FAILURE MODE AND EFFECT ANALYSIS AS A TOOL FOR RISK MANAGEMENT IN CONSTRUCTION PLANNING

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ABSTRACT

Construction projects are known for having an inherent risk affecting both schedule and cost considerably. High levels of uncertainty and risk are typical for the construction industry and are significantly manifested as project size and complexity increase. Risk management practices are underutilized in the construction industry. This paper focuses on the use of Failure Mode and Effect Analysis (FMEA) within the Last Planner System (LPS) as a tool for risk management at the lookahead planning level which connects master and phase scheduling to production planning. FMEA has been widely used in the manufacturing industry to study potential failures along with their impacts and suggest remedial measures. However, its use in construction remains very limited especially at the planning level. The purpose of this paper is to study the integration of FMEA into construction planning for projects using the Last Planner System and its impact on workflow and project performance. The paper introduces a planning process model with integrated risk management employing FMEA at the lookahead planning level and combining aspects of first-run studies. The model involves: risk identification, risk assessment and analysis, risk monitoring, and contingency planning. The study contributes to the overall understanding of construction planning by laying-out a framework for identifying risks, mitigating those risks, and allocating contingencies.

KEY WORDS

Risk management, FMEA, lookahead planning, LPS, workflow.

INTRODUCTION

With a varying but omnipresent uncertainty, construction projects always witness a challenge for completion within project objectives. Meeting schedule, cost, quality, and safety requirements remain the basic performance measures to assess projects. Construction planning is a crucial process that helps in achieving successful outcomes in project management (Hamzeh et al., 2012). However, planning should account for project related uncertainties to cater for the need of managing them early on. This is where risk management practices need to be employed as an effective tool for monitoring different risks in construction projects.

According to Akintoye and Macleod (1997), around 70% of construction contractors and project managers do not have any formal risk management technique

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used in their companies. Moreover 52% of projects are uncertain at the start of construction with the majority finishing behind schedule and over budget (Howell, 2012). These alarming percentages underline the need for integrating risk management in the construction industry as a basic step in planning to avoid failures. In fact, improper planning and methodology rank among the leading causes of project failures where 78% of projects in the MENA region fail due to poor planning (Skaik, 2010). Risk management tools vary and represent effective means to avoid planning failures if carried out properly. This paper explains the use of Failure Mode and Effect Analysis (FMEA) at the lookahead planning level for projects using the Last Planner System (LPS). A process model is included to show the framework for implementing FMEA in planning. Finally, advantages of using risk management techniques to enhance construction planning and reduce failures are listed.

FMEA

LITERATURE REVIEW

Failure Mode and Effects Analysis (FMEA) is a risk management and planning technique that can be used to identify and prioritize potential errors/failures within a project/system/process and come up with possible solutions to avoid these errors. Identification of potential problems is usually achieved by brainstorming and opinion-sharing between experts within the operating field. Failure modes and/or errors are then ranked or prioritized based on a Risk Priority Number (RPN) which is calculated according to three main factors: severity of the risk, frequency of occurrence, and probability of detection (Bahrami et al. 2012, Sawhney et al. 2010, Carbone & Tippett, 2004).

FMEA was first implemented by the US army in 1949 and used for military operations (Carbone & Tippett, 2004) and then proposed by NASA in 1963 for reliability requirements, and has since then, been an indispensable technique for system safety and reliability analysis (Bahrami et al., 2012). Nowadays, FMEA is being used in various operational sectors. For example, it is an inseparable measure of the ISO-9000 and QS-9000 quality certifications (Carbone & Tippett, 2004).

