Using FMEA to address lead-time variability: A tutorial

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Abstract
Consistent and reliable supply chain delivery times are a key source of competitive advantage. This tutorial describes how to use the Failure Mode and Effects Analysis (FMEA) technique to diagnose the risks and address the causes of delivery time variability.

Keywords*: supply chain, lead-time, Failure Mode and Effect Analysis (FMEA), variability*

Introduction

Numerous researchers report that the time dimension to logistics is a strategic issue with important links to competitive advantage (see Jayaram, Vickery and Droge, 2000 for a discussion of this issue). Allied with this is the importance of consistent, on-time delivery (see for example Trent and Monczka, 1999; Simatupang and Sridharan, 2002; Skjoett-Larsen, 2000). This means that although minimising the order to fulfilment lead-time is critical to competitive advantage (Stalk and Hout, 1988), the reliability or consistency of the lead-time should be viewed, to a point, as equal or indeed more important (Christopher, 2005).

Defining lead-time variability

A review of the literature reveals there is a lack of consistency over which term to use when describing lead-time variability, with alternative terms including:

- order fill rate (what proportion of orders are completely filled within the stated lead-time) (Christopher, 1998)
- delivery time variance (Cooper, 1984)
- order cycle time consistency (Emerson et al, 1996)
- variance of flow time (Grout, 1998)

- reliability of delivery time (Jayaram et al, 2000)
- In Full On Time (Livingstone, 1992)
- punctuality of delivery (Salvador et al, 2001)
- On Time In Full, OTIF, where: "this measures the performance of the business against fulfilling a complete customer order (In Full) on the desired date (On Time)" (Sehgal, Sahay and Goyal, 2006)
- Perfect order, where: "the perfect order rate is the percentage of orders that precisely meet customer expectations" (Novack and Thomas, 2004)

For the purpose of this paper the term 'lead-time variability' is employed due to its fit with a quality perspective on the topic and the fact that the work addresses lead-time variation in general, not just in the delivery of products. Specifically, the term 'lead-time variability' is taken as meaning:

The failure to fulfil an agreed customer need at the specified time.

The implication of this definition is that performance is measured relative to a fulfilment time specified by the customer. It also implies that the customer's need must be fulfilled in full.

Failure Mode and Effect Analysis (FMEA)

FMEA is a technique generally associated with quality management. One of the objectives of quality systems is the reduction in process variability (Salvador, Forza, Rungtusanatham and Choi, 2001) and: "Total Quality Management (TQM) has been widely accepted as the ways and means for maintaining supply chain quality" (Bandyopadhyay and Spague, 2003). Therefore taking fulfilment time variability as a supply chain quality issue points to the applicability of employing quality management techniques as a means of addressing this issue.

Palady (1998) identifies FMEA as one of the most effective techniques for predicting problems and identifying the most cost effective solutions for preventing these problems. FMEA has broad generalisability and: 'could be used for almost any type of improvement project' (Slack, Chambers, Harland, Harrison and Johnston, 1995). Although originally intended for use in product design development (Ben-Daya and Raouf, 1996) FMEA is also

applicable to existing processes (McDermott, Mikulak and Beauregard, 1996). This means that lead-time time variability can be viewed as a process variability problem that can be addressed by using FMEA.

FMEA Explained

FMEA seeks to identify the ways that a process can fail, i.e. its failure modes, and the effect of these failure modes on the performance metric under examination. Conventional applications of FMEA focus on product quality so they consider the effect of each failure mode on product quality. In a supply chain context a failure mode could affect not just product quality but other aspects of performance as well. This includes cost, average lead-time, inventory levels and shrinkage as well as lead-time variability. It is therefore necessary to clarify the effect statement to focus only on the specific issue within the scope of the project. In order to provide this focus the effect statement used when addressing lead-time variability becomes, 'Potential effect(s) of failure on on-time fulfilment'.

A scoring system is used to assess which failure modes present the greatest risk to effective performance. This scoring system comprises the following three criteria:

1. Severity - The consequence of the failure should it occur.
2. Occurrence - The probability or frequency of failure occurring.
3. Detectability - The probability of the failure being detected before the impact of the effect is realised.

Each criterion is scored against a scale and the three scores multiplied to give the Risk Priority Number, RPN. The role of the RPN is to allow failure modes to be ranked. Therefore the specific values assigned against each criterion during scoring are not critical as the purpose of the exercise is to determine relative magnitude, i.e. which failure modes present the most risk relative to the others. The key to success is therefore to ensure that scoring is consistent. To assist scoring consistency scoring guides are necessary. These are discussed later.

