หอสมุดกลาง ศูนย์วิทยทรัพยากร จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER I
INTRODUCTION

1.1 Background

Currently, development of construction projects, such as multi-storeyed buildings, elevated expressways, and subway stations, is expected to have more significant impact on economic development and advancement in developing countries. A number of large projects are being implemented and others are planned for construction in the future. Generally, projects launched in Bangkok Metropolis are very complicated and involve a large number of risk factors. Bored piles usually used to complement the usual large dimension foundation is often required for the subsoil conditions in Bangkok because of the presence of thick soft clay on the top, followed by a series of alternating stiff clay or hard clay and dense or medium dense sand layers.

Construction projects in Bangkok still do not achieve project goals sufficiently and are also frequently delayed. The major reasons for this are the existence of external and internal risk factors inherent in all construction operations. An emergency condition resulting from equipment breakdown, frequent change of steel wire ropes for the grab, obstruction by overbreak concrete during panel excavation and stop-end removal, problems due to site restrictions and disposal of excavated soil, weather condition, local regulations, late land acquisition, delay in contractor's mobilization, site planning difficulties, and an accident are the main problems in bored pile, diaphragm wall and barrette construction (Thasnanipan, N. et al., 2000). Common risk factors, for example, a lack of design information, material unavailability, contractor inability, uncertain economic and political environment can be encountered. In addition, large size of the project, a high level of involvement of external agencies, a complex project, accelerated construction, an inappropriate location, and unfamiliarity with construction cause a number of risk factors and profound impacts.

If impacts of risk factors occur for many activities along a network path, the variability of the path's duration may be significantly increased. If the path is critical or near critical, the variability of its duration will bring about the variability in the project duration. Increased variability in the project duration increases the uncertainty of completing the project by a target date. As a result, impacts of risk factors probably create an unexpected schedule overrun.

A method providing a better understanding and meaningful of the impacts of risk factors would make the schedule a more effective management tool by offering a more accurate estimate of uncertainty in the operation duration and assisting in prioritizing risk factors having the greatest impacts on the operation duration. However, the conventional scheduling methods, for example the critical-path method (CPM), probabilistic models such as program evaluation and review technique (PERT), and Monte Carlo simulation, evaluate the duration of each activity in a schedule network independently and rarely integrate impacts of risk factors into the duration estimating process. As a consequence, these methods will not capture the impacts of risk factors on the operation duration and the correlation of duration of different activities in the schedule network.

All the above mentioned problems call for the development of more comprehensive and flexible scheduling methods for better treatment of risk, estimate of uncertainty, and representation of impacts of risk on operation duration and project duration in an easily understandable and meaningful form. Several models have been proposed to evaluate impacts of risk and integrate their results into the network schedule. A simulation – based model is one of them which is developed and applied widely as a practical tool for scheduling and analysis in many industries. simulation is considered as a useful tool to measure the effects of external factors. The effects of external factors, like those mentioned above, can be evaluated by introducing randomness into the analysis of tunneling processes. Consequently, different conditions and random events can be appropriately modeled by simulation. The simulation outputs are the useful information for construction participants to carefully plan and control the high – risk projects like the tunneling projects (AbouRizk and Halpin, 1992). Using simulation, not only the improvement of the decision – making process, planning, scheduling, and cost forecasting of the tunnel construction can be achieved, but also inherent risks could be minimized. Reducing cost and time obtained by efficient pre-project planning brings about productive tunnel construction projects.

The special purpose simulation concepts were used to develop the tunneling templates. The special purpose tunnel templates developed with Simphony were used to model and analyze the tunneling process for shielded tunnel boring machines

(TBM) and hand tunneling. The CYCLONE methodology was also used to model the microtunneling process regarding the uncertainty associated with the prediction of underground soil conditions, which could be considered as the main obstacle in microtunnel projects (Nido and Abraham, 1996). However, CYCLONE is inappropriate to simultaneously model different truck sizes and to visually arrange entity flows among activities or entity nodes when simulated operations are complex or a lot of resources are considered.

STROBOSCOPE (Martinez, 1996) is a general – purpose construction simulation programming language. It is capable of accessing to simulation state resource characterization so that it is able to model almost all type of construction projects which cannot be modeled by other construction process simulation tools. The STROBOSCOPE was used to model the tunneling process. The comparison between two construction methods for rock tunneling (Conventional vs. New Austrian Tunneling Method (NATM)) was provided using the STROBOSCOPE simulation system (Ioannou and Martinez, 1995).

