REDUCED DURATION OF THE DESIGN PROJECTS WITH THE CONCEPT OF EARLY ESTIMATION OF DESIGN TASKS

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ABSTRACT

Reducing the lead time of construction projects is a great challenge in today's competitive world and especially where the LD (Liquidated Damage) is high. The duration is commonly lengthened due to high dependencies among activities/parties. Greater concurrency can shorten project duration and this can be achieved by getting early information from precedent activities especially in the design phase. The concept of using early estimated information is found to be useful in reducing the duration of the design project. However, this concept imposes rework for successor(s) if there is mismatch between used estimated information and the original information that comes from full analysis. On project completion, the impact of rework due to the use of early estimated information is of great concern. Therefore, this study examines the benefit from early information through estimation and the adverse effect of rework.

In the design process, some activities are estimable while some are not. Moreover, most of the events are stochastic in nature including the probabilistic nature of the activity durations and potentials for rework. For this reason, in order to validate the abovementioned concept, the simulation technique has been utilized to model the design process.

KEY WORDS

early estimation, rework, reduced duration, design process

INTRODUCTION

Construction is commonly delayed by the lateness of design deliverables including drawings, calculations, and reports (Wang et al. 2006). Difficulties arise in the design phase since these activities are highly and even cyclically dependent on each other for design information (parameters). Moreover, diverse parties across organizations are typically involved in various activities in design leading to complexity in design coordination. Similar findings have been described by Alarcón & Mardones (1998). Their study shows that the main problem in design is the lack of information and the designers do not deliver enough information on time to the construction field and to other participants in the design process which result in a chaotic scene. These

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dependencies inadvertently lengthen the design process.

Critical Path Method (CPM) was developed in the period of 1956-1959 to schedule the various tasks to be performed for a project. This method has been found to be very effective in network-based project management despite its numerous limitations. In its application to design management, it has limitations for modeling information dependencies and loops, and early information sharing and rework. In an attempt to reduce project duration, Critical Chain Method (CCM) (Steyn 2002; Rand 2000) cutoffs duration for each activity and puts a buffer at the end of the critical chain and near critical chain. However, CCM suffers the same limitation; it cannot handle concurrency; and model information exchange for interdependent design activities. The Design Structure Matrix (DSM), on the other hand, has been found to be very effective in identifying and managing information flows between activities, and ordering tasks for greater concurrency and reducing cyclical loops (Austine et al. 2000; Oloufa et al. 2004).

Although, DSM can produce an appropriate order of design tasks to account for information dependency and minimize feedback loops, it is typical that the design schedule strictly following this order by waiting for confirmed parameters from preceding design tasks far exceeds the duration of the project. In practice, it is common to utilize early information from precedent activities in order to significantly shorten project duration. However, this introduces the possibility of rework for succeeding activities if the estimated (early) information is found to deviate substantially from the subsequent confirmed information.

This study examines the concept of estimability for greater concurrency in an attempt to reduce the project duration while taking into account the time for rework. Especially, this study quantifies the time saved using early estimated information and the additional time subsequently needed for rework. Due to the dynamic characteristics of the design tasks and probabilistic events for the possibility of rework, the simulation technique has been used to model the design process. Through a case study of an oil refinery project, it can be found that considerable time is saved by using early estimated information. It outweighs the adverse effect of rework and shortens the overall duration of the design process.

BENEFIT OF EARLY ESTIMATION AND ACCOUNTING FOR REWORK

Parameter based dependencies provide better insight to depict the true relationships between activities. As evident from Fig. 1, dependency relationships are drawn based on the parameters required from its precedent activities. For example, Activity A1 produces parameter P_{12} which is required by Activity A2, parameter P_{13} which is required by activity A3, and parameter P_{14} which is required by activity A4. The other activities are similarly dependent on each other through the parameters that are produced and successively required.

