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MODELLING TO RESOLVE DESIGN LINKED DELAY IN CONSTRUCTION PROJECTS

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Consultants are the major role players in design of construction projects. It is well acknowledged that the consultant and design linked issues are more or less integrated and influence delay in a project. Therefore, the objectives of the investigation are to identify the influential consultant and design related variables, which cause delay; to evolve the causal feedback relations among the most influential consultant and design linked variables and delay; and to develop a model to estimate the reduction of delay under varied strategic interventions. For this purpose a survey was conducted among 120 stakeholders and professionals from various construction projects in India. By using System Dynamics (SD) modelling principles, causal feedback relations among the most influential parameters that influence delay were established and dynamic hypotheses were evolved for developing policy interventions to reduce delay. A SD model was developed by using data from medium sized building projects in India to examine the behaviour of the project schedule and delay under different simulated scenarios, and estimate the reduction of delay under different policy interventions based on the dynamic hypotheses framed. Findings suggest that there exist definite causal feedback relations among the consultant and design linked variables, such as late reviewing and approving of design documents by consultant, delay in approving major changes in the scope of work by consultant, delay in performing inspection and testing by consultant, poor communication/coordination between consultant and other parties, inflexibility (rigidity) of the consultant, delays in producing design documents, complexity of project design, mistakes and discrepancies in design documents, and unclear and inadequate details in drawings, which essentially cause delay. However, the model results revealed that policy interventions based on (1) causal feedback mechanisms involving appointment of highly competent consultant and design team, delay in producing the design documents and delay in construction; and (2) provision of effective communication mechanism, conflict resolution and delay in construction can reduce delay significantly.

Keyword: Building, Construction, Consultant, Delay, Design, System dynamics modelling.

1. INTRODUCTION

Consultants and consequent design linked errors are considered to be among the primary contributors to delay in construction projects. Design errors generally lead to a significant amount of rework, which cause both schedule delays and cost overruns (Han, Love, Pena Mora, 2013). The designed linked errors mostly emanate from the consulting firms or individual designers. The reasons could range from lack of knowledge and competency, poor conceptual understanding, computational errors, mathematical and graphical representation errors to sometimes because of poor communication among the stakeholders and non-understanding of the clients requirements. The errors are caused by a chain of actions, which lead to development of further actions that cause schedule delays. The consulting firms or individual designers have the responsibility to understand the chain of actions and take corrective measures at the source or immediately when they occur to prevent subsequent unwarranted consequences. However, the major challenge is that effort to understand the mechanisms based on a chain of events that lead to design errors or subsequent schedule delays by the consulting firms or other stakeholders have been undermined (Han, Love, Pena Mora, 2013). Besides, there seems to be lack of appropriate method or technique that has been appraised, which could enable the consulting firms, designers and stakeholders to comprehend the mechanisms qualitatively and quantify the consequences of the errors, i.e., quantum of delay and also reduction in delay in quantitative terms if certain resolving strategic interventions are undertaken. Therefore, the objectives of the investigation are to identify the influential consultant and design linked variables, which cause delay; to evolve the causal feedback relations among the most influential consultant and design linked variables and delay; and to develop a model to estimate the reduction of delay under varied strategic interventions. The investigation was conducted by using a case study of a medium sized building construction project in India. A survey research method followed by System Dynamics (SD) modelling approach was used for this purpose. Findings suggest that there exist definite causal feedback relations among the consultant and design linked variables, such as late reviewing and approving of design documents by consultant, delay in approving major changes in the scope of work by consultant, delay in performing inspection and testing by consultant, poor communication/coordination between consultant and other parties, inflexibility (rigidity) of the consultant, delays in producing design documents, complexity of project design, mistakes and discrepancies in design documents, and unclear and inadequate details in drawings, which essentially cause delay. However, the model results revealed that policy interventions based on (1) causal feedback mechanisms involving appointment of highly competent consultant and design team, delay in producing the design documents and delay in construction; and (2) provision of effective communication mechanism, conflict resolution and delay in construction can reduce delay significantly.

