Risk Assessment of a Ready-Mix Concrete Supply Chain

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ABSTRACT

In today’s business environment, the coordination of just-in-time (JIT) production and transportation is one of the most challenging aspects to ensure timely delivery of materials to distributed customers. Several risk factors make JIT supply chains more vulnerable and methods for analyzing and understanding supply chain risks are still needed in construction. This paper describes the implementation of failure mode, effects, and criticality analysis (FMECA) tool and discrete event simulation to assess supply chain risks, identify vulnerabilities, and measure the impact of disruptions of a ready-mix concrete supply chain. Interviews with concrete batch plant managers and current demand, production, and delivery performance data served as input for analysis. We provided a systematic method that can be used by concrete suppliers to improve planning and delivery of ready-mix concrete. Different mitigation strategies were suggested based on our findings.

INTRODUCTION

Risk management is a process aimed to identify and assess risks in order to enable the risks to be clearly understood and managed effectively (Hillson 2002). This process is a critical part of project management of large engineering and construction projects in an attempt to reduce uncertainties and to achieve project success (Akintoye 2008). Unmanaged or unmitigated risks are one of the primary causes of project failure (Royer 2000).

Supply Chain Risk management is emerging as an important contributor to most fields of management decision and control. Managing supply chain risk is difficult because individual risks are often interconnected. As a result, actions that mitigate one risk can end up exacerbating another (Christopher 2004). For example, a just-in-time supply chain, while low inventory levels decrease the impact of over forecasting demand, they simultaneously increase the impact of a supply chain disruption. Supply chain risks can become full-fledged supply chain problems, causing unanticipated changes in flow due to disruptions or delays. Supply chain disruptions are unintended, undesirable events that degrade both supply chain and project performance (Wagner and Bode, 2008). Thus, the goal of supply chain risk management is the design and implementation of a supply chain which anticipates and successfully copes with disruptions. Despite increasing awareness among practitioners, the concept of supply chain vulnerability and supply chain risk are still in their infancy (Blackhurst 2003). There is compelling research illustrating the
importance of effectively managing supply chain disruptions as well as the lack of preparedness of most companies (Mitroff and Alpaslan 2003).

Construction supply chains are not different. Construction managers need better methods for analyzing and understanding supply chain risks and vulnerabilities. This paper describes the implementation of failure mode, effects, and criticality analysis (FMECA) tool and the results of discrete event simulation to assess supply chain risks, identify vulnerabilities, and measure the impact of disruptions of a ready-mix concrete supply chain. This paper does not intend to present the detailed simulation experiment but present the benefits of using this tool with FMECA to provide useful information for the construction planning process.

Ready-Mix Concrete Production System: Supply Chain Risks

The National Ready Mix Association (March, 2011) indicate that ready-mix concrete is a $30 billion industry in the USA, with an annual output of 351 million cubic meters, and nearly 75% consumption of cement is through the ready-mix concrete route (National Ready Mix Concrete Association: http//www.concnt.org).

Several sources of risks can be identified in the production system for ready-mix concrete:

a) Ready-Mix Concrete Plants have Limited Capacity: A plant’s capacity is determined by either batching capacity or delivery capacity. Batching capacity is determined by the time needed to measure, dispense, and mix ingredients, then load them into a truck. Delivery capacity is determined by the number of trucks and drivers that service the ready-mix concrete plant. Typically, a ready-mix concrete plant may own 25 to 30 trucks and plant operators will try to keep them busy at all times.

b) Demand Fluctuation: Demand for ready-mix concrete fluctuates throughout the day, week, and year. At the time a contractor calls in an order to a ready-mix concrete plant, many unknowns will be revealed. How the plant and the contractor handle these unknowns can be the determining factor for managing the risk of ready-mix concrete delivery disruptions.

c) Placement Size: Large placements require uninterrupted supply of concrete in order to avoid unplanned construction joints. To achieve the required continuity of delivery, plant and site must communicate in real time. A large job may tie up a considerable number of trucks and thus a plant’s capacity.

d) Delivery Cycle and Location: Since concrete should typically be placed no longer than ninety minutes after addition of water, travel from ready-mix concrete plant to a site should not take much more than half an hour or so. A plant’s operating radius therefore tends to be limited based on the nature and condition of haul roads.

e) Accuracy in Order Quantity: Accuracy in order quantity is important because contractors tend to order a little less than what they actually expect to need and count on being able to get an extra truck on short notice should one be needed in the process of finishing a placement.