Undertaking an FMEA

In a supply chain context, FMEA should be undertaken by a team of stakeholders from across the process under examination. Every effort should be made to engage these stakeholders at each stage of the activity to ensure (i) their expertise is harnessed, (ii) they understand and trust the process being followed and (iii) they commit to implement the actions required to improve fulfilment time performance.

A FMEA exercise follows a sequence of steps:

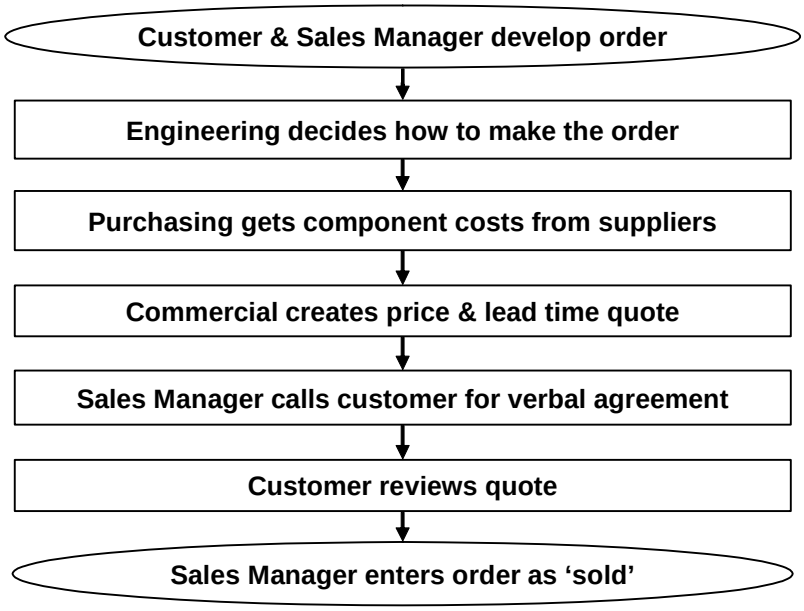
1. Map the process
2. Measure the process
3. Identify the possible failure modes
4. Score the failure modes
5. Identify causes of the highest scoring failure modes
6. Identify possible solutions to reduce risk
7. Plan and implement solutions

These points are discussed in detail below.

Step 1: Map the Process

Mapping a process helps a team understand the current sequence of operations. Creating the process map involves following something, such as a product or an order, through all the activities that lead up to its delivery to a customer and writing down these steps in a flow chart. An example process map for an ordering process is shown below.

Figure 1: Process map of an ordering process

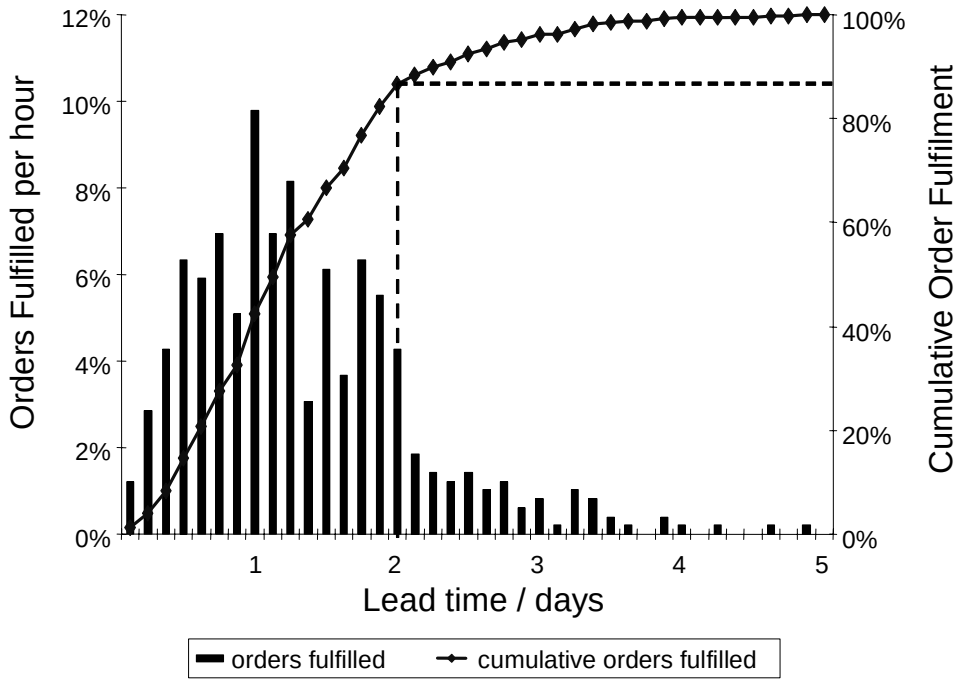


A good process map is one that easily communicates the sequence of events undertaken.