2. LITERATURE REVIEW

The construction process is subject to many variables and unpredictable factors; therefore delays are inevitable and become integral part of the project's construction life. Despite the availability of advanced technology, and understanding of project management techniques, construction projects continue to suffer delays (Stumpf, 2000; Bon Gang & Lay Peng, 2013; Bon-Gang, Shimin, 2014; Bon-Gang, Xianbo, Lene Lay, 2015). The sources of delay are varied, which include the performance and involvement of stakeholders, resources availability, environmental conditions, contractual relations, and so on (Kaming, Olomolaiye, Stumpf, 2000; Odeh and Battaineh 2002; Alaghbari, Razali, Kadir and Ernawat, 2007; Bon Gang & Lay Peng, 2013; Bon-Gang, Shimin, 2014; Bon-Gang, Xianbo, Lene Lay, 2015). However, a number of studies have established that design linked errors contribute significantly to delays in projects (Singh, 2010; Doloi et al., 2012; KPMG and PMI, 2012; Han, Lov*e,* Pena Mora, 2013). The design errors can be caused because of both human and technical reasons. For example, eerroneous decisions made during design can occur due to impaired human cognition (Busby, 2001; Love, Edwards, Han, Goh 2011; Han, Lov*e,* Pena Mora, 2013), specifically when designers lack experience and are under stress due to schedule and cost pressures (Love, Edwards, Irani, 2008). Besides, designers may omit a few important aspects in the design process such as fail to involve other stakeholders in design decisions, fail to inform them of assumptions made, neglect to elicit the needs and schedules of other stakeholders like clients and contractors, or fail to understand the history of problem solving in a replicated design (Han, Love, Pena Mora, 2013). Furthermore, according to the phenomenological approach of Love et al. (2011), uncertainty and inevitability of error are not perceptions, but are realities for design consultants, resulting from the exogenous factors influencing their ability to perform tasks effectively. These factors among others include schedule pressure, design fees, client procurement strategy and skilled labour supply. Also, it is observed that many design and construction organizations pay limited attention to errors and the resulting rework or failures that may occur in practice (Rounce, 1998; Robinson-Fayek, Manjula Dissanayake, Campero, 2003; Love, Edwards, Irani, Walker, 2009; Love, Lopez, Edwards, Goh, 2011; Han, Love, Pena Mora, 2013). Similarly, the size and complexity of a project, the number of professionals involved in its design and construction, and the complexities of procurement and price determination for services have a significant bearing on the occurrence of design errors (Love,. Edwards, Han, Goh, 2011). Other systemic problems may include lack of design reviews, checks and verifications, re-use of specification and details, unrealistic schedules, understaffing, and lack of project governance (Love, Lopez, Edwards, Goh, 2011).

The combination of these factors and the chain of actions triggered by them significantly prompt lower project performance by generating rework, requiring additional time and resource expenditure. Besides, if errors are discovered during construction, it demands additional time and resources for demolition of incorrectly constructed components. In such circumstances construction managers tend to avoid rework on problematic activities by modifying designs and specifications (Park , Peña-Mora, 2003) and rely on scope changes to solve problems that may arise during construction, installation and commissioning (Love, Edwards, Han, Goh, 2011). However, if impacts of sudden changes in scope or design are not properly assessed, they could induce additional problems by significantly altering project execution sequences and/or resource profiles (Burati, Farrington, Ledbetter, 1992; Love 2002). Moreover, if design errors that may be deemed minor in nature are overlooked, it would invariably take significant time to correct them (Love,. Edwards, Han, Goh, 2011) and therefore any design error that may emanate from any reason should not be overlooked or undermined.

3. METHODS

The study was conducted by considering building construction projects in India. A survey research method was used for collection of data. Statistical analyses- descriptive statistics and Cronbach alpha test were employed to check the reliability and suitability of the data set. The influence of the variables causing delay was evaluated by Likert scale. However, a case study of a building construction project in India was used for modelling purposes. The parameterization for the model development was done by concurrent appraisal of the influence of the variables as obtained from the survey, discussion with stakeholders and literature review. A SD model was developed to calculate the delay under varied scenarios of causes of delay and policy interventions to resolve the delay.

A survey research method was employed to collect primary data from the various stakeholders that include consultants (18.0%), contractors (16.0%), clients (11.0%), project managers (12.0%), engineers (14.0%), architects (10.0%), estimators (11.0%), and skilled technicians (8%) in construction projects in India. A total of 120 questionnaires were administered, of which 100 were returned (approximately 85% response rate). The respondents were chosen from 22 projects that include residential building projects (54.5%), shopping complexes (19.2%) and social infrastructure building projects (27.3%). The survey was conducted by applying simple random sampling process and semi structured interview techniques.