Even though simulation can assist users analyze and design works and management policies, it is not widely applicable to the case of tunneling processes. By nature of tunnel construction, data related to a large operational process that is typically complex and unique cannot be sufficiently collected for performing the statistical analysis. Therefore, it is difficult to create an appropriate probability distribution function (PDF) for activity duration which consequently limits the utilization of simulation in the tunnel construction. Several studies have be done for defining probability distributions for activity duration through a small amount of sample data and also historical data in the construction field (Abourizk and Halpin, 1992, Fente et al., 2000). With the merit of a beta distribution, users can easily assign the end points of an activity duration distribution, if they are familiar with the construction conditions, technical dependencies, and resource constraints related to the target activity. The accuracy of the developed beta distribution of activity duration, therefore, depends mainly on experience, knowledge and judgement of estimators or experts.

Although the probability based methods (e.g., simulation) can be used to estimate duration under uncertainty, they are limited themselves to a particular type of uncertainties stemming from random contributions. For uncertainties due to systematic and unknown contributions, the probability theory which is based on classical measure theory is inapplicable to a cooperative action between uncertain values (e.g., A and B) or some sort of inhibitory effect (incompatibility) between uncertain values.

The simulation – based models proposed to capture impacts of risk can be broadly divided into four groups: implicit and explicit risk assessment and impact evaluation in conjunction with direct and indirect elicitation of correlation of duration of different activities. Explicit models logically and systematically evaluate the impacts of risk by using quantitative data and present the result in the form of equation or rule, while implicit models mostly depend on judgement of experts by using the subjective assessment and do not illustrate the result by a physical and analytical format. Direct – elicitation models transform values of impacts of risk into correlation coefficients, while indirect – elicitation models evaluate the effect of correlation based on impacts of risk without explicit specification of correlation coefficients.

Examples of direct–elicitation models are the exact simulation, the quantile simulation, the modified second random number, and the factored simulation. Indirect–elicitation models consist of the simulation–based MUD (Model for Uncertainty Determination) (Carr, 1979); the DYNASTRAT (DYNAmic-STRATegy) (Padilla and Carr, 1991); the PRODUF (Project Duration Forecast) (Ahuja and Nandakumar, 1985); the PLATFORM (Levitt and Kunz, 1985); the CEV (Conditional Expected Value) model (Ranasinghe and Russell, 1992), and the NETCOR (NETworks under CORrelated uncertainty). Models eliciting correlation between duration of different activity in conjunction with explicitly performing risk assessment and impact evaluation are the duration valuation process (DVP) (Pipatanapong, 2004) and the duration evaluation model developed by Zayed and Halpin (2001).

The MUD, DYNASTART, and PRODUF require extensive inputs and historical data, while the PLATFORM depends on the performance of completed activities and treats all risk factors as having the same effects. The NETCOR evaluates schedule networks when activity durations are correlated by using qualitative estimates of the sensitivity of each activity to each risk factor. Therefore, the dependencies among risk factors are discarded. Mostly, these models are based on statistic and probabilistic theory so that only a particular type of uncertainty (non-cognitive uncertainty) is taken into account. In addition, these methods require data which are sufficient for statistical analysis, but in the case of construction either

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historical data or factual data are usually unavailable. The historical data may be inapplicable, while the factual data may be unobservable. To overcome the data unavailability problem, subjective data are used to adjust data acquired through other approaches.

Many recent researches attempt to integrate risk assessment and impact evaluation methods with scheduling methods in a variety of ways. Most of proposed methods focus exclusively on the accuracy issue, but values of impacts of risks on activity duration can be accurately examined only very simple processes. Besides, for complex ill-defined processes the previously proposed models are not only unable to find accurate results, but also and more importantly they are unable to extract knowledge from the data in the form (e.g., equation, rule) that can be easily understood and interpreted. In other words, the existing methods cannot provide an accurate and readable result for the complex ill-defined construction projects. Even though some methods (e.g., ANNs and simulation) can capture input-output data representing relationships between risks and activity duration and specifically results obtained from ANNs can be presented in the form of a mathematical equation, it is difficult to formulate a mathematical description with its transparency and linguistic interpretability. These models cannot visually or linguistically demonstrate inter-dependencies among risks and inter-relationships between risks and activities and correlation between durations of different activities in the meaningful and easy understanding form.