Moreover, slight alterations to the FMEA have been made in order to adjust it for use in different domains where for instance, Bongiorno (2001) introduced a Design FMEA (DFMEA) altered for specific use within design processes. Furthermore, an altered Risk FMEA (RFMEA) has been introduced specifically for risk assessment. Alterations included name amendments to the factors that produce the RPN where “impact” replaced “severity” and “likelihood” replaced “occurrence”. Such alterations were made so that these factors would better describe the actual situation within the intended sector use. RFMEA introduced an additional risk indicator (termed: risk score) which is calculated solely on impact and likelihood (Carbone & Tippett, 2004). Fuzzy FMEA was suggested for use along with chain scheduling for a more efficient project delivery (Razaque et al., 2012). Others have made use of FMEA by introducing a new parameter termed Risk Assessment Value (RAV) in order to help improve the reliability of the Lean system after it was critically suspected to have a high failure probability (Sawhney et al., 2010).

Furthermore, FMEA is thought to be a useful tool that would help decision makers eliminate doubt and become more confident about trying and implementing new construction innovations with mitigated risk potentials (Murphy et al., 2011). Other suggestions included incorporating FMEA in every phase of the construction industry as that would help reduce risks and avoid failure. The suggestion included all stages of construction, yet a sample case study focused on excavation (Bahrami et al., 2012).

FMEA is also found to be used in other wide ranges of the industry such as aerospace, nuclear, and automotive manufacturers such as Peugeot and Citroen (Ebeling, 2001). This has been substantiated in another automotive manufacturing company case study, where evidence showed that there was "a reduced number of prototypes needed to approve product components. In addition, there was a positive influence on the product development decision-making process, evidenced by better allocation of resources among projects at the program". The results of the case study can be exploited to encourage the use of FMEA not just in automotive manufacturers, but in all industries that deal with new product development (NPD) (Segismundo & Miguel, 2008).

THE LAST PLANNER SYSTEM

The Last Planner System (LPS) is a production planning and control system used on construction projects. While planning is key to successful projects as it sets the goals to be achieved and strategies to be followed, proper control is crucial to monitor and adjust plans with actual work, re-plan, and learn from plan failures (Ballard, 1998). In this context, LPS is different from traditional project management systems as it involves production control (Ballard, 2000). The Last Planner System has 4 planning levels: master scheduling, phase scheduling, look ahead planning, and weekly work plan.

Starting with the master schedule at the level of the project, milestones are set and work strategies are defined. Next, the phase schedule is developed using collaborative planning. Reverse phase scheduling is performed and hand-offs are specified based on previously defined milestones. Look ahead planning with constraints analysis is then carried out to reach the weekly work plan for execution. Reliable plans are generated and these are tracked by measuring PPC continuously, analyzing failures, and learning from them (Hamzeh, 2009).

Implementing the Last Planner System turned out to be an efficient tool to improve productivity, if properly implemented (Liu et al., 2011). However, research area focused on improving work flow and shifted the interest to enhancing work flow reliability. This is directly related to the dynamic nature of construction projects where reliable planning mitigates for uncertainty and its resulting risks.

USE OF FMEA IN LPS

Despite its wide usage in many industries, FMEA remains underutilized in the construction industry. The main reason behind that is the unawareness of construction companies of the urgent need for risk management. An important feature of FMEA relates to its proactive behavior (Bahrami et al., 2012). Rather than being reactive, FMEA identifies failures before they occur, giving the needed time for avoiding them when possible or looking for proper mitigation measures to reduce their effect. In this paper, failures in construction projects are related to planning failures. These failures are categorized into: (1) failure in completing task on plan, (2) failure due to lack or poor planning, and (3) failure due to intrinsic uncertainty. In planning, FMEA helps in identifying critical and risky activities and assess their impact on project schedule.

Dealing with uncertainty in the planning phase can be also enhanced through the use of the Last Planner System for production planning and control. The LPS reduces uncertainty as it reduces workflow variability and increases reliability of plans. Based on lean principles, the LPS improves reliability by allowing action at multiple planning levels (Ballard and Hamzeh 2007).

The use of FMEA in LPS takes place at the look ahead planning level; it is carried out in parallel with the constraints analysis. It allows for risk analysis and enhances operation design as it provides for an additional means of filtering critical activities and managing their associated risks. A detailed process model zooming on the use of FMEA at this level will be presented in the following section.

