

# **Applying Selected Quality Management Techniques to Diagnose Delivery Time Variability**

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## **Abstract**

**Purpose:** This research sought to identify and apply techniques that can be used in a supply chain context to diagnose the causes of variability in delivery lead time.

**Methodology / Approach:** A literature review was conducted and a number of quality management, QM, techniques were selected as candidates for diagnosing delivery time variability. A case study of the application of these techniques is provided on the UK based defence supply chain that supported British operations in the Iraq war of 2003.

**Findings:** Candidate QM techniques for diagnosing delivery time variability were identified, namely: Process Chart; Histogram; Failure Mode and Effect Analysis and; Cause and Effect Analysis. These techniques were successful in enabling the diagnosis of the causes of delivery time variability in the context of the case study investigated.

**Practical Implications:** The work illustrates how QM techniques can be employed to address issues with supply chains, not least with regard to the important problem of variability in delivery lead time. In practice, this highlights benefits that result to practitioners in order to improve the performance of operations in a dynamic setting, such as the defence supply chain studied here.

**Originality/value:** This work has value in presenting the findings of an in-depth case study on the application of QM techniques in a multi-echelon supply chain setting. It is also original in employing the FMEA technique together with an end-customer perspective to assess the effect of failure modes in operations across a supply chain. FMEA also provided the means to examine supply chain risk, thus providing a research instrument for deploying risk as a lens. The application of QM techniques in this novel setting provides support for their application beyond the conventional setting of internal operations.

**Keywords:** Lead-time; Variability; Diagnosis; FMEA; Quality Management; defence supply chain.

**Paper Category:** Case Study.

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## Introduction

Numerous researchers report that the time dimension to logistics is a strategic issue with important links to competitive advantage (see Jayaram et al, 2000 for a discussion of this issue). A key element in the strategic role of time is the importance of consistent, on-time delivery (see for example Trent et al, 1999; Simatupang et al, 2002; Skjoett-Larsen, 2000) with Arvis et al (2010) commenting (on trade logistics performance) that, "The reliability of the supply chain is the most important aspect of logistics performance." That is, although the order to delivery lead-time is critical in respect to competitive advantage, the reliability or consistency of the lead-time can be viewed, to a point, as equally or indeed more important (Christopher, 2010). The complication however is that whilst often raised as an issue, little advice is offered in the literature on methods for diagnosing the causes of variability in delivery time. In order to address this gap in knowledge, this paper presents the findings from an investigation into the methods for diagnosing delivery time variability and a case study of their application. The specific aims of this investigation were to:

1. Select quality management techniques that could be used to diagnose delivery time variability.
2. Test the applicability of the selected techniques through their application to UK based facilities in the defence supply chain during wartime operations.
3. Critique the use of the selected quality management techniques and draw conclusions on their validity in diagnosing delivery time variability.

The approach employed to achieve these aims is described in the section on methodology, below.

## Methodology

Supply chain management and quality management are well researched topics so it was appropriate to undertake a literature review, in order to identify the state of the art in these particular fields (Gill et al, 1991). Working within the positivistic paradigm (Hussey et al, 1997) a review of the literature was undertaken to provide a base on which to construct hypotheses. These hypotheses were tested for association against empirical evidence using data collected from observation and experience.

Despite the availability of literature on supply chain management and quality management there is a general lack of prior work on operationalising supply chain quality management, hence the use of a case study to provide empirical evidence was particularly appropriate (Eisenhardt, 1989). In this instance the opportunity to exploit a rare and extreme circumstance warranted the focus on a single case study (Eisenhardt and Graebner, 2007), with acknowledgement given to the limitation to the generalisability of findings that results from this method. The approach used to conduct the case study was consistent with the five stage research process model proposed by Stuart et al (2002), and heeded advice on good practice in undertaking case study research from Voss et al (2002) and Yin (2003).

The data gathering exercise consisted of an investigation of the four locations that constitute the Royal Air Force, RAF, element of the United Kingdom, UK, based defence supply chain during Operation TELEC, British military operations in Iraq relating to the Iraq War, 2003. Data on operational performance was gathered from archive records held electronically in a logistical information system. This data consisted of records of orders showing the date of creation of an order and the date the order was received at its destination. Data on the problems that faced the Operational supply chain was obtained through interviews of operational and managerial staff in each of the four sites along the supply chain. The people selected for interview were those with a firsthand understanding of operational tasks, for example through their daily work. Quantitative and qualitative data gathered through on-site interview was recorded in a structured way on worksheets. These worksheets were the standard templates used when undertaking Failure Modes and Effects Analysis, FMEA, a technique that is described below.

The combination of multiple sources of data, for example quantitative results from an information system and qualitative results from interviews, was undertaken to allow these independent sources to be triangulated. This method allows a balance to be drawn between the rich but fallible nature of interviews and the objective but detached nature of a numerical data set.

## Literature Review

This literature review begins by considering the broad nature of supply chain management before focussing on the role of quality management in a supply chain context and the nature of delivery time variability. Against this background, the applicability and selection of appropriate quality management tools is discussed.

### Considering Delivery Time Variability in a Supply Chain Context

Numerous researchers report a link between the performance of an organisation's supply chain and its effectiveness in achieving strategic aims (Harrison et al, 2010; Drucker, 1998; Gattorna, 1998; Cooper et al, 1997). The discipline of supply chain management has been developed in order to harness this link, with supply chain management being the control of relationships between customer and supplier, both up and down stream, to deliver superior customer value in the market place at less cost to the supply chain as a whole (Christopher, 2010). Consequently, the management of the supply chain requires cross-functional involvement (Lambert et al, 2008).