Existing quantitative risk assessment and impact evaluation techniques usually need a lot of calculation efforts to assess risk, evaluate its impacts on activity duration, and then establish the probabilistic density function of activity duration accounting for impacts of risk factors. On the other hand, the subjective risk assessment and impact evaluation techniques which are far more preferable in the areas of construction are obstructed by human factors (e.g., judgement, experience, risk attitude) which in turn affect not only an accuracy and consistency of the estimated duration, but also the readability of modeling results. These problems eventually bring about difficulties in estimating the project duration by applying a model integrating risk assessment and impact evaluation methods with scheduling methods.

There has been a paradigm shift in science concerning the treatment of uncertainty involved in risk. Not only the statistical treatment of ambiguity, but also the treatment of vagueness with fuzzy set and logic is provided. Vagueness is often encountered in linguistic expressions that do not crisply place a given subject matter in one class and require fuzzy sets (Blair, 2001). Fuzzy set theory (Zadeh, 1965), in other words, provides a broader framework than probability theory for formalizing uncertainty. A mathematical methodology based fuzzy set theory is useful to interpret and address the uncertain activity duration resulting from systematic and unknown contributions, which still cannot be appropriately handled by a model based probability theory.

The fuzzy set theory has been used in most measurement under real and physical conditions, when measurement errors are unavoidable. It has been applied to project duration forecasting, decision making and control action selecting techniques so as to address uncertainty, vagueness, imprecision, subjectivity (Zadeh, 1965). Fuzzy logic techniques have been used in construction project planning and scheduling (Nasution, 1999, Duobis and Preade, 1988, Chanas and Kamburowski 1981, Lootsma, 1989). Impacts of factors such as site conditions, weather, and labor performance which are expressed in terms of linguistic expressions are also evaluated by applying fuzzy logic approaches (Ayyub and Haldar, 1984, AbouRizk and Halpin, 1992, Wu and Hadripriono, 1994, Lorterapong and Moselhi, 1996, Oliveros and Fayek, 2005). Further, fuzzy theory has been applied to address uncertainty in the production environments through continuous simulation (Dohnal, 1983, Fishwick, 1991, Negi and Lee, 1992, Petroive et al, 1998, Southall and Wyatt, 1988).

Fuzzy set and logic theory is applied to aspects of the system that can be abstracted using fuzzy set and logic. Quantification of subjective information by a fuzzy inference system using fuzzy sets involves variable definition, rule composition, translation, and execution. In a fuzzy inference system, a fuzzy inference algorithm puts together elements of the fuzzy IF-THEN structure. These elements include fuzzy variables, membership functions, fuzzy IF-THEN rules, implication process, and decomposition.

The fuzzy – stochastic model (Blair, 2001) combines the functions of the fuzzy and the stochastic models. This model is applied to components of the system that have at least one random variable and are fuzzy. The fuzzy – stochastic model is used when historical data is unavailable to categorize the underlying statistical distribution. The distribution categorization is based on subjective information provided by experts. This is done fuzzy stochastically. Then, the results are inputted into the simulation process where Monte Carlo simulation is performed. Linguistic variables are translated into mathematical measures by fuzzy sets and conventional procedures like the PERT are used.

Although the fuzzy – stochastic model integrated the estimation of construction duration with impacts of risk which were represented by fuzzy sets, the measurement of risk performed by a pair of the probability of occurrence of an event, and the consequence associated with the event's occurrence was implicit. The relationship between an event's probability of occurrence and the expected consequence was not logically examined. The relationship information was not included in the fuzzy system.

1.2 Problem Statement

Time is one of the main objectives of any project. It is also the measure of performance achievement of any project. If a project is finished within stipulated time as envisaged during the planning stage, the project will have successfully accomplished its goals. Construction projects are exposed to uncertain environments due to the presence of several risks which in turn become the major obstruction for the accomplishment of construction projects. Risk factors related to soil condition, weather, labor skills, site conditions, design, material availability, equipment availability, statutory regulation, economic and political environment often cause variation in duration of construction activities. The risk factors might be correlated and have impacts on either one or multiple activities. In addition, uncertainties are inherent in projects due to – increasing complexity of projects with more disciplined involved, increasing involvement of external factor (e.g., government regulations, limited availability of resources on the market, available technologies and equipment with the capability to meet the project requirements) and environmental concerns (weather and local lobbies). Perry (1986) also stated that risk and uncertainty are brought about by project size, complexity, speed of construction, location of the project and the degree of unfamiliarity to the client. Any new project is characterized by their complexity in execution due to limitation or unavailability of experience: there is a lack of experience when certain conditions are exceeded (i.e., ground condition).