Step 2: Measure the process

In order to understand the performance of the process it is necessary to gather data on the fulfilment time at the customer. The data must be a representative sample of all deliveries and the sample size needs to be large enough to give confidence that it accurately reflects overall performance. Figure 2 below shows the lead-time data for a sample of 490 orders that were processed through the ordering process shown in Figure 1. This graph shows the time taken to fulfil each order and also the cumulative profile for fulfilling all the orders.

Figure 2: A graph showing order fulfilment lead-time performance



In this example the target for fulfilling orders is two days. The data shows that average time to fulfil a quote is slightly over one day (nine hours, assuming an eight hour day), well within the target. However the data also reveals there is high variation in the lead-time, with 12% of orders falling outside the two day target. This demonstrates the need to undertake a FMEA exercise to diagnose and address the cause of this lead-time variation.

Step 3: Identify the possible failure modes

The simplest way to conduct the FMEA exercise is work as a team and brainstorm how each step in the process could go wrong. To facilitate this group exercise, write the name of each process step on a separate sheet of paper and stick them process horizontally along a wall. Taking each step in turn, brainstorm the ways each step could go wrong, i.e. the failure modes.

The brainstorming requires every person to have a pack of sticky notes and a marker pen. The rules of the brainstorming session are:

1. Start with the first step and move sequentially along the process, one step at a time.
2. Focus on each step for 1 minute.
3. When brainstorming, write each idea on a separate sticky note.
4. Do not talk to each other.
5. Aim for quantity of ideas over quality, e.g. each person should aim for more than 3 ideas per step. It is okay to duplicate ideas.

An example of what the result looks like is shown below.

Figure 3: An example of the results of a brainstorming session

Having brainstormed the possible failure modes, the results need to be grouped and organised. That is, duplicate ideas need to be stuck on top of each other and very similar ideas grouped under a common heading. At this point it is useful for the group to count the number of failure modes they have identified across the whole of the process and to stand back from their work and reflect on what they have uncovered so far. A first point is that it may seem surprising that any work is fulfilled on time given the opportunities for delay that are uncovered. A second point is to recall Murphy's Law – whatever can go wrong, will go wrong!

Step 4: Score the failure modes

The group is likely to have brainstormed many failure modes. The challenge is now to deploy Pareto's Principle and identify which failure modes are the vital few amongst the trivial many. To achieve this requires a scale by which each failure mode is evaluated. Table 1 shows a scoring guide. This uses a scale of 1 to 5 for the three criteria of severity, occurrence and detectability.

Table 1: A Scoring Guide for Evaluating Lead-time Variability

Score	Severity of Delay	Occurrence of Delay	Detectability of Delay
5	Many days late	Many times per day	No warning of delay
4	A day late	Daily	Little warning
3	Many hours late	Weekly	Some warning
2	About an hour late	Monthly	Significant warning
1	A few minutes late	Once in many months	Clear warning of delay

Where a failure mode has no effect on fulfilment time then it can be removed from the analysis at this stage.

The key to successful scoring is consistency so to begin with the group should work slowly in order to establish a common understanding of what each score means.