Kuei et al (2008) note that, "The importance of quality to a supply chain's long-term success is well known", citing a range of authors, and make the case for "supply chain quality management," and the need for a, "structured quality approach" to be adopted, which as they describe, "involves measuring, analyzing and continually improving products, services and process". Picking up on this theme, several performance measures have been used to study the performance of supply chains (Sinha et al, 1998), not least the ability to satisfy customer needs in terms of cost; quality, and; time. More broadly, there are important, systemic links between these criteria that means they need to be managed in a holistic manner, a point discussed in depth by Chow et al (2008). However given the relative importance to customers of a defence supply chain of receiving the items they ordered on-time, the focus in the work presented in this paper is time and in particular on-time delivery.

A review of the literature on this subject revealed that there is a lack of consistency over which term to use when describing this phenomenon, with alternative terms including:

- "order fill rate." (what proportion of orders are completely filled within the stated lead time.) (Christopher, 2010)
- "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)
- "Delivery reliability" ("the ability of SC systems to meet promised delivery dependently, consistently and accurately") (Kuei and Madu, 2001)
- "punctuality of delivery." (Salvador et al, 2001)

Noting the broad overlap between these terms, and aligning with the purpose of this paper, the term 'delivery time variability' is employed due to its fit with the quality perspective taken here to this topic, a matter that is discussed below.

### **Understanding Supply Chain Delivery Time Variability**

The issue with diagnosing delivery time variability is that it sits in the overlap between quality and time. That is, quality means conformance to requirements (Crosby, 1979) and on-time delivery is conformance to a delivery time requirement. One of the objectives of quality systems is the reduction in process variability (Salvador et al, 2001) so viewing delivery time variability as a supply chain quality issue points to the applicability of employing quality management techniques as a means of addressing this issue. This position has support in the literature, where it is recognised that process improvements directly affect supply chain time performance (Jayaram, et al, 2000), that, "total quality management (TQM) has been widely accepted as the ways and means for maintaining supply chain quality." (Bandyopadhyay et al, 2003), six sigma methodologies, including quality management tools, can be viewed as having applicability to supply chain improvement (Knowles et al, 2005), and the importance of quality in logistics services deserves emphasis as it can positively affect business performance (Kersten and Koch, 2010).

### **Selecting Appropriate Quality Management Techniques**

Smart et al (1996) propose a generic approach to process improvement based on their field research of twenty organisations. This general approach features five phases:

- Develop Strategies.
- Identify key processes.
- Analyse existing processes.
- Redesign processes.
- Implement new processes.

The "Develop Strategy" phase is predetermined in this research due to the focus on delivery time variability. Also, the fifth phase of "implement new processes" is outside the scope of this work, which is limited to diagnosing the causes of delivery time variability and making proposals on supply chain process redesign. This leaves the steps of "Identify key processes" and "Analyse existing processes" as the phases where quality management techniques need to be selected in order to diagnose delivery time variability.

When selecting appropriate techniques, a number of authors cite the "Seven Tools of Quality" assembled by Ishikawa as being valuable aids to improvements (Bicheno, 2000; Dale et al, 1998; Haksever, 1996). Amongst other factors, this selection of tools enabled and aligned with Ishikawa's belief that all workers should be involved in quality improvement (Anon, 2011).

Within the Seven Tools of Quality, three tools appear to have particular relevance for identifying processes and analysing delivery time variability. These tools are:

- Process chart / flow chart, to document the process of receiving and satisfying an order.

- Histogram, to document variation in delivery time performance.
- Cause and effect analysis (using the Ishikawa diagram), to help diagnose the root causes of delivery time variability.

There are a number of techniques and tools for documenting processes (Prasad et al, 1993) and process mapping is regularly used as a technique for documenting supply chains (Gregory et al, 1997). Prasad et al (1993) suggest three criteria that a process mapping technique should satisfy:

- Provide a simple mechanism towards easy understanding of current works, methods and practices.
- Encourage communication and discussion.
- Provide a visual means to seek inputs from those not originally involved in the documentation of the process.

Against these criteria the block flow diagram format appears to have considerable merit. The block flow diagram is the simplest type of flow chart (Maull et al, 1995), using a notation of boxes to represent activities and arrows to represent relationships between activities.

In addition to describing the supply chain process and measuring its performance there is a need to document the ways (modes) that the steps in the process can fail and effect delivery time. A technique for identifying the possible ways a process can fail is Failure Modes and Effects Analysis, FMEA. The literature suggests FMEA has broad applicability and that it, “could be used for almost any type of improvement project.” (Slack et al, 2010). 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. Although intended for use in product design development (Ben-Daya et al, 1996) FMEA is capable of yielding huge benefits through its application to existing processes (McDermott et al, 1996).

In a supply chain context FMEA has been used to diagnose the opportunities for stock loss (Beck, Chapman and Peacock, 2002), for risk assessment of the security of containers (Sameer and Verruso, 2008) and has been proposed as a technique for addressing supply chain vulnerability (Chapman et al, 2002; Christopher et al, 2004), a proposal taken up and applied by Oehmen et al (2009).

A summary of which quality management techniques have been selected and how these techniques link with Smart et al's (1996) generic approach to process improvement is shown below in Table 1.