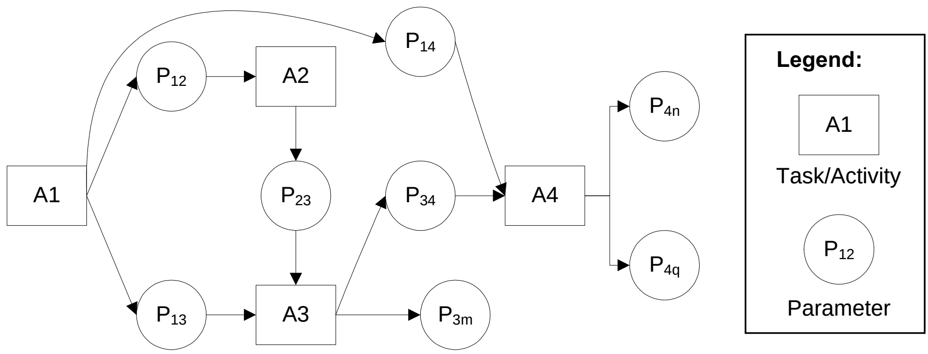

Figure 1: Parameter dependencies associated with activities

Traditionally, schedule of the above network is done with finish-start dependency as shown in Fig. 2(a) wherein the succeeding activities start only after the predecessors have completed the full analysis so that required parameters are available. This inevitably lengthens the design completion. In contrast, as depicted by Fig. 2(b), if parameters/information from A1 is estimable then A2 can start earlier as soon as the preliminary value for parameter P_{12} is has been established instead of waiting for the full analysis of A1. Similarly, activity A3 can start earlier if A2 is estimable and as soon as the preliminary values for parameter P_{23} from A2 and P_{13} from A1 are available. This increases the concurrency of the design process and reduces the overall duration, though, for some parameters; the successors have to wait for full completion of the precedent activities. For example, the structural design of a building must follow the architectural drawing. Architectural drawing cannot be estimated in order to start the structural design earlier.

Chua and Song (2005) describe the similar idea for greater concurrency using the concept of evolution of parameter states and early information sharing. Parameters go through states from preliminary or conceptual and eventually approved for construction. Each of the later states is more defined and accurate than the states before until the final which is used for construction and should govern the downstream design processes. Early information sharing utilizes the tentative earlier states to generate greater concurrency. However, the study has not quantified the reduced duration and explicitly considered the impact of rework. Thus, in Fig. 2(b), upon completion of the full analysis of A1 and A2, the confirmed parameters P_{13} and P_{23} (from A1 and A2 respectively) have to be compared with the estimated parameters that had been used earlier. Since the estimated information is not coming from full analysis, the information might not be 100% accurate. Consequently, rework may be necessary in downstream activities as a result of discrepancies when the parameters are eventually finalized. For instance, if any of the two sets of parameters (estimated P_{13} and P_{23}) deviates from the assumed design range, then rework is necessary for A3. This has impact also on succeeding activities downstream. In particular, there could be rework on A4 when confirmed parameter P_{34}

deviates from the design range assumed earlier.

Rework entails additional cost and time for the project. For simplicity, the present study does not quantify the cost but only focuses on quantification of additional time needed for rework for the design tasks.

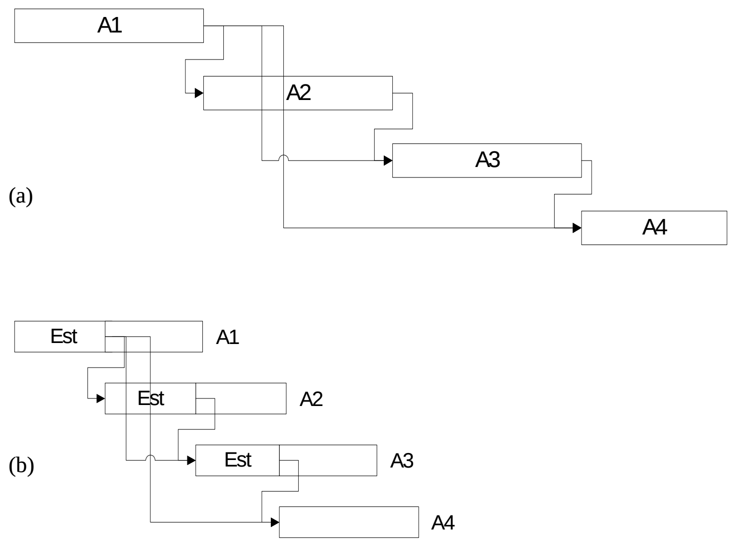

Figure 2: (a) Traditional finish-start dependency, (b) Early information sharing with estimation