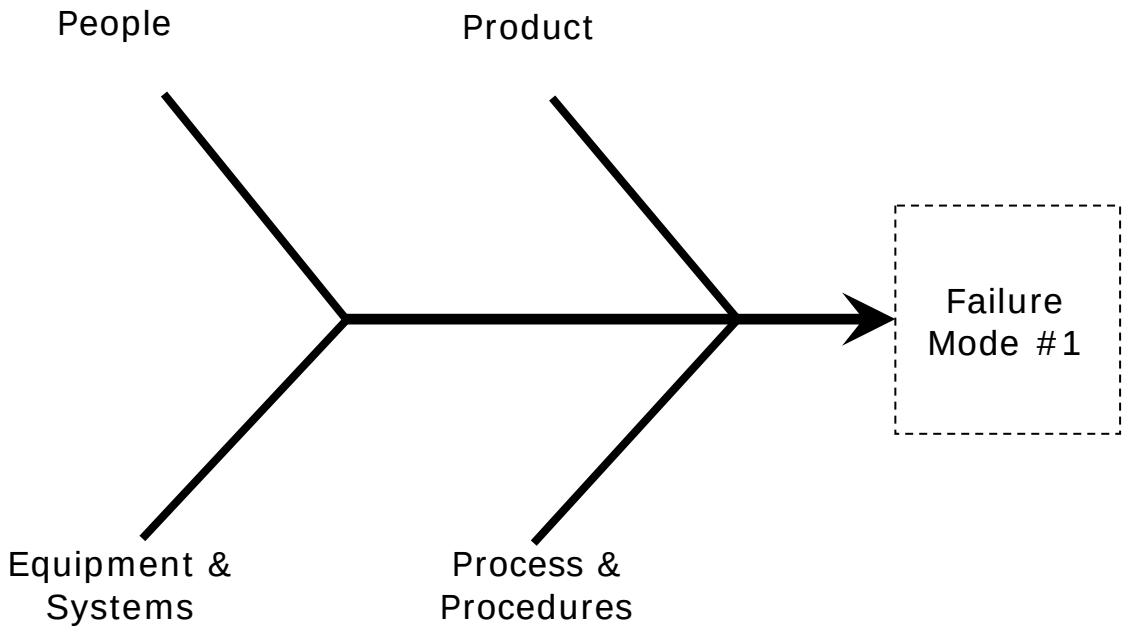
The scoring can be undertaken in one of two ways, either (1) quick or (2) thorough. The quick way to score is to record the score for each criteria in the separate corners of the sticky note. The fourth corner is where they are multiplied together into the Risk Priority Number, RPN.

The thorough way to score is for someone to record the team's discussion and the results of the analysis in a spreadsheet. This spreadsheet can be 'beamed' onto a screen through a data projector so the team can watch the FMEA worksheet being populated. An example of such a spreadsheet is shown in Appendix 1.
Having scored all of the failure modes it is now possible to identify the ones that pose the highest risk to fulfilment. It is these high risk failure modes that are a priority to be addressed.

Step 5: Identify causes of the highest scoring failure modes
The highest scoring failure modes need to be addressed first, followed by as many further failure modes as the team has time and resource to tackle. The analysis seeks to uncover the root causes of the failure mode by using the techniques of (i) Cause and Effect Analysis and (ii) 5 Why analysis.

Cause and effect analysis
Cause and effect analysis involves drawing a cause and effect diagram on a flip chart, like the one shown in Figure 4.

Figure 4: A Cause and Effect Diagram.



Use sticky notes and brainstorm the possible causes of variation in fulfilment time. Once again, follow the brainstorming rules introduce earlier. On this occasion spend one minute per heading and stick the sticky notes on the diagram.

Having completed the brainstorming, use voting to identify the most likely causes of the failure mode. Each person has two votes and they use these by making a tick / check mark (✓) against the two ideas they believe are the main cause of the failure mode. Having identified the most likely causes, undertake a 5 Why analysis.

5 Why analysis

This technique helps compile a list of the root causes of variation in fulfilment time. This involves four further cycles of (i) brainstorming possible causes followed by (ii) voting to identify which causes are believed to be the most important. The aim is to ask 'why'? five times in total.

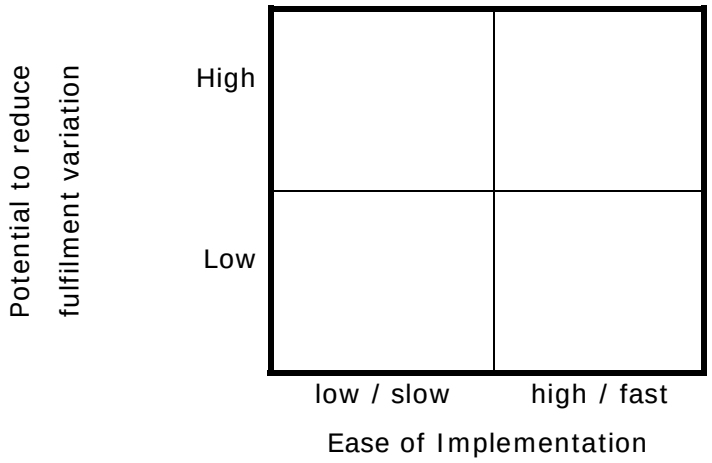
This exercise is complete when the team has a rich understanding of the range of causes that underlie the failure mode and a view on which causes are a priority to address. It is these causes that solutions should be developed to tackle.