FMECA

In this study, the researchers have studied the immediate supply chain partners of a ready-mix concrete plant. The network model included two suppliers (S1-
cement, S2-chemicals), the plant, the delivery channels (including trucks) and final customers (multiple job sites) that dictate the demand structure. This is a typical case of just in time supply chain. The process starts when a customer’s order arrives at plant with the following attributes: customer name, company name, and contact phone number. Delivery address, date of delivery, either “will call” or “active order”, total yardage of the day (if not known an estimate), number of loads and load sizes, concrete specifications, and payment method.

In order to identify the major risks inherent to this supply chain, a series of interviews were conducted within the company (ready-mix plant). Ten people directly involved in the fabrication, delivery, and purchasing of critical materials participated in this research. Based on these interviews, a FMECA table was built (tables 1 and 2). FMECA is a well-documented method used to quantify and analyze safety concerns for a product or a process. As an input, it takes plans, probabilities and frequencies based on historical knowledge. As an output, FMECA provides a list of most critical risks as well as some target mitigation actions. Each entity of the supply chain network that may be exposed to different risks is listed on column 1 of Table 1. For each of these entities, the failure modes have been defined (column 2, Table 1). This information was gathered from expert interviews and brainstorming sessions. Once the potential failures are identified, the potential effects have been listed (column 3, Table 1). The effect of each probable fault on the overall system performance is examined in a systematic way and each failure mode is associated with a severity index (S) (column 4, Table 1). The severity index is used to classify the relative importance of the effects due to a failure mode.

Engineering judgments and historical records stored in databases were used to determine the severity index. The research team then listed the potential causes of the failure modes (column 1, Table 2) and evaluated the likelihood/probability of their occurrences (column 2, Table 2) using information obtained from past statistical data sources about the process, monthly reports on traffic monitoring, and daily operator performance evaluation results. Occurrence rate is a numerical subjective estimate of the likelihood that the cause, if it occurs, will produce the failure mode and its particular effect. Finally, failure detection and possible correction actions have been determined to prevent the cause and occurrence for the potential fault scenarios (columns 3 and 4, Table 2). The ready-mix plant already performs some of the process control activities listed in column 3 (Table 2). They can be used to identify and detect the failures or to prevent the cause of the failure modes from occurring, while some of them represent the proposed control processes which can be put in place. In column 4 (Table 2), the possible control and detection process is assessed to determine how well it is expected to detect or control the failure modes or the probability that the proposed process controls will detect a potential cause of failure or a process weakness. Higher rankings represents remoter likelihood that risk factor can be controlled. It is common practice to assign a number from a 1–10 scale for the severity (S), probability of occurrence (O), and detection difficulty (D). The higher the assigned number is the higher the importance of the failure mode is with respect to the related index. Even though a great amount of historical data and information is available, decision makers still need to make judgments to score these parameters. This process is somewhat subjective and relies on the interviewees’ experience and
their confidence on the information available during the interview process.

Twelve common supply chain disruptions have been determined and classified into four main groups. A criticality analysis is further performed to enable a priority ranking among the identified risks. This ranking is done using the S, O and D values and referred to as the risk priority number (RPN).

\[ RPN = S_i \times O_i \times D_i \]

For a given failure mode \( i \), the higher the RPN\(_i\), the more critical the failure is. Thus, RPN\(_i\) draws the system analyst’s or supply chain manager’s attention towards the most critical activities to eliminate or to reduce potential failure modes.

The FMECA table provides practitioners with valuable information. First, the Risk Priority Numbers in column 5 (table 2) reveal the following most critical failure modes for each one of the entities studied. For example, poor quality of the purchased raw materials from supplier has the highest RPN (RPN = 120) for the supplier entity. Related to the Ready-Mix Concrete Plant entity, technical problems and breakdown of the machinery has the highest RPN (RPN = 168). Technical problems with delivery trucks (RPN=224) and human errors (RPN=128) are critical for the delivery channel entity. Finally, fluctuations in customer demand (RPN = 448) and loss of market share (RPN = 378) are the highest values for the customer entity. Second, analyzing column 3 (table 1), the common potential effects of the failure modes was observed and expressed either in terms of delay or in terms of cost (or profit). Finally, the columns 1 and 3 (table 2) provide practitioners valuable information on the possible actions to put in place. For instance, in the case of the failure mode due to the machine breakdowns, insufficient maintenance is shown as a potential cause and periodic maintenance is proposed as a mitigation action.