PROCESS MODEL

The process model below portrays the integration of FMEA in the look ahead planning. It shows the different steps involved at this planning level until activities are moved to the weekly work plan for execution.

OVERVIEW OF LOOK AHEAD PLANNING

Look ahead planning connects master and phase scheduling to weekly work plan. It covers activities that span 5 to 6 weeks ahead as uncertainty in further work makes planning unreliable and meaningless. The time span for look ahead usually depends on the reliability of forecasting activities and making sure these can be made ready. Look ahead planning provides for detailed production planning and involves three main tiers: breaking down activities into smaller tasks or operations, identifying and removing potential constraints through constraints analysis, and designing operations (Ballard et al. 2007, and Hamzeh 2009).

Look ahead planning has a vital role in controlling workflow in the production system. It helps reducing uncertainty from tasks by removing constraints and thus reducing variability. In look ahead planning, schedule, budget, and resources are sized so as to meet each task requirement. Ready tasks are identified and moved for execution during the weekly work plan. Finally, a workable backlog is created for the upcoming execution week (Ballard et al. 2007, Hamzeh 2009).

MODEL DIAGRAM

The diagram in Figure 2 shows the look ahead planning process and the use of FMEA technique for risk analysis at the operation design level. The legend depicted in Figure 1 below was used to draw the model above. Each shape along with its annotation is indicated.

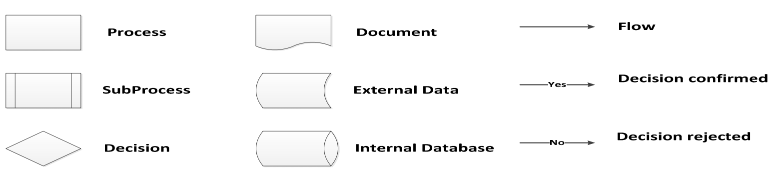

Figure 1: Legend for process model

Terminology and Detailed Processes

Looking at the diagram, several processes need to be defined to understand what each of them comprises.

First Run Studies: these studies are essential for the purpose of operation design; they are usually done 3 to 6 weeks prior to starting a new task. They portray in a realistic manner the task to be performed as a trial and learning process in order to find best practice and identify resources available or needed as well as the interaction of the task with other operations. Processes that are categorized as new, critical, or repetitive usually require first run studies to promote proactive scheduling and avoid surprises. However, these studies are not limited to repetitive tasks but are advised for any operation as they reduce impending variability and uncertainty associated with construction operations (Ballard & Hamzeh, 2007). First run studies help in speeding up the operation on field as crews are prepared and acquainted with the situation. Areas of uncertainty can be identified and dealt with to find coping strategies. First run studies also aid in controlling safety and quality in designing the operation early on. Finally, first run studies help capture best practices and lessons learned to be applied for future projects.

Constraints Analysis: this process is described as "Examine Prerequisites" in the model. It helps identify ready tasks, constrained tasks, and those to be made ready. Screening activities is performed to check the status of each based on its constraints and decide whether to advance it or retard it. Activities are scanned relative to their prerequisites such as information, space or sequence, resources, contractual, and external conditions. Typical constraints related to information are for instance the need for a RFI (Request For Information), a submittal approval, etc. Space and sequence refer to the previous work being done or not and the access to the work area. Resources are also examined to make sure that labor is available to perform the job, needed equipment is available and functional, and on time materials delivery is ensured. Contractual constraints could result from variation orders and being unaware of specifications or code requirements. These are associated with flaws in contract documents or inappropriate documents and could lead to claims, disputes, disruption of work, etc. (Akintoye & Macleod, 1997) Finally, external conditions may be always prevailing; these include weather changes, litigations, strikes, etc.

Constraints Log: the constraints log encloses constrained tasks identified in look ahead planning for constraints removal. If constraints are not removed, they are held back in the constraints log until assigned. The status of constraints is controlled as long as these are placed in this log (Hamzeh, 2009).