Step 6: Identify possible solutions to reduce risk
Based on the analysis of the root causes of the failure modes, possible solutions can be identified using brainstorming techniques that will reduce the risk of delivery time variation. The solutions should reduce the risk of delivery time variation by targeting all three of the scoring criteria used in the FMEA exercise. This means that the aim of the brainstorming exercise is to develop proposals that:

1. Reduce severity.
2. Reduce occurrence.
3. Increase detectability.

Having developed these ideas, they can be assessed for usefulness by plotting them on a proposal categorisation grid, as shown below. This grid can be drawn on a sheet of flip chart paper and each idea written on a sticky note, which is positioned on the grid by group consensus.

Figure 5: Proposal categorisation grid



The purpose of plotting the ideas on this grid is to help the team trade-off implementation issues against benefits and in doing so identify which ideas are going to be the best ones to focus on.

Summarise the Solutions
Bring together the separate ideas into a list and group together those that fall into similar areas. The headings used in the cause and effect analysis, plus 'performance measurement' provide a useful, generic set of headings for categorising the solutions:

- People and organisational structure
- Process and procedures
- Equipment and systems
- Product
- Performance measures

An example of how to summarise and communicate proposed changes would be to draw process map of a new process. If there was a suggestion to change the way an operation is managed then an organisation chart would be helpful to communicate this.

Step 7: Plan and implement solutions
In order to reduce delivery time variability, the solutions developed as a result of the FMEA exercise need to be implemented and their effectiveness evaluated. A detailed description of the tasks involved in planning and implementing these solutions is outside the scope of this tutorial. That said, the basic tasks are to create a project plan that contains the steps necessary to implement those proposals that will reduce lead-time variability and bring the process under control.

To bring the process under control, it is necessary to ensure that the process improvements are delivered and that the process continues to work effectively in the long term. This means that the implementation plan must contain a mechanism to evaluate the effectiveness of the implementation. This is also a need to describe the plan to ensure the process will continue to work effectively in the long term.

In addition to these technical and rational steps there remains the ongoing need to keep the project team and a wider group of stakeholders informed and engaged.

Summary

Consistent, on-time fulfilment provides organisations with competitive advantage and helps supply chains operate effectively. Achieving this goal requires the opportunities for delivery time variability to be removed or their effects mitigated.

An effective way to undertake this work is through an FMEA exercise that targets delivery time variability and engages stakeholders from along the process. As this tutorial describes, this exercise is relatively straightforward and with careful facilitation can be interesting and engaging for those involved. Of significance to the organisation, this type of exercise can be undertaken as a project, one that can deliver effective solutions in a relatively short time frame.

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Appendix 1: A Sample FMEA Worksheet

Process Step	Potential Failure Mode(s)	Potential Effect(s) of Failure on Fulfilment Time	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Current Process Controls	Detectability	RPN	Suggested Action(s)	New Sev	New Occ	New Det	New RPN
Purchasing gets component costs from suppliers	Request emailed by purchasing but not received at supplier	Order fails to meet lead-time target	4	IT system off-line due to IT infrastructure failure	4	IT crash - no control	5	80	1. Improve resilience of IT system. 2. Provide alternative system to cover down time and cover IT redundancy	4	1	5	20
	Component costs not supplied within processing time	Order fails to meet lead-time target	4	- Lack of labour to meet increase in volume of orders to meet schedule. - Labour balance not aligned with peaks and troughs in orders	4	1.Shift management 2.Visibility of future demand levels	4	64	1. Reconfigure shift patterns to match demand 2. Focus attention on critical path issues 3. Improve demand forecasting	4	2	2	16
	Order delayed in purchasing	Order fails to meet lead-time target	4	Purchasing clerk out of office, e.g. off sick or on vacation	3	none	5	60	1. Improve order tracking so critical path delays are flagged 2. Staff meetings to communicate planned absence and phone in procedure on un-planned absence. Reallocate critical path work	4	3	1	12