Measuring Response Capabilities in the Order Fulfillment Process

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Abstract

This paper introduces a systematic and quantitative approach for assessing manufacturing responsiveness at the operational or tactical level in a manufacturing business. In particular the paper presents a methodology for investigating response capabilities across the entire order fulfilment cycle, **highlights** specific research issues and presents industrial case study results.

Previous work carried out at the Institute for Manufacturing at Cambridge University has developed working definitions of responsiveness and tools and frameworks for assessing qualitatively the impact of disturbances on, and the response capabilities of, production operations (Matson, 1999). Although response characteristics are now more clearly understood, what is yet to be developed is a systematic and **quantifiable** method for assessing the impact of disturbances and associated response capabilities. Additionally, it is necessary to extend this assessment to cover the entire order fulfilment cycle.

The work reported here is concerned with the development of approaches for the measurement and benchmarking of response capabilities.

Introduction

Background

As manufacturing businesses operate in an environment of continuous change, their ability to deal with external and internal disturbances to their smooth operation is extremely important. With competition becoming more fierce and markets more segmented, the need to understand how businesses deal with uncertainty in their operational environment is crucial in enabling sensible strategic and tactical management decisions to be made. For the past decade and a half there has been a strong research interest in the topics of flexibility, agility and responsiveness (Stalk, 1990; Kidd, 1994; Goldman, 1995; De Toni, 1998). However responsiveness has not had the attention that either flexibility or agility have commanded and there have been considerable difficulties in establishing definitions for all three concepts and their interrelationship that are widely accepted (Beach, 2000). Additionally the need to measure flexibility, agility and responsiveness has taken on an increasing importance as effective comparison of performance can only be carried out when appropriate measures have been designed and tested (Neely, 1995).

Significant levels of confusion have existed concerning the definitions of flexibility, agility and responsiveness. (For example there exist over seventy different definitions of flexibility alone in the literature (Shewchuk, 1998)). Agility has been defined as the ability of a company to operate "profitably in a competitive environment of continually, and unpredictably, changing customer opportunities". Agile companies seek to master change and uncertainty by influencing or controlling the environment in which they operate as well as reacting appropriately to unforeseen events. This proactive behaviour is a fundamental characteristic of an agile business.

Responsiveness, in contrast, is the ability of a company to react to unforeseen disturbances using a series of capabilities, firstly recognition of their existence, then making appropriate decisions to deploy, or not, further capabilities to mitigate their effects. In contrast flexibility is a property of a business component, system or sub-system that enables it to change easily from one distinct state to another. A review of the literature defined flexibility as "a property of the system that indicates the system's potential behaviour, rather than its performance" (Gupta, 1989).

Thus responsiveness is the reactive content of agility and uses the flexibilities of the business components as a deployable capability when dealing with a disturbance, see figure 1.

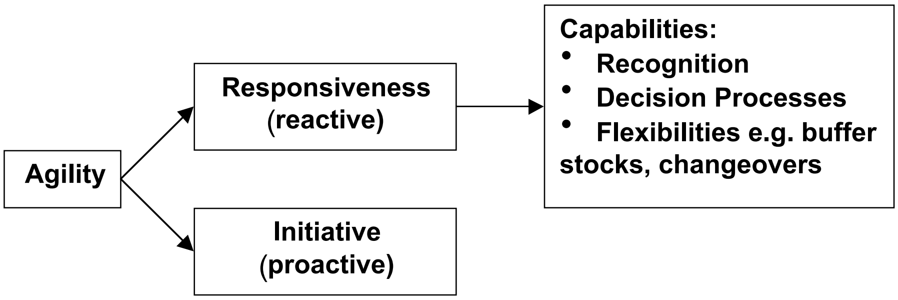

Figure 1. The hierarchy of agility, responsiveness and flexibility

In this work we wish to use measures of responsiveness and flexibility to help in the assessment of best practice and the possible benchmarking of manufacturing operations. We are more concerned with the tactical response level than with the justification of capital investment decisions but the tools we have developed and used are capable of identifying shortcomings in the responsiveness capabilities of a manufacturing operation that could be cured by capital investment.

Measurement of Flexibility

Most research into measures has centred on flexibility. The attractiveness of being able to measure types of flexibility is understandable. The direct application of such a measure and its usefulness to industry is questionable. Whereas from a research point of view the ability to say if one cell or manufacturing process is more flexible than another and by how much is of interest. The only time the flexibility of a process demonstrates its worth is when it is called into use. Then knowledge of its potential and whether this was fully exploited can justify the investment in it, as flexibility does not come free.