DESIGN CONSIDERATIONS

Fig. 2(b) illustrates that early information sharing reduces overall project completion. So, it is worthwhile to check whether an activity is estimable or not through estimability. Estimability is defined as the degree of ease with which the parameter value can be estimated so that the estimate could be utilized as early information for downstream activities instead of having to wait for confirmed information after full analysis. This, however, introduces the possibility of a rework if the confirmed values of the parameters deviate from the assumed design range. The probability of rework for an activity will depend on the type of information that has been incorporated in the full analysis. For example, activity A3 can get parameter P_{23} from A2 in three ways: early estimation, full analysis and confirmed value after checking for rework. The check is necessary because activity A2 itself depends on parameter P_{12} from A1 which could have been estimated when the analysis was performed. Generally, there are three types of information derivable from activity i to j denoted as P_{ij}^{est}, P_{ij}^{full} or $P_{ij}^{confirmed}$, similar to the case from activity A2 to activity A3. In the case of activity A1 to A3, parameter from the full analysis is the confirmed parameter since it has no predecessor so that the parameter used in the analysis has not been estimated.

If confirmed information from the precedent activity (such as $P_{23}^{confirmed}$ from A2) is utilized then it is fair enough to assume that no rework is required. Otherwise, there is a possibility of a rework even with full analysis of the predecessor since the information incorporated in that analysis may have been estimated from its predecessor. The probability of rework is highest when only estimated value is used. In general, the parameters utilized in the full analysis are in a combination of states (estimated, full analysis, or confirmed) depending on the status of the predecessor activities. This will give an intermediate probability for rework. A simple formulation for the probability has been assumed in the case study.

The time to estimate the parameters needed by successor(s) depends on characteristics of the design activities. Estimation might be done from design results of similar project, past experience, or any other base line data. Based on the characteristics of the design activities, duration for estimation is a fraction of the duration for its full analysis. The duration for rework is also a fraction of duration for the full analysis. Usually, the greatest amount of time needed in a design activity involves the understanding of the details, devising the approach and developing the model for analysis. When a rework is necessary, the designer is already familiar with the design procedure and details, and the analysis models have already been developed so that significantly less effort is required to change the value of the parameters adopted in the design.

CASE STUDY

A project in the oil and gas industry has been used to validate the abovementioned approach of concept of estimability and rework. It is a design and build project with an estimated duration of 12 months for the design phase. The project master plan comprises 83 design tasks involving various phases of work: process study, civil and structural, equipment, piping, instrumentation and electrical. Taking into account for the abovementioned design considerations, a simulation model for the design master plan is developed based on the parameter dependency of the activities. STROBOSCOPE (Martinez 1996) has been employed for the simulation. In the absence of data, a normal distribution has been assumed for all activity durations in the present study although other distributions can also be conveniently utilized given the specific parameters of the distribution. A coefficient of variation of 20% has also been assumed. Each simulation is based on one thousand runs. For 95% confidence, the experimental mean results would not deviate by more than 4.3% of the true mean (see approximation used by Moder et al., 1983).

With the traditional finish-start relationships, the design master plan requires 432 working days to complete which far exceed the expected duration. To reduce this duration, it is inevitable that activities have to utilize early information from their predecessors. From the nature of the activities, 40 activities have been deemed to be estimable so that estimation can be done to obtain preliminary parameters' value after a fraction of the normal duration of the activity and utilized earlier for immediate successors without waiting for its confirmed values. Time to do estimate is assumed to be 40% of the duration of the full analysis in this study with a coefficient of variation remaining unchanged at 20%. To account for specific situations in a project where for some reason it is not possible to estimate these activities, a probability of estimability is assigned to these activities ranging from 0.6 to 1.

In order to measure the effect of rework, it has been assumed that whenever an activity requires rework, time to do that is 20% of its original full analysis; however, any other duration can be assigned depending on the characteristics of the activity. It is important to note that the check for whether an activity need rework can only be done when all the confirmed information from precedent activities are available. As mentioned in the preceding section, the probability of rework for an activity is determined based on the type of data used by that activity. For the simplicity of the model, it is assumed that if a parameter comes from estimation then it is Type 1 while if it comes after full analysis then Type 2 and if it is confirmed after rework then Type 3. Then the probability of rework is calculated by the following formulae:

$$probability\ of\ rework = 1 - \frac{avg.\ type\ of\ \ parameter\ used}{3}$$

If the type of all the parameters used for full analysis is confirmed, the probability of rework is null (i.e. probability of rework = 1-3/3). On the other hand, if the parameters are all estimated, the probability of rework is greatest at 0.667 (i.e. 1-1/3). With other combinations, the probability of rework will be intermediate between these limits. Empirical data or other relations can be incorporated in place of this relation.