General Approach Phase	Selected Quality Management Techniques
Identify key processes	<ul style="list-style-type: none"> <li>• Process chart / flow chart</li> <li>• Histogram</li> </ul>
Analyse existing processes	<ul style="list-style-type: none"> <li>• FMEA</li> <li>• Cause and effect analysis</li> </ul>

Table 1. Selected Quality Management Techniques for Diagnosing Delivery Time Variability.

Taken together this phased general approach and associated tools can be considered as the 'hard' side to quality management however the intention is to retain and enfold the 'soft' side to quality management, i.e. the associated management concepts and principles such as leadership, employee empowerment and culture (Fotopoulos and Psomas, 2009).

### ***Hypotheses.***

Our first aim in this research was to select quality management techniques that could be used to diagnose delivery time variability. Drawing together the results of the literature review leads to the proposition that supply chain delivery time variability can be diagnosed by employing quality management techniques, namely: Process Chart; Histogram; FMEA, and; Cause and Effect Analysis, within a supply chain context. This proposition is decomposed into a series of hypotheses, which are:

H1. The causes of delivery time variability can be diagnosed through employing selected quality management techniques.

In order to answer H1, the following series of sub hypotheses are proposed:

H1a. Process mapping can be used to document the activities involved in the supply chain wide process of receiving and satisfying an order.

H1b. Histograms can be used to document variability in delivery time performance.

H1c. FMEA can be used to identify the possible ways for the supply chain process to fail, i.e. its failure modes, and to rank those failures in order of criticality.

H1d. Root cause analysis can be used to help diagnose the root causes of delivery time variability.

H2. Delivery time variability in the service to end customers needs to be diagnosed through taking a supply chain perspective.

The construction of these hypotheses concludes the desk research. The validity of these hypotheses will be tested against empirical evidence collected during fieldwork. The fieldwork is described below, comprising the application of the proposed diagnostic method to the defence supply chain.

## Diagnosing Delivery Time Variability. A Case Study of a Defence Supply Chain

The context for this case study is that deployed military units take a calculated range of replacement and consumable spares to cover their expected needs. However it is not physically possible or effective for them to carry an entire inventory that would cover all eventualities so, “Any weapon system requires support (e.g. maintenance, spares, fuel) to function effectively for any period of time,” (O’Fearn et al, 2002) and it is necessary to resupply forces in theatre in line with their unfolding needs. The experience from other conflicts reveals that this cannot always be depended upon where, “procedures at national-level warehouses have caused tremendous hardships at forward-distribution points in-theatre and have damaged the combat readiness of units on the line,” and as a result, “Readiness in combat suffers, and nonmonetary costs are staggering. Second-order effects include a general loss of confidence in the supply system at the tactical level.” (Smith, 2007)

The delivery lead-time of inventory from UK stock holding points to the end customer in the frontline during Operation TELIC was measured against a set of targets. Included in these were lead time targets for delivery of spares to theatre, noted elsewhere as a key performance measure for an operational support system (Ghanmi, 2011). Post Operational reports identified were frequently not met (Ministry of Defence, 2003) with the conclusions drawn from this data that the supply chain that supported the Operational deployment was sub-optimal (Defence Logistics Organisation 2003) and that the situation must be improved in the future. This case study was undertaken in response to this need to identify what improvements to make, with the first step being to diagnose the causes of delivery time variability.

### ***Identifying Key Processes in the Defence Supply Chain***

The order to delivery cycle in military logistics is similar to that of its industrial counterparts, such as the cycle shown in Figure 1 below.

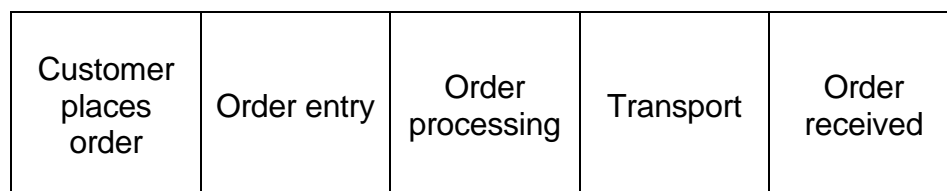


Figure 1. An Archetypal Order to Delivery Cycle (adapted from Christopher 1998)

In the Operational environment, the order cycle starts in theatre when the customer places an order via a deployable Inventory Management System (IMS) that has the ability to interrogate theatre stock holdings before searching the overall defence inventory system for required stock. Once the asset and its



location have been identified, the customer enters an order onto the Inventory Management System and requests the date by which it is to be delivered.

The items distributed through the supply chain come in all shapes and sizes, from individual specialised nuts and washers to aircraft engines. It is the general principle that all inventories can be demanded and delivered with the same velocity through the same lines of communication. Figure 2 shows a high-level process map of the activities involved in moving an order along the defence supply chain to satisfy customer requirements in theatre.