Risk Analysis: this represents the stage at which FMEA is employed. In order to proceed with risk management, necessary data need to be collected. Experts' data are investigated, statistics are checked, and the company's records are revised; all of which are compiled for use. This risk management technique starts by identifying potential risks associated with the operation at hand. Next, the different parameters are computed. The probability of occurrence of the risk is determined, the severity or impact of the risk is assessed, and the probability of detection is obtained. It is worth mentioning that all these values are based on the collected data and may not be perfectly accurate but should be representative for each operation. Also, detection of the risk depends on the nature of that risk. Finally, the Risk Priority Number is

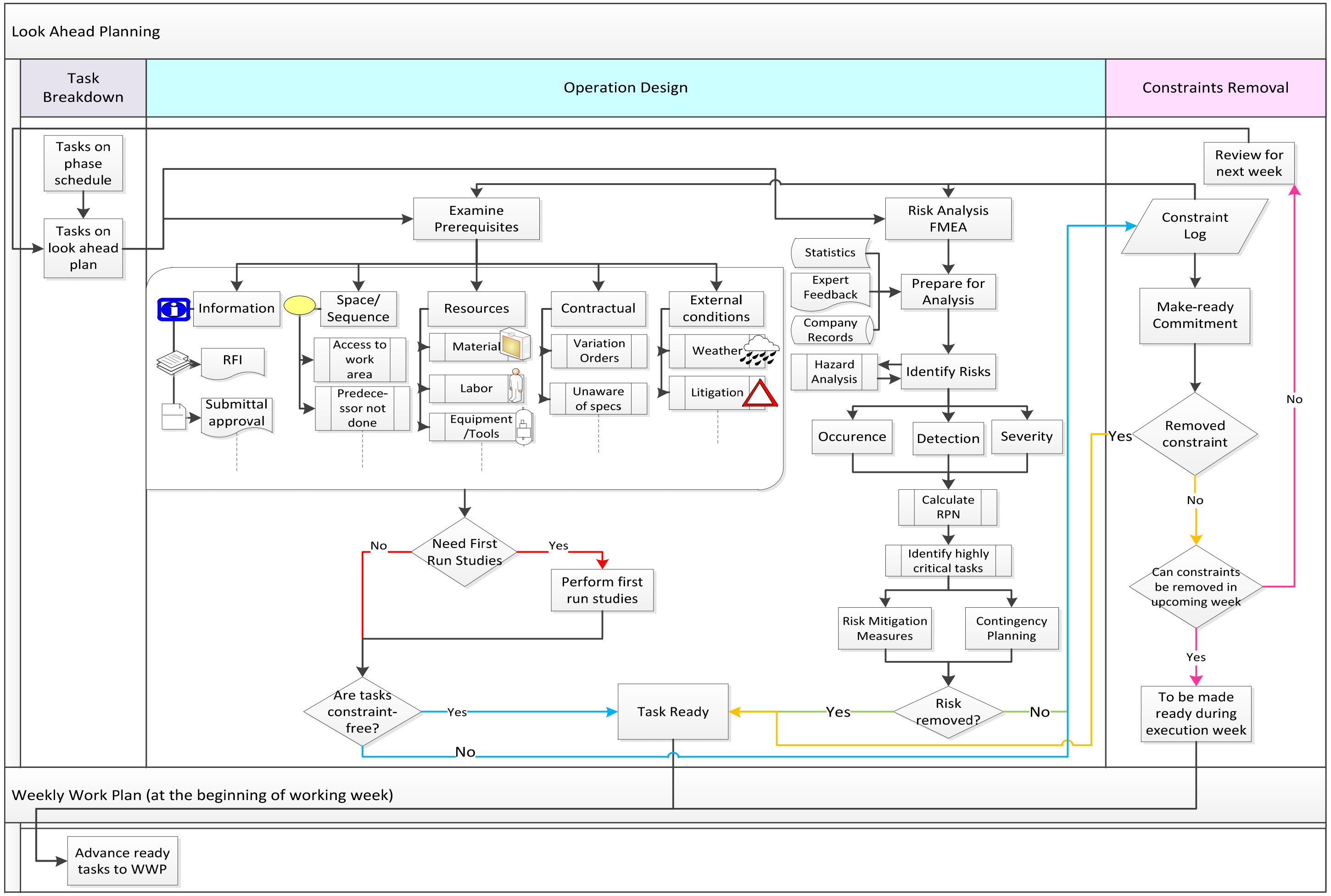

Figure 2: Process Model showing the integration of FMEA in look ahead planning

calculated to classify tasks. Highly critical tasks are recognized and risks associated with them are managed through mitigation measures or contingency planning.