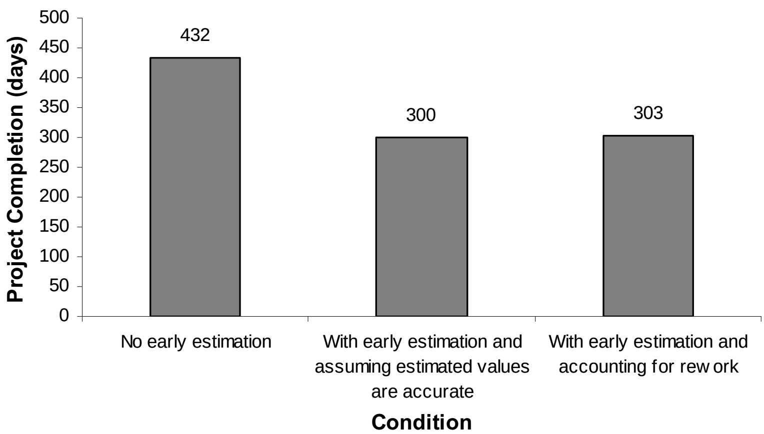

Figure 3: Variation in project duration for the case study

Fig. 3 shows the design completion time with early information incorporated wherein 40 activities are deemed to be estimable. When all the estimated parameters are assumed to be accurate so that rework is unnecessary, the mean duration for completion of the design is found to be 300 days with a standard deviation of 23.8 days. Accounting for the possibility of rework, the mean duration is increased slightly to 303 days. Early estimation in 40 activities (about 50% of the network) reduces design completion by 129 days or about 30% of the original. Although the use of early information poses rework in its successor(s), rework can be done in parallel along with other design tasks so that the overall effect on design completion is only an additional 3 days (or about 1%).

This concurrency of doing rework can be better understood from Fig. 4. The Figure shows the average finish date of each design task in ascending order of finish dates for the full analysis for the ideal case of no rework. This is compared with the finish dates of rework for the corresponding activities. These results are based on estimability of 1.0 for all activities. As can be seen from the Figure, the two finish dates for some activities are very close or equal. If they are equal, the associated activities need no rework and if they are close then the reworks are started shortly after finishing its full analysis. In the case where the two finish dates are apart, the trend indicates that the reworks for these activities cannot be started shortly after finishing the full analysis because the confirmed information from their precedent activities are yet to be available. Once all the confirmed information has arrived, rework can be done. However, the amount of delay to finish a design task due to rework is not very significant so that it should not be a big concern as long as the schedule is caught up at the end of the project. The Figure shows that finish date for full analysis for the last activity is on 184th day and the finish of the last rework is on 190th day. Altogether there is a 146 mandays of rework which is distributed throughout the project and concurrently performed with the other design activities so that the overall delay is only 6 days for rework.

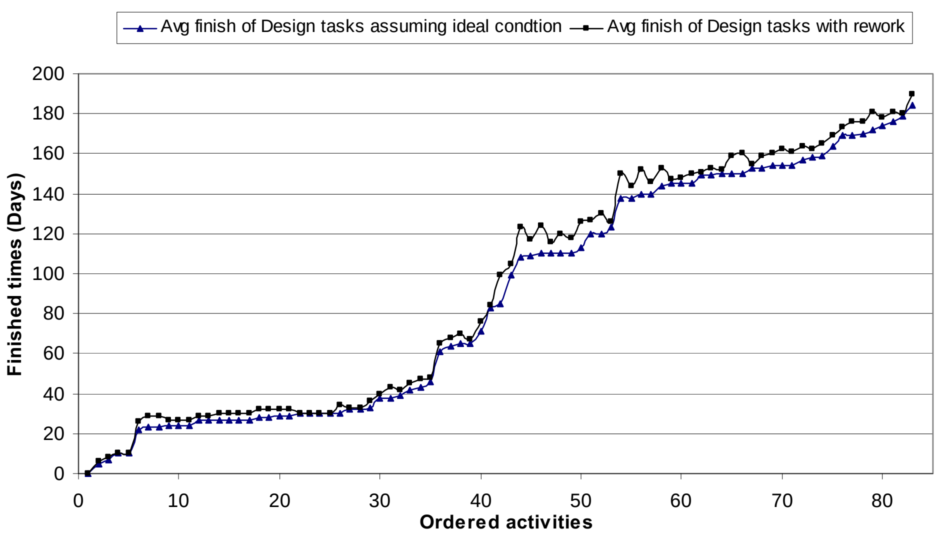

Figure 4: Comparison of finish dates of each design tasks in ideal condition and with rework