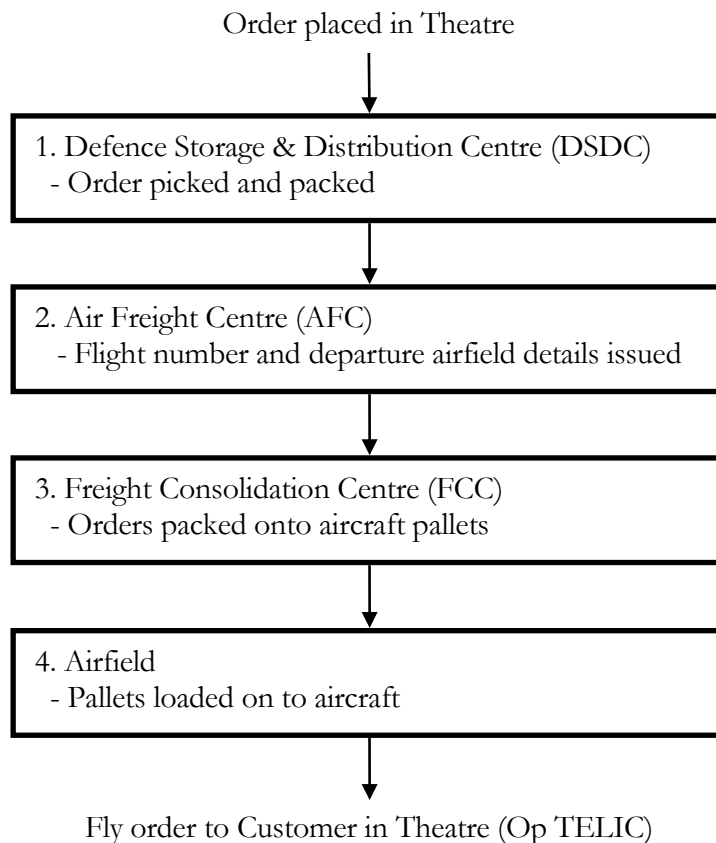


Figure 2. A Flowchart of the Defence Supply Chain for Operation TELIC

## Supply Chain Performance

The defence supply chain operates four service levels for delivery of orders to customers in theatre. Delivery time targets for these service levels are listed in Table II below.

	Delivery Time Target
SPC1 (Air)	48 hours
SPC2 (Air)	96 hours
SPC3 (Sea)	Less than 30 days
SPC4 (Sea)	Less than 39 days

Table II: Defence Supply Chain Metrics used in the Operational Environment (source: Ministry of Defence, 2002)

This case study considers SPC1 and SPC2, the two highest priority categories of orders from theatre, which require delivery by air. These categories are known to have relatively poor on-time delivery performance whilst the two other categories, which are delivered by sea, are known to have relatively good on-time delivery performance.

The data used to measure actual performance was gathered from a logistical information system archive. Delivery time records from 40 SPC1 orders and 523 SPC2 orders were collected and performance for each category was analysed in line with the method described previously.

### Review of SPC1 Order Delivery Time Performance

The delivery time for SPC1 Orders was plotted on a histogram, shown below as Figure 3.

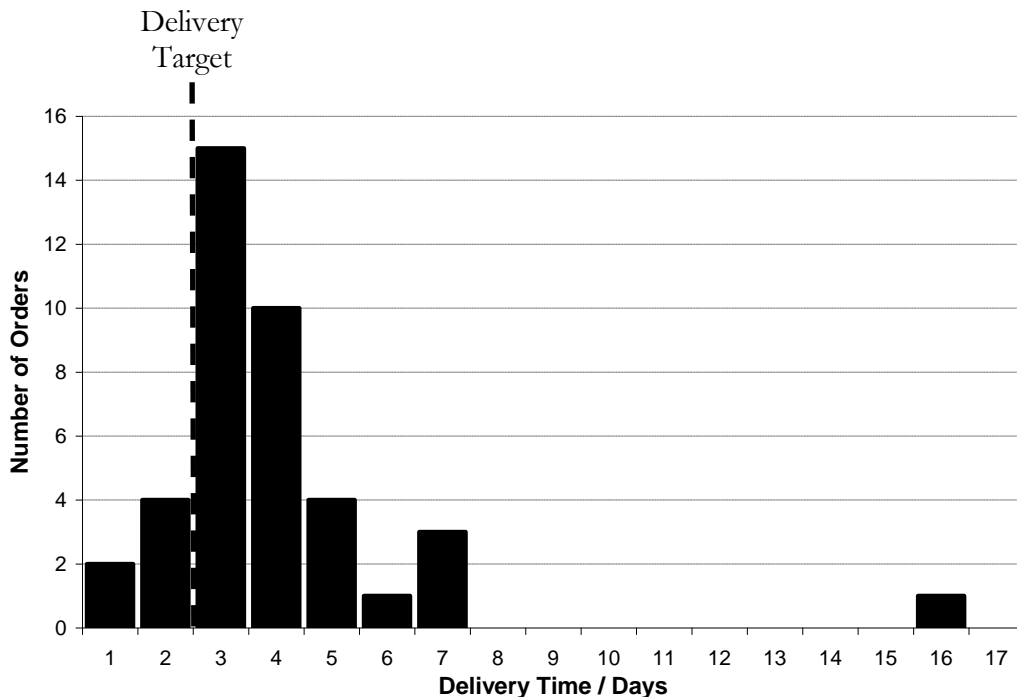


Figure 3. A Histogram Showing the Delivery Time Performance for SPC1 Orders

Figure 3 above shows the distribution of the delivery time performance for SPC1 orders. This distribution approximates to a Normal Distribution according to the chi-squared test (chi-squared statistic of 35.6). The distribution has a skewness value of 3.4 indicating an asymmetric tail extending toward the more positive values, due in particular to an outlying value at sixteen days. Table III below summarises the delivery time performance for SPC1 orders.