While developing questionnaires, care was taken to incorporate most of the key attributes under the consultant and design linked factors as observed from the reviewed literature. The questionnaires were refined and finalised after initial discussions with some stakeholders. The respondents were asked to offer their opinions on the influence of the various parameters that cause delay from the experiences in the projects they were involved in a five point Likert scale of 1 to 5 (1= not influential, 2 = less influential, 3 = influential, 4 = significantly influential and 5 = most influential) (Gravetter and Wallnau, 2008; Doloi, et al, 2012a). The mean score of the Likert scale evaluation was taken as the delay index (DI).

Besides, a conceptual model by using SD modelling principles was developed. A construction project was considered as the system or environment while developing the model (Forrester, 1968; Von Bertalanffy, 1974; Sterman, 2000). The influential factors, their positive and negative influences on the related factors and the causal relationships among them were considered to develop the conceptual SD model. Published literature and discussions and experiences of the professionals were used as a precursor to establish causal relationships among the variables within and across the major parameters. Followed by a quantitative SD model was developed and simulated to compute the project duration and delay period under different scenarios and strategic interventions to reduce delay.

4. MODELLING, RESULTS, FINDINGS AND DISCUSSIONS

4.1 Evaluation of Design Linked Factors Influencing Delay

Table 1 presents the significant attributes and factors that influence consultant and design linked delay in construction. Under consultant related factors, late in reviewing and approving design documents by consultant (DI=4.10), delay in approving major changes in the scope of work by consultant (DI=3.95), delay in performing inspection and testing by consultant (DI=3.85), poor communication/coordination between consultant and other parties (DI=3.80), inflexibility (rigidity) of consultant are the significant causes of delay (DI=3.65), whereas delays in producing design documents (DI=4.25), complexity of project design (DI=4.10), mistakes and discrepancies in design documents (DI=4.15), and unclear and inadequate details in drawings are the design related factors (DI=4.20), which are of the causes of concern with regards to delay in construction.

Table 1: Significance of attributes and factors influencing delay in construction

Group/ Attributes	**Factors**	**Delay Index (DI) (Likert scale Mean Score)**	**SD**	**Cronbach'α**
Consultant	Delay in performing inspection and testing by consultant	3.85	0.34	0.90
	Delay in approving major changes in the scope of work by consultant	3.95	0.31	
	Inflexibility (rigidity) of consultant	3.65	0.25	
	Poor communication/coordination between consultant and other parties	3.80	0.28	
	Late in reviewing and approving design documents by consultant	4.10	0.32	
	Conflicts between consultant and design engineer	3.20	0.22	
	Inadequate experience of consultant	3.25	0.25	
Design	Mistakes and discrepancies in design documents	4.15	0.35	0.92
	Delays in producing design documents	4.25	0.38	
	Unclear and inadequate details in drawings	4.20	0.39	
	Complexity of project design	4.10	0.29	
	Insufficient data collection and survey before design	3.75	0.25	
	Misunderstanding of owner's requirements by design engineer	3.60	0.24	

(Note: External factors have not been considered as they are beyond the control of project management team.

4.2 Modelling

The consultant and design related issues are more or less integrated, and therefore both of them are considered together while developing the conceptual model. As seen from the Table 1, late in reviewing and approving design documents by consultant, delay in

performing inspection and testing by consultant, delay in approving major changes in the scope of work by consultant, poor communication/coordination between consultant and other parties, inflexibility (rigidity) of consultant are the significant causes of delay, whereas delay in producing design documents, complexity of project design, mistakes and discrepancies in design documents, and unclear and inadequate details in drawings are the design related causes, which are responsible for delay in construction.
As shown in Figure 1 the causal feedback mechanisms manifest that complexity of the project influences the delay in production of the design document by consultant, which essentially cause construction delay through the action balancing feedback relations DB1. Complexity in design also can lead to mistakes and discrepancies in design document, which can lead to unclear and inadequate detail drawings through balancing sub loop DB1A. Similarly, delay in production of design document is influenced by delay in performing inspection and testing by consultant, delay in approving major changes in the scope of work of the consultant by the client, and late reviewing and approving the document by the consultant. Therefore, complexity of design can disrupt the construction or cause construction delay through balancing feedback mechanism DB1 supported by mechanism shown by DB1A. However, on the other hand, appointment of highly competent consultant and design team will able to meet the challenges of complex design as well as eliminate the problems of mistakes and errors, and enhance clarity in detail drawings through feedback mechanism (sub loop DR1A). Consequently, it will reinforce the reduction of delay by reducing the delay in producing the design documents through feedback mechanism DR1. Thus, causal feedback mechanism DR1A reinforces causal feedback mechanism DR1.