In order to better understand the impact of early information on deviation and rework, further analyses have been done. In the first instance, all the activities are assumed to be estimable and the model has been run for different probabilities of estimability. Fig. 5 compares the percent reduction in design completion and impact of rework for different estimability. As expected, the overall project duration reduces with higher estimability. The reduction increases from a mere 4.5% of the original duration for 10% estimability (i.e. activities have 10% probability of being estimable) to a level of 56% of the original duration if all design tasks are always estimable (i.e. with probability one). This trend depends on the specific network configuration of a project and the amount of time required for getting the early information through estimation.

At the same time, rework durations are measured for each activity and accumulated for all activities. Total rework duration is computed as mandays assuming that one person is assigned for each design task. As expected, the amount of rework also increases with estimability. For 10% estimability, the loss in productivity is 1.1%, whereas for 100% estimability, the loss in productivity rises to 9.7%. However, compared to the reduction in design duration because of utilizing early information, the amount of rework is not very significant. With 100% estimability, total rework of 9.7% is small compared to the significant reduction of 56% in design completion.

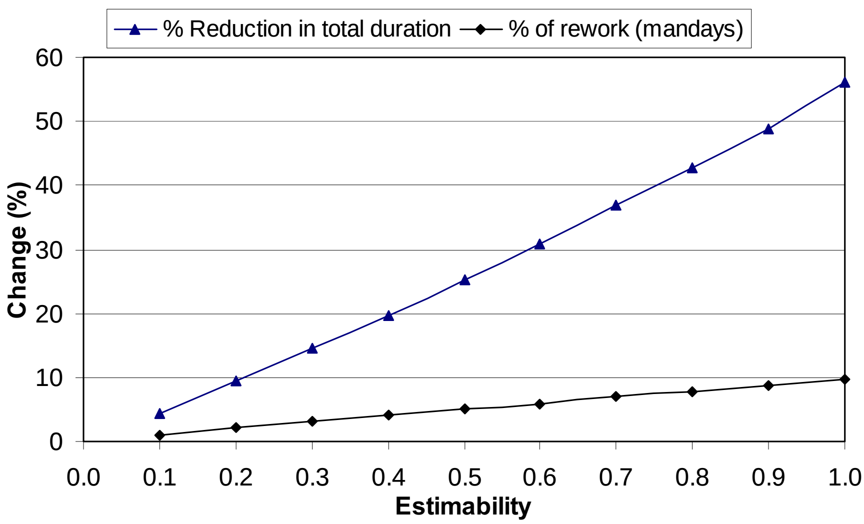

Figure 5: Comparison of reduced duration and amount of rework for different estimability

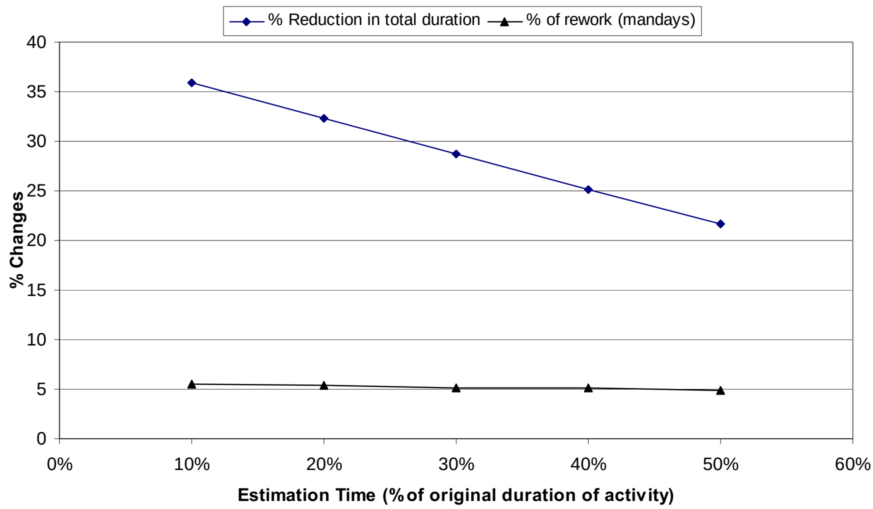

Figure 6: Comparison of reduced duration and amount of rework for different fraction of time for estimation