Typically, scheduling is determined as the process of estimating the duration of project activities so as to accomplish organizational objectives and satisfy any constraint. Efficient construction scheduling should require that contractors carefully examine the variation in duration of project activities due to risk factors based on available information because time overruns of a project is one of the major sources of disappointment to the management of a construction organization. Extreme uncertainties in the project must be considered during planning stage. There are two groups of scheduling methods such as probability – based methods and fuzzy set – based methods developed to model uncertainty in the activity durations which depend on the situation and the project manager's preference (Long and Ohsato, 2007).

The inherent variation in activity duration due to risk factors is described by the term aleatory uncertainty. This is because the representation of risk factors is randomly distributed quantities that can take on the values in an established or known range, but for which the exact value will vary by chance from project to project or from time to time. The mathematical representation most commonly used for aleatory uncertainty is a probability distribution. When substantial experimental data are available for estimating a distribution, there is no debate that the correct model for aleatory uncertainty is a probability distribution. Simulation is one of the effective probability – based methods. Propagation of the probability distributions through a modeling and simulation process is well developed and described in many publications (Oberkampf et al., 2004).

Evidence from general projects shows that existing probability – based methods for estimating duration of project activities do not effectively consider the risk factors and cannot provide accurate duration estimates, especially at an early stage of construction when data are unavailable and insufficient. Another disadvantage of the conventional methods is that the relationship between the essential design parameters (i.e., technical requirements, construction schedules, resource demand and availability) and risk factors is not adequately established. The reason for these is that current duration estimating methods cannot integrate information obtained from the risk assessment into the construction schedule. These methods also cannot provide accurate, rapid, and easy reference to technical and economic information for the project team.

Several disadvantages of the probability – based methods are that these methods rely on the quantitative data. By nature of construction projects, data are usually unavailable and insufficient. Due to lack of historical data about activity duration and uniqueness of some activities in the construction projects, a project manager may not correctly characterize the activity duration represented by a random variation for the case of using the probability – based methods. By using historical data collected from the completed projects to forecast variation in activity duration of an ongoing project, although the historical data might be statistically sufficient, the historical data cannot reflect specific characteristics of a project in investigation because each project is unique. Subjective data are usually required to adjust the historical data based on available information associated with a project being considering. The factors that have influence on the subjective judgement are divided into two main categories: (1) complexity of working and conditions for judgement and (2) level of education and experience Cho et al. (2002).

With the merit of a beta distribution, a project manager can easily and accurately assign the end points of an activity duration distribution, if he/she is familiar with the construction conditions, technical dependencies, and resource constraints related to the target activity. The accuracy of the developed beta distribution of activity duration, therefore, depends mainly on experience, knowledge and judgement of estimators or experts. Also, a wide variety of shapes of the beta distribution can be flexibly defined by subjectively assigning values of the parameters.

A great deal of the factors influencing the subjective judgement in construction does not comply with randomness properties of probability theory because uncertainty associated with these issues is not random. Using subjective information is the main cause of uncertainty and thus does not lend itself to precise measurement. Several authors have highlighted some serious shortcoming related to the Bayesian statistics. Zadeh (1965) suggested that the assumptions associated with Bayesian function namely, mutual exclusivity of events, conditional independence, and exhaustivity of events do not always hold. Probabilistic approaches are best suited to mechanistic systems where the accuracy and precision are considered important. If any lack of knowledge or information makes the risk assessment and duration estimate to be performed by the subjective judgement of the experts, fuzzy set – based methods for risk assessment and scheduling are introduced for addressing uncertainty associated with the subjective information. Any lack of knowledge, limited understanding of complex physical process, and lack of information in the risk assessment and scheduling are described by the term epistemic uncertainty. Fuzzy set theory has proved to be a powerful technology modeling ill – defined, complex, and unstructured problems due to incomplete and imprecise information that characterize the real – world project.

During project planning and execution, many unexpected events may occur, and the manager will have to rely on his/her subjective knowledge, judgement, experience and assumption about actual situations to estimate variation in activity duration due to risk factors, so that the risk assessment is mainly cognitive in nature. For this reason, fuzzy set – based methods are able to provide viable alternative in such situations. Many fuzzy set – based methods have been proposed for risk assessment and project planning and scheduling (Nasution, 1999; Chanas and Kamburowski, 1981; Zadeh, 1965; Dubois and Prade, 1980, Kaufman and Gupta, 1985; Gazdik, 1983; Lootsma, 1989; Lorterapong and Moselhi, 1996, Pierre et al., 2004; Adriana and Aminah, 2005; Long and Ohsato, 2006; Goldratt, 1997; Ayyub and Haldar, 1984; Smit and Hancher, 1989; Wu and Hadripriono, 1994; and Oliveros and Fayek, 2005). It has been applied to project duration forecasting, decision making and control action selecting techniques so as to address uncertainty, vagueness, imprecision, subjectivity (Bojadziev and Bojadziev, 1997). Further, fuzzy theory has been applied to address uncertainty in the production environments through continuous simulation (Dohnal, 1983; Fishwick, 1991; Negi and Lee, 1992; Petroive et al, 1998; Southall and Wyatt, 1988; and Zhang et al., 2003).