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Major reviews of the types of flexibilities have also included discussion on proposed measures (Sethi, 1990). Eleven different flexibilities were defined and for each a purpose (the why), the means (the how) and the various ways that it has been proposed to be measured are given. It was also noted that some studies had reported confusion between short-term (response) flexibility and longer term (range) flexibility among the managers of the same company. Other reviews have classified the research studies by method, for example economic consequences, performance criteria, Petri-nets etc and also by whether they were qualitative or quantitative and theoretical or non-theoretical (Gupta, 1989). No studies of performance criteria were found that fell into both the quantitative and non-theoretical categories.

Measures for volume and product-mix flexibility have been derived but were plant specific and needed values for industrial best practice in order to be calculated (Cox, 1989). A "Perception of Responsiveness" was proposed as a useful non-objective measure.

The ratio of product families to set-up times has been suggested as a measure of flexibility (Ettlie, 1994). This was derived from the correlation of results from a survey of 40 plants undergoing modernisation. It was also found that a number of managers believed that the benefits of investment in flexibility would not be seen for a generation or more of product evolution.

The effects of increasing the process flexibility, how many different products can be made by a plant, across parallel plants in a supply chain has been assessed theoretically (Jordan, 1995). He found that small increases in process flexibility made significant improvements in capacity utilisation against a stochastic demand, but full flexibility, where every plant was capable of manufacturing every product added little extra benefit.

Flexibility as a response mechanism has been attracting greater interest in current competitive environments but there has been no agreement on how it should be measured (Koste, 1999). Four elements of flexibility are defined: range-number, range-heterogeneity, mobility and uniformity. A series of 22 measures for machine flexibility were identified under the four elements. This proliferation of flexibility measures generated would seem not to help establish useful metrics.

While there have been a large number of efforts to measure flexibility most have been theoretical and useful for research purposes with little direct application to industry. The large number of differing definitions of flexibility has also hampered these efforts. This work seeks to develop a series of tools with which to directly capture the real experience of industry and allow managers to evaluate the effectiveness with which they manage unforeseen events and the associated costs.

Agility Measurement

Agility has received less attention in terms of measurement than flexibility. A classification scheme for the research work in the field of agility has been developed (Sanchez, 2001). One such classification was production planning, scheduling and control. No development of measures for this classification was reported in this review. Most studies take the form of the development of subjective auditing tools. Supply chain agility has been discussed and an audit developed to measure industrial views on five factors that bear on this agility (van Hoek, 2001). He asserts that "agility is all about customer responsiveness and mastering market turbulence" and that it needs extra capabilities beyond those of standard lean manufacturing. He goes on to suggest a series of features of agility and potential measures. The main result of the audit was that of the five factors, customer sensitivity was the major concern.

Agility in small to medium sized enterprises (SMEs) has been studied and a four-dimension model of agility with each dimension being subdivided into four sub-categories has been developed (Bessant, 2001). This is then employed as a framework for an audit of the current practice in a company. Examples are given of the use of this subjective strategic level audit in two companies.

Response Measurement

The problem of identifying and assessing the responsiveness of production operations has been the subject of research at Cambridge for several years. Initial studies established a working definition for production responsiveness (Matson, 1997). Wider ranging investigations into manufacturing responsiveness were also carried out (McFarlane, 1999).

As the studies developed, a set of tools for assessing production responsiveness were proposed and tested (Matson, 1999). The assessment method had been recently refined to include subjective measures of the potential effectiveness of each capability deployed and how well that capability had been used.

Disturbances and their effects at machine and system level have been examined using simulation tools (Saad, 1998). Others have investigated the contribution effective decision making processes make to the responsiveness of planning, scheduling and control systems (Kritchanchai, 1999).

Cambridge Response Assessment Tools

The original work, (Matson, 1999), developed response assessment tools restricted to the production operation only. It included the materials supply, production planning, scheduling and control, and the material transformation functions. (Refer to the items within the dotted zone in Figure 2.) It had taken into account both technological and human factors in the production process.

The assessment tools developed were:

1. Data gathering tools (Disturbance Mapping, Goal Mapping)
2. Disturbance Impact Tool
3. Response Capability Tool

The data gathering tools were deployed in a series of interviews with the operations staff. The first aim of the interviews was to gain a complete understanding of the production process and produce a process flow diagram, which could be verified with the interviewees at subsequent meetings. The next objective was to gain an understanding of the local goals for the personnel. A goal hierarchy could then be constructed and verified with the interviewees. Possible goal conflicts or discontinuities could also be recognised.