	SPC1 Orders
Number of orders	40
Average delivery time / days	4.0
Standard deviation / days	2.4
Orders within target delivery time	15.0%

Table III. A Summary of the Delivery Time Performance for SPC1 Orders

This performance data reveals that the average delivery time was four days. This average is double the target delivery time of two days. Another view of this level of performance is that six out of forty orders (fifteen percent) reached the customer within the delivery time target of two days.

### Review of SPC2 Order Delivery Time Performance

Figure 4 below shows a histogram of the delivery times for SPC2 orders.

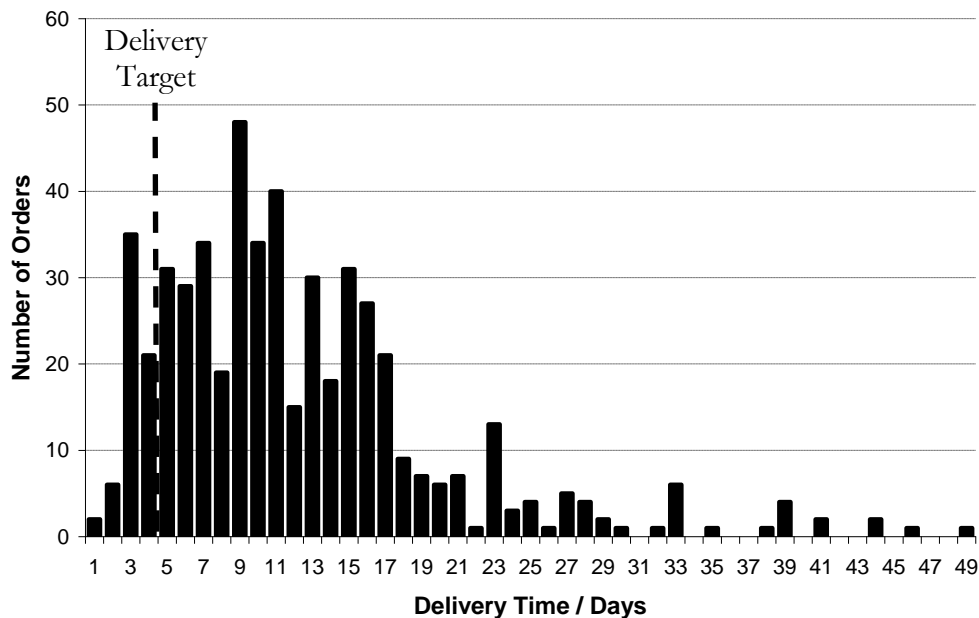


Figure 4. A Histogram Showing the Delivery Time Performance for SPC2 Orders

The distribution of delivery times for SPC2 orders approximates to a Gamma Distribution. A characteristic of this distribution is its skew, which is notable in Figure 4 as the asymmetric tail extending toward more positive values.

A summary of the delivery performance for SPC2 orders is shown below in Table IV.

	SPC2 Orders
Number of orders	523
Average delivery time / days	11.1
Standard deviation / days	7.8
Orders within target delivery time	18.2%

Table IV. A Summary of the Delivery Time Performance of the Defence Supply Chain

The delivery time target for SPC2 orders is four days from the time the customer placing the order to the customer receiving it. Eighteen percent of orders were delivered within the four day target with the average delivery time exceeding eleven days.

### ***Summary of Current Process Performance***

Examination of the delivery time findings for SPC1 and SPC2 orders shows that:

- The average level of performance for delivery does not achieve the delivery time target.
- Variation around the average is high.

In order to bring the performance of the supply chain under control it was necessary to diagnose the causes of delivery time variability.

### ***Analysis of the Causes of Delivery Time Variability***

Each of the four UK based sites along the defence supply chain shown in Figure 2 was visited. These visits were undertaken in order to conduct a first-hand examination of the steps in the order delivery process. This examination consisted of following the progression of an order through the process and interviewing supply chain managers and operations staff to identify the failure modes in the process that could lead to delays and introduce variability in delivery time. These findings were compiled into FMEA worksheets to record possible failure modes, effects of the failure modes, the causes of failure modes and suggested remedial actions. A sample worksheet from one of the sites examined is shown in Appendix 1.

## Findings

In total, 52 failure modes were identified across the four echelons of the supply chain located in the UK. The number of failure modes identified at each supply chain echelon is shown in Table V below.

Supply Chain Echelon	Number of Failure Modes Identified
Defence Storage & Distribution Centre	17
Air Freight Centre	11
Freight Consolidation Centre	16
Airfield	8
<b>Total</b>	<b>52</b>

Table V. Number of Failure Modes Identified in the FMEA Exercise at each Supply Chain Echelon.

The FMEA technique was used to prioritise the various failure modes and their associated effects and target the critical risks for action. This prioritisation involved scoring each risk to assess its: severity; probability of occurrence; and detectability. The scores against these three criteria are multiplied to determine the Risk Priority Number. In this exercise the three highest scoring risks for each echelon were identified and subjected to cause and effect analysis to determine their root causes. This exercise followed the conventions associated with cause and effect analysis, that is an Ishikawa diagram was used to capture the brainstormed ideas of a mixed group of people who conduct the operation under investigation.

The results of the risk assessment exercise were reviewed and the risks classified into three categories:

- Specific risks whose causes are linked to one particular site.
- Specific risks whose causes exist in isolation but at multiple sites.
- Shared risks whose causes span multiple sites.