Further, provision of an effective communication mechanism between consultant and other stakeholders will assist in conflict resolution among client, contractor, design team and consultant, and thereby reduces delay through causal feedback mechanism DR2. Besides, DR2 will be further reinforced by feedback mechanism DR2A, as effective communication will eradicate the challenges created by poor communication like misunderstanding of client's requirement leading to reduction in the challenges of complexity of design. Thus, the feedback mechanism DB1 causing construction delay will be balanced or negated by the feedback mechanisms DR1 and DR2. So, the causal feedback mechanisms involving appointment of highly competent consultant and design team, delay in producing the design documents and delay in construction; and provision of effective communication mechanism, conflict resolution and delay in construction are the dynamic hypotheses, which need to be considered while developing policy interventions for reducing delay from consultant and design point of view.

Based on the above postulated concept and causal relations, a quantitative SD model was developed and simulated to observe the project duration and delay component in a construction project. For the purpose a middle sized residential complex project in India comprising of residential apartments and associate infrastructure was used as a case study. Table 2 presents the various project attributes, project boundary and simulation variables used in developing and using the model.

While developing the model, project duration is considered as a stock and there are three rate variables, such as, normal construction rate (NCR), construction rate due to delay in producing design documents and construction rate due to complexity of design.

Delay in inspection, delay in making appropriate changes in design and drawings, and delay in approval of drawings are the auxiliary variables, which contribute to rate variable construction rate due to delay in producing design documents. Similarly, mistakes and discrepancies in design documents, unclear and inadequate details in drawings, and misunderstanding of owner's requirements by design engineer are the auxiliary variables which influence the rate variable construction rate due to complexity of the design. The maximum construction period of 48 months is considered as the model boundary and variables exogenous to the consultant and related factors in construction, which include client, contractor, materials and equipment, weather, and environment related factors were kept out of the scope of modelling. The model was built by using STELLA software and employing algorithms developed based on the inter-relationship of the variables. The major algorithms used in the model building are given in the Equation (1 to 4). The simulation time unit considered was one month up to a maximum period of 48 months. Euler integration method with a time step of 0.03150 (for instance, in one month it integrates 1/0.03150=32 times) was used for simulating the model.

