambo International Airport expansion works as a case study. The SD approach was used to model delay and cost overrun causes to the project as a result of impacts of weather phenomena revealed during the research methodology. For a better understanding, various SD models were developed to demonstrate real world complexities of unexpected events like the change in weather conditions that are commonly severe than planners may predict on mega project construction.

This paper further discussed how to use the SD model to improve the understanding and accuracy of the management of all forms of severe weather events in megaprojects construction and hope that the construction industry in Africa and similar economies in the world would be able to use it as a benchmark for a better forecast when such uninspected events occur during megaproject development and construction in Africa.

FUTURE RESEARCH

While the process for generating risks such as Social, Technology, Economic, Ecology and Political (STEEP) in construction and engineering projects is matured and well documented, the process for using system dynamics to create models for multi-criteria decision making requires much effort and experts. As a result, the future research will look into STEEP risks from more megaprojects to support the building of decision making to improve the understanding and accuracy of the management of megaprojects using system dynamic models.

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