Table 1. A failure Mode Effects and Criticality Analysis (FMECA)

<table>
<thead>
<tr>
<th>Entity</th>
<th>Potential failure / error mode</th>
<th>Potential effect(s) of failures</th>
<th>Severity (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suppliers</td>
<td>1-Poor quality in purchased raw materials from supplier</td>
<td>1-Quality problems in productions of ready mix concrete, loss of customers</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2-Raw materials scarcity</td>
<td>2-Delayed arrival of raw materials at the plant</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3-Loosing the competitive advantage of supplier</td>
<td>3-inefficient capacity utilization, Inflexibility in supply</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential cause(s) of failures</td>
<td>Occurrence (O)</td>
<td>Detection/current controls</td>
<td>Detection score (D)</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------</td>
<td>---------------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Low suppliers reliability</td>
<td>3</td>
<td>1-Quality control, inspection</td>
<td>8</td>
</tr>
<tr>
<td>2-Orders planning and scheduling errors</td>
<td>1</td>
<td>2- Forecasting, MRP, Communication and information sharing with suppliers</td>
<td>3</td>
</tr>
<tr>
<td>3-Monopoly, contractual agreements</td>
<td>1</td>
<td>3-Alternative suppliers</td>
<td>4</td>
</tr>
<tr>
<td>Operator, dispatcher or driver absence, strike</td>
<td>1</td>
<td>1-Motivation, good relations with Labor union</td>
<td>7</td>
</tr>
<tr>
<td>2-Insufficient</td>
<td>3</td>
<td>2-Periodic maintenance</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 2. A failure Mode, Effects and Criticality Analysis (FMECA) – continued
<table>
<thead>
<tr>
<th>Maintenance, low technical reliability,loss of motivation, lack of experience or training, working conditions</th>
<th>2</th>
<th>3-Training, ergonomic analysis of working conditions, rewards system, social activities</th>
<th>4</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Stress on crew, lack of training, long working hours</td>
<td>2</td>
<td>1-Personnel training, shorter working intervals</td>
<td>8</td>
<td>128</td>
</tr>
<tr>
<td>2-No scheduled maintenance</td>
<td>4</td>
<td>2-Periodic maintenance</td>
<td>7</td>
<td>224</td>
</tr>
<tr>
<td>3- Traffic and environmental issues</td>
<td>2</td>
<td>3-Visibility, scheduling</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>1-Inefficient or missing CRM (customer relation management)</td>
<td>7</td>
<td>1-Demand forecasting, flexible production system</td>
<td>8</td>
<td>448</td>
</tr>
<tr>
<td>2-High competition in the marketplace</td>
<td>6</td>
<td>2-inventory management and control</td>
<td>7</td>
<td>378</td>
</tr>
<tr>
<td>3- Behaviors of the competitors</td>
<td>3</td>
<td>3-Marketing strategies</td>
<td>7</td>
<td>126</td>
</tr>
</tbody>
</table>

The major potential failure modes that act as supply chain risk factors have been included in the discrete event simulation model (i.e. the quality problems arising from the purchased raw materials from suppliers, technical problems and breakdown of the machinery at the Ready-Mix Concrete plant, technical problems with delivery trucks and fluctuations in customers demand). When any concrete order is being processed and delivered, if any failure is observed, the ready-mix plant can first try to solve the problem caused by this failure. This adds up additional time for analysis, but the company will save money and time in the long run.

**SIMULATION EXPERIMENT – DATA INPUT AND SUMMARY RESULTS**

As explained above, the focus of this study is not to describe the details of the discrete event model. Instead, the authors believe that the description of the process related to the analysis of input data is an interesting contribution of the study due to the amount and complexity of the data received from the ready-mix plant. The data contains eight months full orders details and delivery trucks time table include the following:

Order details: Order date (ticket date), order number (ticket number), truck
number, order time (ticket time), order delivery date, order delivery time.
Trucks time table details: truck begin loading time, truck leaving plant time,
trucks arriving at delivery site, begin pouring ready-mix concrete time, finish
pouring concrete time, truck arriving at delivery site time, truck leaving plant
time, ready-mix concrete quantity (squared yards) per order, number of delivery
trucks per order, arriving at site early/late (20/30 min).