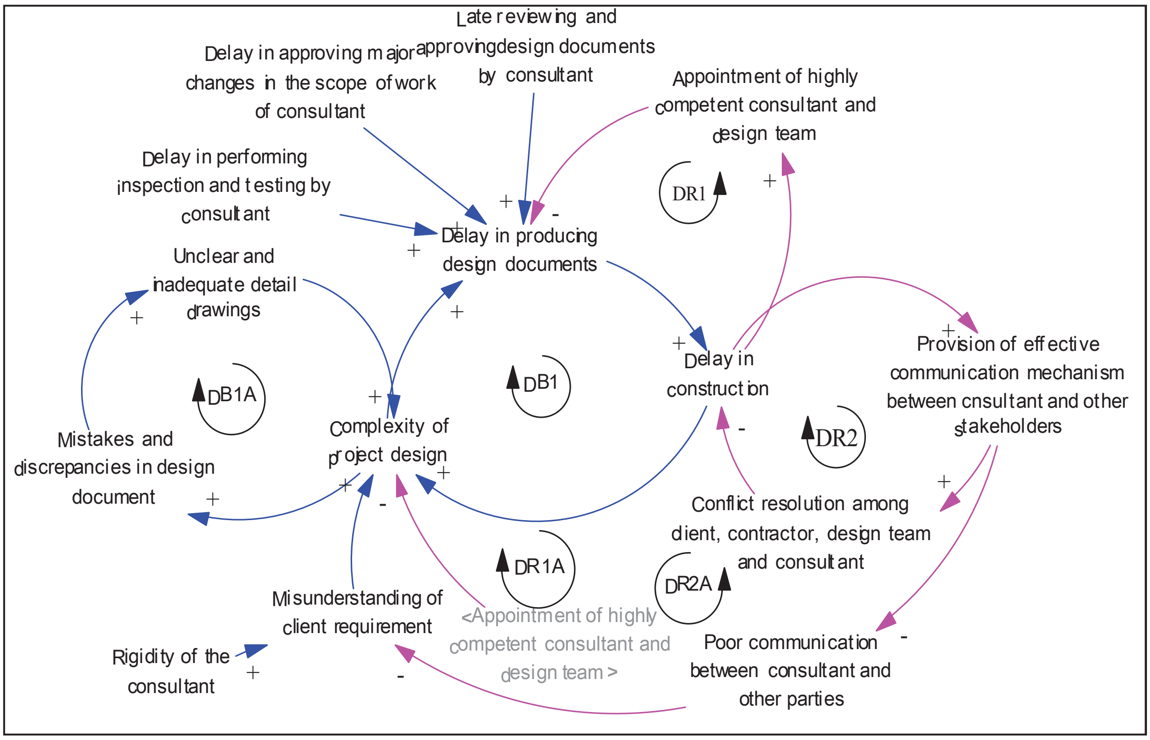

Figure 1: SD model based on causal feedback relations among the consultant and design linked factors causing delay

Project period (t) = Project period (t-dt) + $\int_{t0}^{t} \text{Project period}\ (t-dt) * (NCR + AIDCR * w1 + AACCR * w2 + AADCR * w3 + AMDCR * w4 + AUDCR * w5 + AMOCR * w6 - CACCR * w7 - CECCR * w8) * dt$ ………. (Eq. 1)

Project period normal scenario (t) = Project period (t-dt) + $\int_{t0}^{t} \text{Project period}\ (t-dt) * NCR\ dt$ ………. (Eq. 2)

Delay Normal scenario (D_{tn}) = [Project period (t) - Project period normal scenario]/ Project period normal scenario ………. (Eq. 3)

Delay original Estimate scenario (D_{te}) = [Project period (t) - Project period original estimate]/ Project period original estimate ………. (Eq. 4)

Where

NCR= Normal construction rate
AIDCR= Accumulation to project period due to (reduction in construction rate) inspection delay
AACCR = Accumulation to project period due to (reduction in construction rate) delay making appropriate changes
AADCR = Accumulation to project period due to (reduction in construction rate) delay approval of drawings
AMDCR= Accumulation to project period due to (reduction in construction rate) mistakes in design and drawings
AUDCR = Accumulation to project period due to (reduction in construction rate) unclear and inadequate details in drawings
AMOCR = Accumulation to project period due to (reduction in construction rate) misunderstanding of owner's requirements
CACCR= Contribution to construction rate due to availability of competent consultant
CECCR= Contribution to construction rate due to effective communication
wi, are the weightages given to the respective variables as observed from historical data and expert discussion for sensitivity analysis

Table 2 Project variables and simulated scenarios

Project Variables	**Variable attributes / values**	**Remarks**
Type of project	Residential complex (Apartment)	
Maximum project period	4 years (48 months)	
Units of construction duration considered	in days	
Initial estimated construction duration	775 days	
Construction rate factions		
Normal rate of construction	0.0012 units/day	Obtained from the stakeholders discussion and historical data of projects
initial effective communication fraction	0.10 0.0016	obtained from Historical data of

initial availability of competent consultant factor fraction		0.0011	projects
wi		0.10-1.0	Based on experts and stakeholders discussion
		Simulated scenarios	
Scenarios		Simulation variables	Combined effects considered
Normal scenario	S1	Business as usual (normal rate of construction as envisaged during project planning)	
Scenarios causing delay	S2	Production of design document	
	S3	Combination of delay in Production of design document and complex design	Production of design document and complex design
	S4	Effective communication	
Scenarios of reduction of delay under policy interventions	S5	Combination of appointment of competent consultant and effective communication	Appointment of competent consultant and effective communication