Specific risks that occur at a particular site are ones caused by issues found in that one place. For example, only the airfield deals with aircraft and it was the only location affected by the late alteration of an aircraft load. In these cases local solutions will be needed to address these local causes.

There are a number of risks that exist at multiple sites but which have causes that are isolated from each other. These risks are independent manifestations of having to face the same challenges and are caused because the various sites share a number of common features. Where there is a risk associated with a particular cause then this risk can manifest itself at all points that share this cause. A useful feature of these risks is that the solution to address the problem at one site should be applicable to all the sites. Examples of these risks were:

- The flow planning of work through the facilities and its knock-on effect on manpower, which affected the DSDC, FCC and the Airfield.
- Storage, which had a particular effect on the FCC and the Airfield.

The third category of risk is the shared risks at multiple sites whose causes are common. These are risks that occur at various locations because of a shared problem. These shared risks were directly connected, such as:

- Delay at both the DSDC and AFC caused by the poor reliability of a shared IT system.
- The reprioritisation of orders after they had entered the supply chain affected the AFC, FCC and the Airfield.

These shared failure modes are represented in Figure 5 below.

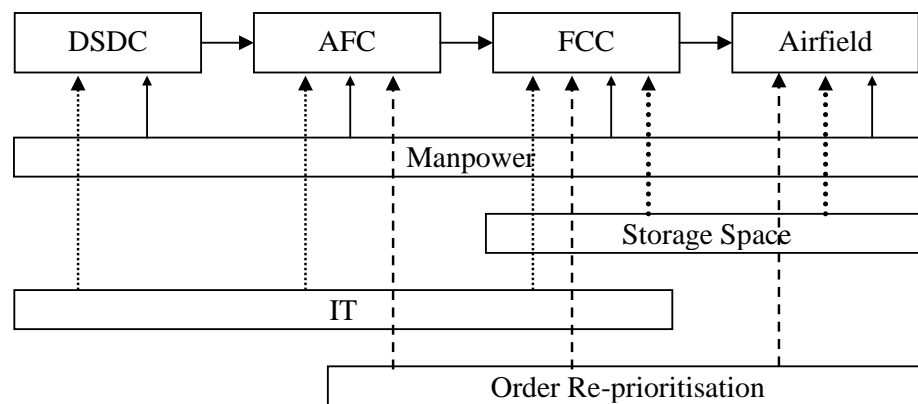


Figure 5. Shared Failure Modes Across the Operational Supply Chain

Examination of the shared risks along the supply chain found a small number of common causes lay at their heart. These common causes were identified as:

- Poor IT reliability.
- Manpower shortages caused by uncoordinated flow patterns, creating insurmountable peaks in activity.
- Changing the priority of the order during its progression through the Operational supply chain.

The impact of each of the three categories of risks is that they all contributed to the variability in delivery time to the end customer. By removing or reducing the causes of risks in the Operational supply chain, performance will become more regular and consistent and the variation in the delivery time will be reduced. This will have a positive effect on the customer's confidence in the capability of the supply chain to provide reliable service, which has several benefits including reducing the inventory that must be deployed to compensate for the current, variable supply chain performance.

## Discussion of Findings

The findings from the case study of a defence supply chain provide empirical evidence against which the hypotheses presented earlier in this paper can be tested. These findings are discussed below together with their limitations.

### **H1. The causes of delivery time variability can be diagnosed through employing selected quality management techniques.**

The sources of delivery time variability were investigated across four echelons of a defence supply chain using techniques normally associated with quality management. Taken together the selected techniques provided a structured way to approach the issue of delivery time variability, undertake the data gathering in the field, analyse the data and deriving suggestion for improving performance. As such the empirical evidence supports H1 although it is acknowledged that the generalisability of this finding has its limitations given the single case method employed. This point should be borne in mind when considering the contributions of particular techniques in helping to diagnose delivery time variability described below against the relevant sub-hypotheses.

### **H1a. Process mapping can be used to document the activities involved in the supply chain wide process of receiving and satisfying an order.**

The process mapping exercise undertaken to document the activities involved in the supply chain can be said to be effective in that it satisfies each of the three criteria suggested by Prasad and Strand. Therefore there is evidence to support sub-hypothesis H1a.

### **H1b. Histograms can be used to document variability in delivery time performance.**

Two histograms were constructed using the data collected on delivery times from (1) SPC1 orders and (2) SPC2 orders. These histograms illustrate characteristics of the delivery time performance by graphically displaying the distribution of delivery time data. They allowed people with a limited familiarity of statistics to understand the key relationship between the delivery time target and the spread of actual delivery times. The histograms proved effective in documenting the variability in delivery times, thereby helping to communicate and share understanding of current performance, providing evidence to support hypothesis H1b. It is acknowledged that the data presented represents a particular time period and while this was not intended to communicate a falsehood or biased view it is possible that were data available from other time periods this could exhibit different properties that would not necessarily support this sub-hypothesis.