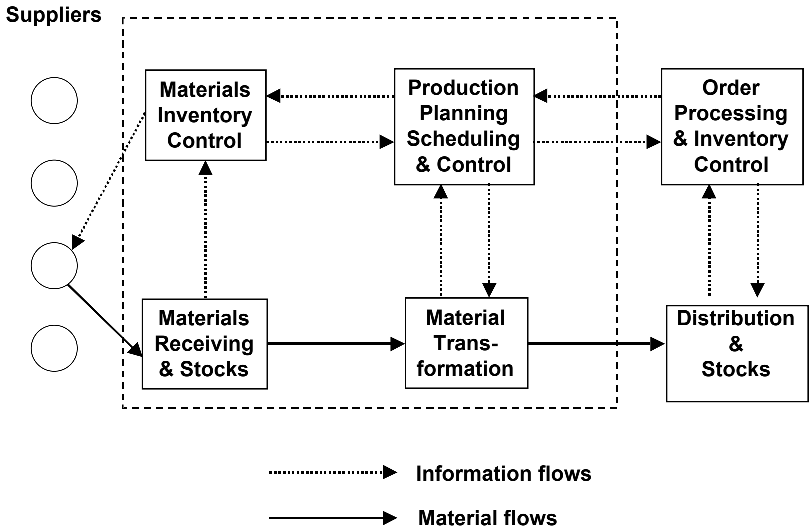

Figure 2. Boundaries of Production Operations with External Interfaces

Next, identification of disturbances and their impact on the goals was discussed. Disturbance characteristics and their impact on production goals were plotted on a chart (see Figure 3). The chart axes rated the characteristics from high to low and an associated table explained the calibration of the chart. For example a high frequency of a breakdown disturbance might be defined as three times a week, in one company whereas three times a month might be high frequency in another.

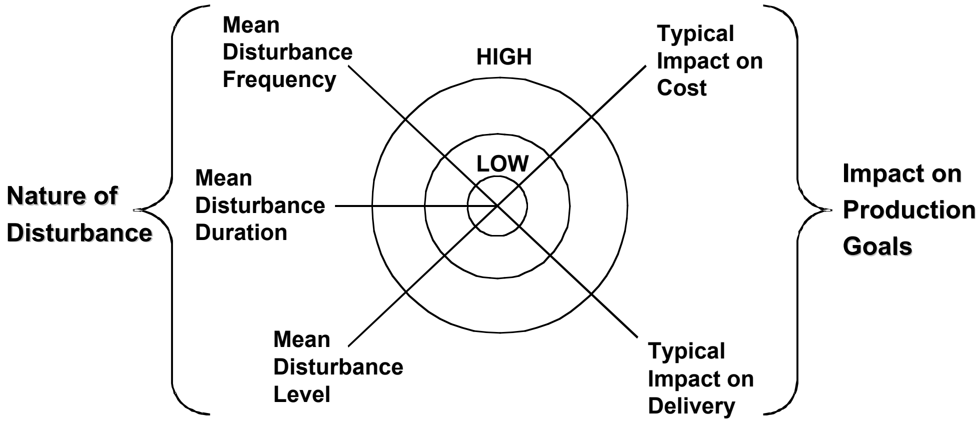

Figure 3. Disturbance class characterisation diagram

A further tool assessed the characteristics available within the production operation for supporting responsive behaviour. Four key aspects of production response capabilities are assessed: recognition, flexibility, buffering and decision making (see figure 4), and again the further from the centre of the chart the better the capability.

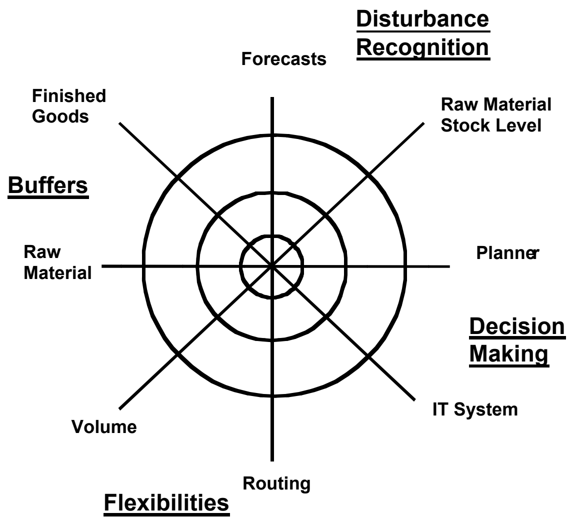

Figure 4. Response capabilities characterisation diagram

Two scores were recorded for each capability, one being the potential for that capability to deal ideally with disturbances and the second the actual performance of the business when faced with real problems. This allowed feedback to the business in two forms. Areas where potential was identified as being low indicated where structural change was needed to improve response. Areas where potential was high but utilisation low showed where extra knowledge or training could have significant benefits to response.

Research Approach

The examination in this paper focuses on cross sectoral responsiveness assessment which forms part of an ongoing research project which is currently being carried out at Cambridge in conjunction with Nottingham University ("PROCHART: Towards world class performance in planning scheduling and control; from progress chasers to responsive teams" EPSRC grant no. GR/N34284/01). The project includes five partners from a wide range of manufacturing industry. They are manufacturers of bathroom sealant, pressure transducers, structural steel, aircraft components and lingerie. The approach therefore necessarily involves issues that are both academically interesting but also industrially pertinent, and frequent interaction with the industrial partners is a key aspect of the work.