Fuzzy set theory is not intended to replace probability theory but rather to provide solutions to problems that lack mathematical rigor inherent to probability theory. Specifically, the fuzzy set – based methods handle epistemic uncertainty stemming from systematic and unknown contributions, while the probability – based methods deal with aleatory uncertainty due to random contribution which limits the use of the fuzzy set – based methods and probability – based methods as a practical problem – solving tool for construction. The preeminent issue in uncertainty analysis of construction projects is therefore the representation, aggregation, and propagation of epistemic and aleatory uncertainty. The only solution to scheduling a project affected by several risk factors is by establishing a method integrating the random variables with the fuzzy variables for appropriately representing every uncertainty associated with the risk assessment and project scheduling.

1.3 Research Objectives

The main objective of this research is to develop a comprehensive tool for providing a construction schedule that can address every uncertainty involved in duration of project activities. The proposed model can be used to assist focusing attention on risk factors that have significant impact on duration of project activities. The proposed model also grows the realization of the estimated duration of project activities that leads to a better estimate of a project completion time. This research develop a risk assessment integrated within random–fuzzy network scheduling method based on two interrelated models: (1) risk assessment integrated within activity duration estimation model and (2) project completion time calculating model.

The risk assessment integrated within activity duration estimation model determines both aleatory uncertainty resulting from a random contribution and epistemic uncertainty stemming from systematic and unknown contributions affecting risk variables and a temporal variable in the form of a random–fuzzy variable by using a statistic based method and alternatively a neurofuzzy metamodel. This model provide distributions of the risk variables and temporal variable to the project completion time calculating model, which performs the network scheduling calculation based on mathematics for random–fuzzy numbers for appropriately analyzing uncertainties brought about by different sources. The proposed method provides a project completion time represented in the form of a random–fuzzy number. This research also investigates the effects of a probability distribution functions and membership functions selected for representing random and fuzzy parts of the temporal variable by performing sensitivity analysis.

1.4 Scope

The scope of the risk assessment and impact evaluation integrated into the construction scheduling discussed in this research is applied to construction operations of a bored pile construction project and a tunneling project. For the bored pile construction project, data used to develop distributions of attributes of risk factors and a temporal variable are collected by using the experts' questionnaire sent to respondents from completed projects and a case study project in conjunction with the direct observations. To demonstrate the advantages and effectiveness of the proposed approach by handling all uncertainties, the random–fuzzy variable based simulation model is applied to the tunnel construction which is considered as one of the most complex and risky types. Data are acquired through previous researches. The application of the proposed approach is scoped to significant risk factors identified by experts (e.g., project managers, engineers, and foremen).

1.5 Research Methodology

To meet the dissertation objectives, the following research steps are implemented:

1) Review of literature in the field of risk assessment and project scheduling, and identification of the limitations of existing methods.
2) Analyze practical limitations of current risk assessment and project scheduling methods with experts on the case study project
3) Study the suitability of probability theory and fuzzy set theory for modeling random and nonrandom contributions to uncertainties in the risk assessment and the duration of project activities
4) Present the temporal variable and risk variables in the form of a random–fuzzy variable. To address a random contribution, a model used to perform the risk assessment and establish the probability distribution of activity duration which is further inputted into a simulation process is developed as follows:
   - Identification of risk factors and evaluation of their impacts to specify the domain of applicability for which a simulation model is to be valid
   - Collection of data of the risk variables and temporal variable by using the historical record, interview, and questionnaire
   - Development of a simulation model for the case study project and establishment of probability distributions of activity duration

   Distributions representing systematic and unknown contributions are developed and incorporate into the established probability distribution. The proposed method using a statistical model and neurofuzzy metamodel as a probability–possibility transformation method present activity duration by random–fuzzy numbers which are used to compute a project completion time by using mathematics for random–fuzzy variables.
5) Demonstrate the advantages and effectiveness of the proposed approaches against the probabilistic scheduling methods.