### **H1c. FMEA can be used to identify the possible ways for the supply chain process to fail, i.e. its failure modes, and to rank those failures in order of criticality.**

The FMEA technique was used to review the supply chain in a systematic manner to identify and prioritise failure modes that could lead to delay. This application of FMEA to investigate the delivery time variability of a supply chain problem identified multiple failure modes. These failure modes were a mix of issues that were specific to a particular echelon of the supply chain and those

that were shared across the supply chain. The implication of this finding is that FMEA can be applied to the processes in a particular site, where it will identify failure modes that can be prioritised and addressed. However there were several benefits in diagnosing the performance of operations at a holistic, supply chain level. Having identified a failure mode it is necessary to consider the effects of failure. At a local level the severity of the effect that a failure mode has may appear minor. This judgement lacks an informed view of the consequence to a customer further down the supply chain. For example, the daily delays experienced at the Defence Storage and Distribution Centre (DSDC) caused by the IT system have the effect of frustrating the operations staff on that site but they are able to resort to a manual backup system which mitigates the severity of that failure mode. Viewed from the perspective of a serviceman on Operational duties this same delay may significantly impede his ability to function. The ability of FMEA to diagnose the supply chain from the perspective of the end customer and focus attention on the critical few risks provides evidence to support sub-hypothesis H1c. In considering this finding, it should also be recognised that this analysis includes a degree of subjectivity through requiring interpretation by the people involved. This introduces the risk that they incorrectly interpret a situation either by being misinformed or through applying bias, such as that stemming from a limited perspective. As a result, the findings become dependent on the people undertaking the analysis and are likely to vary when other people are involved, which may lead to findings that do not support sub-hypothesis H1c.

#### **H1d. Root cause analysis can be used to help diagnose the root causes of delivery time variability.**

The root cause analysis was focussed on the three risks at each site with the highest Risk Priority Number. This exercise proved effective in identifying root causes to these risks and provided an input to the development of recommendations to address these risks, thus providing evidence to support sub-hypothesis H1d. Similar to the caveats applied to the findings for sub-hypothesis H1c, in this case it is necessary to acknowledge that as the analysis draws on the contributions of the people involved and their ability to effectively diagnose root causes this will vary between groups of individuals. This means that such an analysis will not always be able to diagnose root causes of delivery time variability.

#### **H2. Delivery time variability in the service to end customers needs to be diagnosed through taking a supply chain perspective.**

The performance of the defence supply chain during Operation TELIC exhibited poor delivery time performance, not least high delivery time variability. This variability meant that frontline customers could not be sure whether their equipment would be ready for use at a given time, a finding consistent with reports on the challenges facing expeditionary forces in general (O'Fearn et al, 2002; Ghanmi, 2011) and to the experience of forces from other nations during the same conflict (Morales and Gehry, 2003; Smith, 2007).

Employing a supply chain perspective when undertaking diagnosis in the case study provided the ability to consider the performance of individual elements of the supply chain and their impact on the delivery time variability to the end



customer. As a result, the supply chain perspective can be associated with the ability to diagnose delivery time variability in the service to end customers. For example, where failure modes were shared across sites if the supply chain was viewed as a series of discrete operations then there would be a tendency to diagnose issues in isolation. A supply chain perspective provides the opportunity to identify the common causes of these shared failure modes and to seek shared solutions. The aim here is to retain consistency across the operations and to optimise performance at the supply chain level and not at the site level. These findings suggest that it is not just the case that delivery time variability in the service to end customers can be diagnosed through taking a supply chain perspective but that this diagnosis needs to be diagnosed through taking a supply chain perspective, thus providing evidence in support of hypothesis H2. As noted earlier however, while the case from which these findings are drawn proved to be a rich and engaging area of study, the confidence in the ability to generalise of these findings remains limited due to this being a single case.

### ***Implications for Theory***

A criticism of the conventional approach to the construction of an FMEA is that it does not include inputs from customers (Tan, 2003). In this application, the voice of the customer was sought by focusing from the start on the delivery time needs of the end customer and by working with 'internal customers' at each successive stage of the supply chain. In this way the standard approach of working with a team of people with direct knowledge of the products and processes concerned (Gilchrist, 1993) was enhanced through gaining inputs from a broad range of stakeholders. In doing so it appears that undertaking FMEA in a supply chain context overcomes concerns that inputs from customers are not included. Thus FMEA should be regarded as a performance improvement technique that aligns with the objectives of supply chain management.

There are several lenses through which supply chains and their performance can be viewed, a topical one of which is risk (see for example Christopher et al, 2004). The diagnosis of delivery time variability presented in this paper demonstrates that FMEA can be used as a means to examine supply chain risk, thus providing the research instrument for deploying risk as a lens. The implication of this finding is that the FMEA technique may have value as a research instrument in examining other risks that compromise supply chains and prevent delivery of the perfect order, i.e. those associated with on-time delivery; completeness of orders; and consistency over time.

### ***Implications for Practice***

This work has implications for the management of defence supply chains and possibly more broadly to other supply chains where on-time reliability remains an issue. With regard to defence supply chains, the continuation and growth of expeditionary operations by NATO and Allied forces where activities in theatre are served from distant permanent bases highlights a need to, "develop a robust system that can respond to the ever-changing military and political

environment” (Amouzegar et al, 2004). Such operations are known to suffer the disconnects observed by Smith (2007) and the work presented here operationalises the objective of bringing operational and tactical logistics back into alignment with their strategic intent through providing the means to resolve the direct issues causing delivery time variability. Not least this is achieved by engaging managerial and operational staff from across the supply chain to achieve an ‘end-to end’ view of the supply chain capable of meeting the needs of those at the front line. This aligns with the observation by Lambert et al (2005) that, “increasingly, one goal of managers is to implement cross-functional business processes and integrate them with other key members of the supply chain.” The contribution of firsthand knowledge provided the foundation from which a series of possible solutions were proposed for removing or mitigating the effects of the failure modes that were prioritised. In doing so, it raises the capability of the UK defence supply chain to achieve what similar organisations in other nations seek for their own forces, which taking the US Defense Logistics Agency as an example is to, “deliver warfighters the right item, in the right place, at the right time, for the right price, every time.” (Dail, 2007).