4.3 Insights from the Simulated SD Models

4.3.1 *Project duration and delay under various simulated scenarios*

The project duration and delay in construction project as obtained from the SD model was analysed under four categories (1) normal scenario (business as usual) (2) project period under important factors causing delay scenarios; (3) project duration under strategic interventions to reduce delay and (4) comparative project duration under different scenarios. Figure 2 presents the project period and the trend of the delay under the scenarios, which cause delay. In this case two important scenarios, delay in producing design documents for the project by the consultant and complexity in design are considered (Table 2). It was observed that under normal scenario the maximum project duration will exceed to a maximum of 6.4% from the original estimate, which is quite marginal. The project period shall exceed the estimated duration by 15.60% under the scenarios of delay in production of design documents, which is fairly high. However, under the scenario of combination of delay in production of design documents and complex design, the project period will be much worse, i.e., it will exceed by 26.91% from the original schedule. So, the simulated scenarios show that while delay in production design documents and complex design independently will cause fair amount of delay in the construction project, however the combined effect is much higher. Therefore, policy interventions are needed to avoid scenarios.

The trend of project period under policy intervention show that if effective communication is eventuated then the rate of delay will be reduced appreciably, however, if the a competent consultant is appointed along with provision of effective communication, then the delay will be reduced much significantly (Figure 2). The comparative analysis (Figure 3) shows that while delay will be higher due to delay in production of design documents, which could be much worse if it is combined with complex design. However, delay can be limited to 18.58% (reduced by 6.5% from the worst case scenario) under policy interventions of effective communication and will be limited to 14.02% (reduced by 10.15% from the worst case scenario) from the original estimate under policy intervention of appointment of a competent consultant and provision of effective communication together. Therefore, provision of effective communication and appointment of a competent consultant become paramount to limit the unwarranted delay because of design linked challenges in a project.

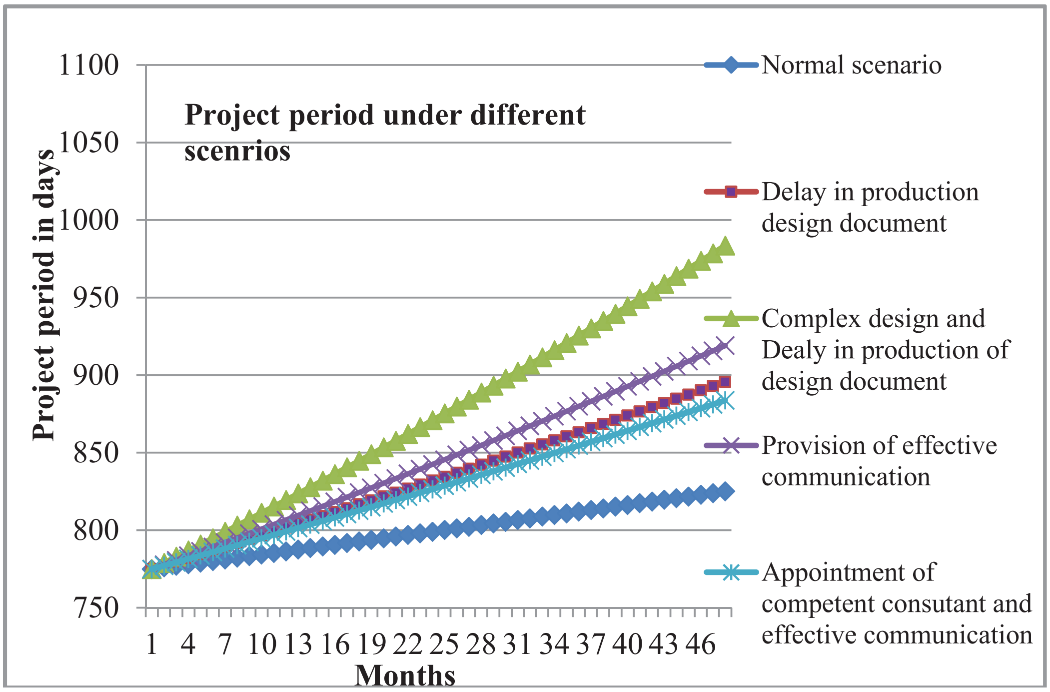

Figure 2 Project period under different simulated scenarios of design linked factors