Hazard Analysis: job hazard analysis is a technique that aims at studying job tasks to pinpoint potential hazards before occurring. A hazard is defined as "the potential for harm…associated with a condition or activity that, if left uncontrolled, can result in an injury or illness." (OSHA, 2002) This analysis studies each job with its related tasks and looks at the relationship between the worker, the tools used, the environment where the task is performed, and the details of the operation itself. Once hazards are identified, measures are taken to avoid them or reduce their effects to tolerable risk levels. This will prevent undesirable and unplanned situations from happening through treating the hazards as potential risks that may cause failure and performing the FMEA procedure to monitor them.

Risk Mitigation Measures: these measures are used when the addressed risk is inherent by nature and cannot be eliminated but simply reduced. Measures are taken so as to control the potential impacts on the scheduled task. Mitigation measures include the investigation of possible risk responses that could alleviate consequences of the risk. Available options may be examined and the impact of each on cost, schedule, and quality is evaluated. Moreover, allocation of buffers on certain tasks may be a feasible solution that cuts down drawbacks.

Contingency Planning: contingency plans are used when risks can be released to cater for their impacts. They may require a change of the current plan to acquire certain conditions. Buffers are again used as contingency means when applicable. Contingency plans induce additional costs but are compensated as they prevent much higher budgets if the risks are not dealt with. These plans contain mitigation measures and are present for use in case the identified risks occur. They take into consideration the prevailing conditions and try to minimize or even eradicate risks.

MODEL LOGIC

Having explained the different processes incorporated in the model diagram, it is time to show how all are integrated to allow this model to track a task from the moment it enters look ahead until it is transferred to weekly work plan.

As a first step in look ahead planning, tasks are entered from phase schedule and transferred there to be broken down into operations. The look ahead plan mainly covers six weeks ahead of execution of the task. Breaking down of tasks is undertaken to evaluate the constraints for each separately.

At this stage, the tasks enter the operation design for constraints analysis through examining prerequisites. In parallel, risk analysis is carried out. These two processes were described in detail in previous sections. After screening tasks and identifying missing prerequisites, pulling is applied to make activities ready after removal of constraints. It should be mentioned that the need for first run studies is inspected after verifying prerequisites. Similarly, after performing the FMEA procedure with all its steps, the status of each activity is checked to determine whether the risk is removed or not. Once the risk is removed and the task is constraint-free, then the corresponding task is moved to *Task Ready*. In case constraints are identified along with related risks, the task is moved to the *Constraint Log* for constraints removal and is held for monitoring its status and checking possible assignments later on.

The constrained task is released from the constraint log if a make ready commitment is undertaken, then the task can move forward. At this level, checking if the constraints are removed leads to two paths. In case of successful removal, the task is moved to *Task Ready*. Otherwise, the constraints are tested for removal during execution week. If enough time buffer or resource buffer for instance are available, then the task is assigned *To be made ready during execution week*. If this is not possible, the task is sent for *Review for next week*. Such tasks are again included as tasks on the look ahead plan and go through the entire cycle again.

Tasks that are advanced to the weekly work plan are those that are made ready for assignments when scheduled. Those are *Task Ready* and tasks *To be made ready during execution week*. It is good to note that a workable backlog is created in case activities are finished earlier than expected or if assignments exceed capacity (indicator of poor management). This backlog mainly comprises tasks that are ready but not critical for potential completion.