According to the number of orders per month, two main seasons for ready-
mix concrete business have been identified, a high season with a peak in July, and a
low season mainly in December (the lowest number of orders per month).
Minitab16 statistical software was used to analyze the collected data set, to
identify the proper Distribution for each set of collected data. This section discusses
the results of the quantitative analysis using the High Season data (month of July’s
orders) when disruptions are most likely to occur. In the month of July there are six
sets of data as follows:
1- Ready-mix concrete delivery trucks travel time.
2- The time between begin loading the delivery trucks and leaving the plant.
3- The waiting time at the delivery site before begins pouring the ready-mix
   concrete.
4- Pouring the ready-mix concrete time.
5- Order processing time.
6- Quantity of the ready-mix concrete per order (square yards).

For each data set, fourteen different type of distribution in Mini tab software
had been used to identify the best distribution fit. The fourteen distributions are 1)
Normal, 2) Lognormal, 3) Parameters Lognormal, 4) Small Extreme Value, 5)
Gamma, 6) 3-Parameters Gamma, 7) Exponential, 8) 2-Parameters Exponential, 9)
Weibull, 10) 3-Parameters Weibull, 11) Largest Extreme Value, 12) Logistic, 13)
Loglogistic, and 14) 3-Parameters Loglogistic.
These fourteen distributions grouped in four sets as follows:
1. First set: Normal, Lognormal, 3-Parameters Lognormal and Small Extreme
   Value Distributions.
2. Second set: Gamma, 3-Parameters Gamma, Exponential and 2-Parameters
   Exponential Distributions.
3. Third set: Weibull, 3-Parameters Weibull, Largest Extreme Value and
   Logistic Distributions.

Figure 1 displays an example of the analysis of travel times in the month of
July. The researchers studied and identified the best distribution type for each set of
data. This process was time consuming but added credibility to the outputs provided
by the discrete event simulation.
Results for High Season Simulation

Table 3 compares the results of two scenarios against the base scenario (ideal case).

<table>
<thead>
<tr>
<th>Risk Scenarios</th>
<th>FMECA Outcome (RPNs)</th>
<th>Simulation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of operator / Dispatcher / Technical problems / breakdown of the Machinery / Human errors.</td>
<td>168</td>
<td>Number of orders handled on the second stage simulation scenario decreased by 31 orders comparing with base scenario</td>
</tr>
<tr>
<td>Human errors / Technical problems with delivery trucks / Traffic and Highway problems</td>
<td>224</td>
<td>Orders handled on the third stage simulation scenario had been decreased by 62 orders comparing with the second scenario and by 93 orders comparing with the base scenario.</td>
</tr>
</tbody>
</table>

The impact of supply risks on the number of orders completed in one month is clear. Supply chain vulnerabilities affect the level of service and may impact the ready-mix supplier profitability and market share due to the low performance in the high season.
CONCLUSIONS AND RECOMMENDATIONS

In this paper, we presented a failure mode effective and criticality analysis (FMECA) methodology combined with simulation modeling approach for risk management of Just-in-Time supply chains.

FMECA and discrete event simulation can be used to model the dynamic nature of the Just-in-Time supply chain network. They provide a thorough understanding of the control logic of the network structure, and can assist in the evaluation of various operational

In real industrial environments, the sources of uncertainties are numerous and in order to get reliable results we need to have reliable estimation of these uncertainties. For instance, a variation in inter-arrival times of the customer demand, operation times, supplier selection decisions, inventory levels, and machinery and delivery failure rates can lead to different results and have different effects. Besides, the risks and their impact vary a lot according to the failure mode category. Therefore, this methodology helps practitioners find the optimal levels of all capacities of the supply chain entities, which cover the ever-changing operation conditions.

Some alternative scenarios are recommended for the ready-mix concrete plant to achieve the desired balance between having more than enough resources and avoiding the risk and disruptions in their just-in-time supply chain: 1) ready-mix concrete plants could expand its delivery capacity by using third-party trucks which may or may not be within its control; 2) ready-mix concrete plants in order to level its load, they should vary its unit price of ready-mix concrete based on the time and day of the week at which concrete is to be delivered, and 3) ready-mix concrete plants should use their excess resources to make the ready concrete construction blocks for commercial use.

REFERENCES