The implementation of these proposals provides the basis for a reliable service by eliminating or reducing process risk with the objective of reducing delivery time variability. This finding indicates that the tacit knowledge of how to resolve the problem of delivery time variability already existed within the supply chain. The managerial challenge remains concerning the so called ‘soft’ side to quality management (Fotopoulos and Psomas, 2009) on how to access this latent understanding and direct it to deliver a lasting improvement in performance.

The access to a defence supply chain during wartime operations provided an example of what Eisenherdt and Graebner (2007) might consider as an, “opportunity to exploit a rare and extreme circumstance”, where an opportunity exists to generalise the findings more broadly in a similar fashion to the point made by Morales and Gehry (2003) in their paper on the American experience of the same conflict, “Commercial supply chains may be able to draw a few lessons from our efforts to accommodate soldiers in the field.” For example, in a microeconomic quantitative description of logistics costs facing landlocked economies, Arvis et al (2007) describe the unpredictability of lead time using histograms to present data on (1) the distribution of dwell time of transit containers in Mombasa port and (2) distribution of transit time between Mombasa and Kampala, in a similar format to that shown in this paper. Their work goes on to consider the magnitude and sources of delays but is unable to go beyond broad categories of causes. It is proposed that working at a more detailed level and employing the additional techniques of FMEA and cause and effect analysis would enable a team working locally to identify specific causes of delivery time variability to a level where actionable solutions could be specified.

## Conclusions

Research was carried out to identify a method for diagnosing delivery time variability. Drawing together the results of a literature review led to the proposition, “supply chain delivery time variability can be diagnosed by employing selected quality management techniques, namely Process Chart; Histogram; FMEA, and; Cause and Effect Analysis, within a supply chain context.” Application of these techniques in the UK elements of the defence supply chain that supported frontline forces in the Iraq conflict in 2003 provided empirical evidence that supports this proposition, albeit with evidence from a single case.

## Recommendations

Whilst several quality management techniques have had prior application in a supply chain context, and Supply Chain Quality Management receiving notable interest (such as by Kuei and Madu, 2001, and; Kuei et al, 2008) the application of FMEA is not widely associated with the diagnosis of supply chain performance. This technique proved effective in helping to diagnose causes of delivery time variability. It is likely that this technique, applied along with the other quality management techniques such as the ones selected for use in this piece of research, will have applicability (1) to diagnosing other aspects of supply chain performance and (2) in other settings. The other aspects of supply chain performance that could benefit from the application of quality management techniques, such as those selected for use in this research, are those that associated with the achievement of the perfect order. This suggests that the selected quality management techniques should be applied to diagnose issues such as stock loss; incomplete delivery; late delivery; and non-delivery. Other settings where this approach to diagnosing delivery time variability in supply chains include commercial industrial supply chains, the service sector and the public sector.

The use of the selected quality management techniques for diagnosing other aspects of supply chain performance in other settings suggests that they should be considered as candidates for diagnosing other causes of poor end customer service in multi-echelon supply chains, for example:

- poor on-shelf-availability in the retail sector.
- poor customer service at ‘moments of truth’ in service industries.
- extended lead times in product development.

It is acknowledged that the combination of quality tools needed to diagnose these issues may be different to the ones employed here. Even where the same tools as used in this research prove to have applicability it may be that the manner of their deployment needs to be tailored. However the possibility of replicating the encouraging results observed in this example suggests that quality management techniques have a valuable role to play in diagnosing a range of supply chain management issues.

Particular limitations of this work are that it is focused on the diagnosis of delivery time variability and it draws on a single case for support. While diagnosis is a precursor for remedial action it does not in itself deliver performance improvement. There remains the need to assess the effectiveness of the diagnosis through acting upon its findings. Therefore the impact of acting upon the findings from the diagnosis of the defence supply chain should be tracked. This will require a method for undertaking the remedial actions to the devised and assessed, including a means of isolating and assessing the contribution of the findings from the analysis.

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## Appendix 1. A Sample FMEA Worksheet

Process Step	Potential Failure Mode(s)	Potential Effect(s) of Failure	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
Receive Order at Depot	Order dispatched by Customer but not received at depot	Order fails to meet processing time target, order cycle time extended	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
Dispatch Order	Order delayed in dispatch	Customer lead time extended	4	Call forward instructions not received from Air Freight Centre	5	Air freight team assigned to manage	4	80	1.Improve reliability of IT link to AFC 2.Improve process of AWB preparation - adopt electronic processing	4	2	3	24
Pick order	Order not picked within processing time	Order fails to meet processing time target, order cycle time extended	4	Lack of manpower to meet increase in volume of orders to meet outlet schedule. Manpower balance not aligned with peaks and troughs in orders	4	1.Shift management 2.Visibility of future demand levels	4	64	1.Change vehicle schedule to balance activity 2.Reconfigure shift patterns to match demand 3.Focus attention on operational issues 4.Employ trained staff during conflict 5.Improve demand forecasting 6.Balance manpower levels to meet peaks and troughs	4	2	3	24

Table VI. A Sample FMEA Worksheet.