LIMITATIONS OF FMEA

Despite its efficiency, the FMEA technique as any risk management tool has its proper limitations. These are discussed briefly for better understanding.

One main concern in using FMEA is that results may sometimes be misleading. Looking at the procedure followed, after identifying risks and computing needed parameters, the Risk Priority Number (RPN) is found. Activities are then classified based on it, and high RPN values define highly critical risks associated with the task. However, having low RPN number does not exclude an activity from being very critical (Bahrami et al., 2012).

Risks are hence quantified based on the RPN value without properly identifying and exploring risk factors. This ambiguity may cause some risks to pass unseen and thus result in poor management through wrong resource allocation and prioritization. For instance, some tasks are being made ready before others that could be of more importance or higher priority. Each of the risk factors leading to the RPN value must be discussed. For example, some risks have low probability of detection while their impact or severity on project planning is very high. Having said that, their calculated RPN may turn out to be low and disregarded while they can affect workflow and reliability of plans considerably.

Moreover, values for the different risk factors as probability of occurrence, severity, and probability of detection are all estimated values that depend on the behavior of the reference contact. Even if statistics, data from experts, and company's records are all documented and checked, these numbers are indefinitely prone to mistakes through their subjective nature. They highly depend on the nature of the people involved in this process. Being risk averse or risk taker is the controlling feature.

CONTRIBUTIONS OF FMEA AS A RISK MANAGEMENT TOOL

Failure Mode and Effect Analysis (FMEA) is a useful tool that can be incorporated in construction planning to provide means for risk management. Through its various steps, this technique allows for a comprehensive risk management process.

First of all, risk identification is done using expert judgment, databases… Next, risk analysis is performed through finding probabilities and calculating necessary values. After identifying and quantifying risks, a risk response must be generated. This is accomplished through various means: (1) risk avoidance, i.e. the risk is eliminated by avoiding it, (2) risk retention, i.e. the risk is accepted but a contingency plan is devised, (3) risk transfer, i.e. the risk is transferred to the downstream or upstream last planner, or (4) risk reduction, i.e. the risk is mitigated by reducing its probability of occurrence (Kululanga and Kuotcha, 2010).

Employing FMEA at the planning level, early on during the project, is crucial for maintaining a reliable workflow as it gives the chance to cater for risks before they happen or draws a framework for managing those risks through different approaches. Another important feature that could enhance construction workflow and make good use of FMEA is by engaging in collaborative planning. Even when FMEA is used, results are much more reliable if concerned parties are contacted to produce more realistic plans that can be executed on time, in case of risk occurrence.

Hence, the FMEA lays down a framework for implementing risk management practices and combine them with traditional constraints analysis done at the look ahead plan to make schedules even more reliable and less prone to planning failures.

CONCLUSIONS AND FUTURE WORK

This paper focused on the use of FMEA at the look ahead planning level to show how risk management can be monitored and controlled in construction planning. To study the utility of integrating FMEA in the LPS, a simulation model can be developed taking into account the skills of the last planners and the project environment. It is important to mention that this paper dealt with risks identified during look ahead planning i.e. specific constraints at the task level. These can be dealt with within 6 weeks prior to execution. Gross constraints which represent higher risks need to be considered in the phase schedule and treated earlier on to avoid their shortcomings.

Making tasks ready is an essential goal of look ahead planning through screening and pulling; different tasks are advanced to weekly work plan and considered as ready for execution after dealing with corresponding constraints and associated risks. However, the model did not account for new tasks that may occur suddenly during the working week, without previous plan for them.

These unanticipated tasks have to be included in the updated look ahead plan and dealt with differently given that no sufficient time is available to perform the traditional analysis approaches and change plans accordingly. This is where improvisation is needed to manage such activities. Actually, improvisation remains an inseparable feature of planning given the high uncertainty of construction projects which consequently demand high flexibility to overcome unforeseen events.

It is therefore important to know how to use improvisation and integrate it in construction planning. Further work consists of adding the newly addressed type of tasks in the model and catering for changes in plan through the use of improvisation.

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