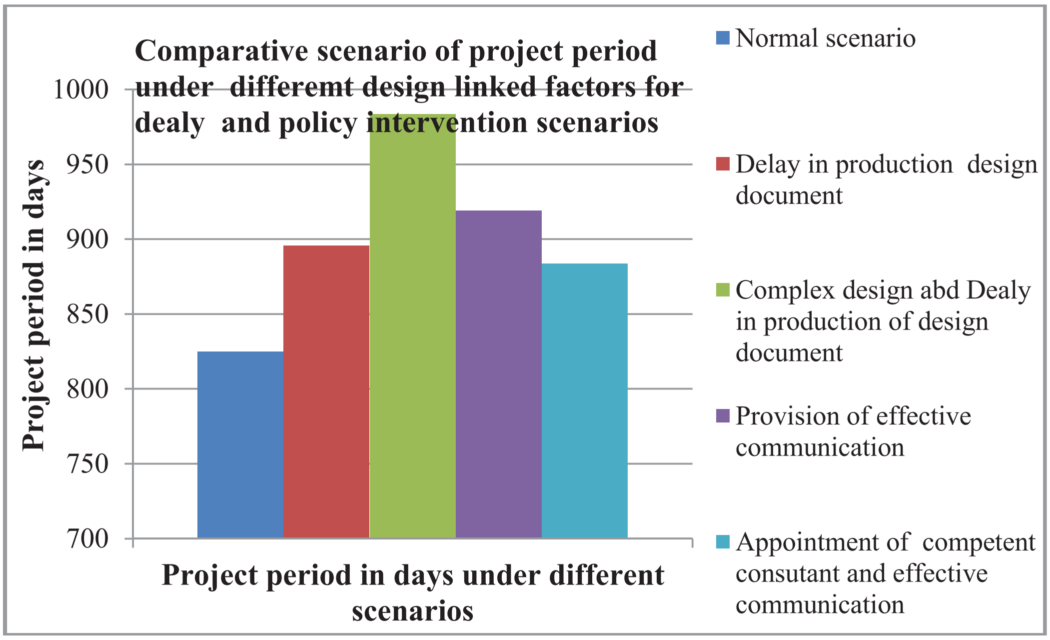

Figure 3 Comparative scenarios of project period under different simulated scenarios of design linked factors

5. CONCLUSIONS

This investigation examined the various consultant and design linked factors that influence the occurrence of project delays in construction. For realisation of this aim a SD model was used to comprehend the amount of delay that can eventuate in a project under individual or a combination of design linked factors that influence a project. Before the SD model was developed, an evaluation was conducted based on a delay index developed with exploratory survey data obtained from construction projects in India. Findings suggest that late in reviewing and approving design documents by the consultant, delays in producing design documents, complexity of project design, mistakes and discrepancies in design document, delay in approving major changes in the scope of work by consultant, unclear and inadequate details in drawings, delay in performing inspection and testing by consultant, poor communication/coordination between consultant and other parties, and inflexibility (rigidity) of consultant are the significant causes of delay, are of the causes of concern with regards to delay in construction.The simulated scenario results reveal that delays that manifest through gaps in delay in producing design documents and complexity of design are the major reasons, which would substantially impact on the timely delivery of projects. This therefore requires the use of policy interventions that could handle deign and documentation and complexity of design issues in construction. The policy should show an appropriate understanding of a dynamic system in which effect of one factor may prove to be the cause for subsequent effects.

The paper's limitation is that although several project actors were surveyed in India, the modelling was done by considering one residential complex construction project to provide insights into the dynamics of delays due to design linked challenges. However, it is visualised that the findings of the investigation will contribute in three ways. First, it could assist project actors' particularly the consultants and design teams to diagnose the delay challenges and evolve mechanisms based on the causal feedback relations presented in this paper. Second, the paper offers a methodology to comprehend the inter-linkage among the various design linked factors causing delay and quantify the extent of delay under different scenarios. Third, the study also provides a platform to the consultant and design team to foresee the impacts of different policy interventions on the reduction of delay so that appropriate actions can be taken.

REFERENCES

Alaghbari, W., Razali, M., Kadir ,S., Ernawat, G., The significant factors causing delay of building construction projects in Malaysia, *Eng Constr Arch Manage*, Emerald, 14(2), 192–206, 2007.

Bon Gang, Hwang. & Lay Peng, Leong., Comparison of schedule delay and causal factors between traditional and green construction projects, *Technological and Economic Development of Economy*, Vilniaus Gedimino technikos universitetas, 19(2), 310-330, 2013. DOI: 10.3846/20294913.2013.798596.

Bon-Gang, Hwang., Shimin, Yang., Rework and schedule performance: A profile of incidence, impact, causes and solutions, *Engineering, Construction and Architectural Management*, Emerald, 21 (2),19 0 – 205, 2014. http://dx.doi.org/10.1108/ECAM-10-2012-0101.