Similar to the different probabilities of estimability, different estimation time also plays a significant role in design completion. Fig. 6 shows the percent reduction in design completion and impact of rework for different fraction of time for full analysis to do estimation. As before, all activities are assumed to be estimable but with probability 0.5. If the estimation time is as low as 10% of the original duration of the full analysis, the reduction in project completion is about 36%, whereas at 50% of the full analysis, the reduction in project completion is 21.6%. For this network, with every 10% reduction of the full analysis for estimation yields about 4% reductions in the project completion. Within this range of estimation time, the variation of impact of rework is insignificant, ranging from 5.6% to 4.9%. Thus, it can be expected that design completion is considerably reduced with lesser estimation time without any considerable increase in rework.

CONCLUSION

This paper presents the concept of estimability describing how early estimation can reduce the overall duration of the design process taking into account the time required for rework. Although early information sharing is posing rework for downstream activities, the overall impact of rework to project completion is rather insignificant compared to the reduction in the duration that can be gained. The simulation results also show that most of the reworks can be done along with other design tasks and hence the impact of rework on overall duration is much less than the accumulated rework. Specifically for the case study, early estimation of 40 activities (out of 83) reduces project completion by about 30% of original (300 days compared to 432 days); this allows the project to be completed within the estimated project duration. However, the additional time due to rework delays the project by only 1% (completion time is 303 days). The case study also reveals that the overall project duration reduces with higher estimability and lower estimation time. For each level of estimability, the amount of rework measured in mandays is significantly less than the reduction gained in duration for project completion.

Although additional cost for rework has not been examined yet, the reduced duration eventually adds high value to the project. This is particularly important for those projects which have to compete in highly competitive market or for which liquidated damages are very high. The current model can readily be extended to quantify the additional cost for doing estimation and rework and hence the analysis of time-cost tradeoff. The additional cost includes the extra effort to do estimation (usually not so much) and additional manpower and resources for the rework. Moreover, the reduced duration can be expressed in monetary terms based on the type of project so that the trade-off can be performed in this term.

The present study considers three states of parameters (estimated, full analysis, and confirmed after rework) in modeling the design process. However, in design phase, some drawings may require approval for which parameters from a group of activities should be aggregated and confirmed information can only be obtained after approval process. The approval may lengthen the overall duration of the design process. Further study is needed to quantify this additional time for approval and the total impact on project completion time.

REFERENCES

Alarcón, L.F., and Mardones, D.A. (1998) “Improving the Design-Construction Interface”. Proc., 6th Annual Conference of the International Group of Lean Construction, Guaruja, Brazil.

Austin, A., Baldwin, A., Li, B., and Waskett, P. (2000) “Analytical Design Planning Technique (ADePT): a Dependency Structure Matrix Tool to Schedule the Building Design Process.” Journal of Construction Management and Economics (2000) 18, 173-182.

Chua, D.K.H., and Song, H. (2005) “Application of parameter states in product-oriented-coordination between design and construction.” Proc., 3rd International Structural Engineering and Construction Conference (ISEC-03), Shunan, Japan.

Martinez, J.C. (1996) “STROBOSCOPE State and Resource Based Simulation of Construction Processes.” Ph.D. Diss., Civil & Envir. Engrg., Univ. of Michigan, Ann Arbor, Michigan.

Moder, J.J, Phillips, C.R., and Davis E.W. (1983) “Project management with CPM, PERT and Precedence Diagramming.” Third Edition, Van Nostrand Reinhold Company Inc. New York 10020.

Oloufa, A.A., Hosni, Y.A., Fayez, M., and Axelsson, P. (2004) “Using DSM for Modeling Information Flow in Construction Design Projects.” Civil Engineering and Environmental Systems, Vol. 21, No. 2, 105-125.

Rand, G.K. (2000) “Critical chain: the theory of constraints applied to project management.” *International Journal of Project Management* 18 (3) 173-177.

Steyn, H. (2002) “Project management applications of the theory of constraints beyond critical chain scheduling.” *International Journal of Project Mgmt* 20 (1) 75-80.

Wang, W., Liu, J.J., Liao, T.S. (2006) “Modeling of design iteration through simulation”. Journal of Automation in Construction 15 (2006), 589-603.