Bon-Gang, Hwang., Xianbo Zhao, Lene Lay Ghim, Tan., Green building projects: schedule performance, influential factors and solutions', *Engineering, Construction and Architectural Management*, Emerald, 22 (3), 327 – 346, 2015.

Burati J.L., Farrington J.J., Ledbetter, W.B., Causes of quality deviations in design and construction, *Journal of Construction Engineering and Management,* ASCE, 118 (1), 34–49, 1992.

Busby, J.S., Error and distributed cognition in design, *Design Studies*, Elsevier, 22 233–254, 2001.

Doloi, H., Sawhney, A., Iyer, K.C. and Rentala, S., Analysing factors affecting delays in Indian construction projects, *International Journal of Project Management*, Elsevier, 30, 479–89, 2012.

Forrester, J. W., *Principles of Systems*, Productivity Press, Cambridge, MA, 1968.

Han, Sangwon, Love Peter, Peña-Morac, Feniosky., A system dynamics model for assessing the impacts of design errors in construction projects, *Mathematical and Computer Modelling*, Elsevier, 57, 2044–2053, 2013.

Kaming, P., Olomolaiye, P., Holt, G., Harris, F., Factors influencing construction time and cost overruns on high-rise projects in Indonesia, *Construction Management Economics*, Routledge - Taylor & Francis, 15(1), 83–94, 1997.

KPMG and PMI., Study on Drivers for Success in Infrastructure Projects 2010: Managing for Change, 2012. available at http://bit.ly/Q6y88X (accessed 28 July 2013).

Love P.E.D., Influence of project type and procurement method on rework costs in building construction projects, *Journal of Construction Engineering and Management*, ASCE, 128 (1), 18–29, 2002.

Love, P.E.D., Edwards, D.J., Han, S., Goh Y.M., Design error reduction: toward the effective utilization of building information modeling, *Research in Engineering Design*, Springer, 22 (3), 173–187, 2011. Doi: 10.1007/s00163-011-0105-x.

Love, P.E.D., Edwards, D.J., Irani, Z., Walker, D.H.T. Project pathogens: the anatomy of omission errors in construction and resource engineering projects, *IEEE Transactions on Engineering Management*, IEEE, 56 (3), 425–435, 2009.

Love, P.E.D., Edwards D. Irani, J., Z., Forensic project management: an exploratory examination of the causal behaviour of design-induced error, *IEEE Transactions in Engineering Management*, IEEE, 55 (2), 234–248, 2008.

Love, P.E.D., Lopez, R., Edwards D.J., Goh, Y., Error begat error: design error analysis and prevention in social infrastructure projects, *Accident Analysis and Prevention,* 2011, doi:10.1016/j.aap.2011.02.027.

Odeh A. M., Battaineh H. T., Causes of construction delay: traditional contracts, *International Journal of Project Management*, Elsevier, 20(1), 67–73, 2002.

Park M., Peña-Mora F., Dynamic change management for construction: introducing the change cycle into model-based project management, *System Dynamics Review,* Wiley, 19 (3), 213–242, 2003.

Peña-Mora, F. and Li, M., Dynamic Planning and Control Methodology for Design/Build Fast-Track Construction Projects, *Journal of Construction Engineering and Management*, ASCE, 127, 1-17, 2001.

Robinson-Fayek A., Manjula Dissanayake M., Campero O., Measuring and classifying construction rework: a pilot study, *Department of Civil and Environmental Engineering, Construction Owners Association of Alberta*, Alberta, Canada. 2003

Rounce, G., Quality, waste, and cost consideration in architectural building design management, *International Journal of Project Management*, Elsevier, 16 (2), 123–127, 1998.

Singh, R., Delays and cost overruns in infrastructure projects: extent, causes and remedies, *Economic and Political Weekly*, Sameeksha Trust, xlv, 43–54, 2010.

Sterman, J., *Business Dynamics: Systems Thinking and Modelling for a Complex World*, p. 982, McGraw-Hill, Boston, 2000.

Stumpf, G., Schedule delay analysis, *Cost Engineering Journal*, 42(7), 32–43, 2000.

Von Bertalanffy, L., *Perspectives on General System Theory'* Edited by Edgar Taschdjian. George Braziller, New York, 1974.