Research Questions

The research being carried out specifically at Cambridge is focused on four questions. Each of these is being addressed through a systematic process that links academic developments with industrial case based analysis. The questions being addressed are:

- *Is it possible to extend or develop the existing tools in order to capture the responsiveness capability issues of the whole order fulfilment process?*

Here we are addressing the different and broader needs of the entire order fulfilment process and hence the different response pressures felt compared to the production operations in isolation. The additional functionalities required to be considered are described in the next section.

- *Can appropriate measurement techniques be established for quantifying responsiveness?*

Generating response measures is relatively straightforward, but determining those which are consistent, timely and for which appropriate data is likely to be available is far more complex.

- *Is it possible to use these measures in developing cross sectoral bench-marking approaches?*

Ultimately we desire to use these measures as a means of comparing the response capabilities of companies within a sector or across different sectors. This add a further constraint on the selection of measures but also on how they are then deployed and integrated.

- *Can these techniques capture all relevant issues in the planning, scheduling and control process?*

The prime focus of the response assessment in the PROCHART project is the role of planning, scheduling and control processes in enhancing and/or impeding response. We therefore seek to determine measures which are sufficiently rich that they can allow a very specific study of these issues.

Outline of Methodology

As a means of verifying the outcomes from this research five in depth industrial studies are being undertaken with the collaborating companies. Each study seeks to test different aspects of the development of the theory of response assessment. The benchmarking work, which focuses on the ability to make cross sectoral comparisons of response capabilities, will draw on the results from a number of the case studies in seeking to verify the approach developed. The reminder of the paper deals with the two issues of assessing the extendability of the tools to deal with the order fulfilment process and the development of suitable measures.

Response Assessment of the Order Fulfilment Cycle – A Case Study

In this section we examine the ability of the existing response assessment tools introduced earlier in the paper (see also Matson, 1999) to apply to the entire order fulfilment process.

Extension of the Assessment Tools

The previous responsiveness work (Matson, 1999) limited the scope of its investigations to the production process only. It has become increasingly important for businesses to understand and manage their process across the wider supply chain. Certainly disturbances generated outside the business can have major negative impacts (Lee, 1997), and investment in appropriate supply chain management techniques has been seen to benefit the agile performance of some companies (Narasimhan, 1999). The PROCHART project seeks to examine the responsiveness of the planning, scheduling and control systems of manufacturing businesses and it was concluded that the existing tools needed to be extended to cover the entire order fulfilment process.

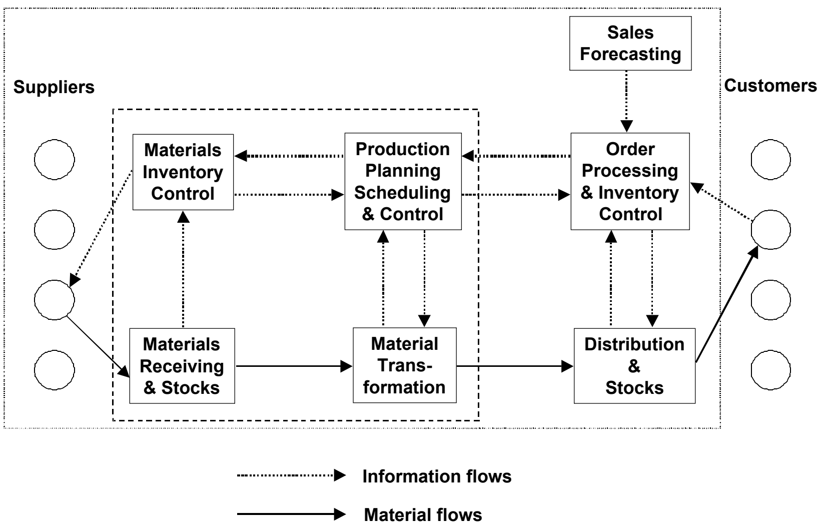

Figure 5. Production and the order fulfilment process

The expansion of the use of the tools raised a number of questions about their deployment and effectiveness. For example in previous studies the finished goods warehouse could be a source of disturbances to the production operation. Now it had become an important source of flexibility acting as a buffer between production and the customer. Disturbances may exist, which have little or no effect on production, but still cause difficulties for the business to continue to achieve its goals. The operational goals of the sections outside production may not be congruent with the goals of production or the business as a whole. Figure 5 above shows the difference in scope of the use of the tools. The larger dotted box encloses the order fulfilment process whereas the smaller one just covers production. Solid arrows show material flows and dotted ones show information passing.

Case Illustration

In order to test the extended version of the tools a case study assessment of the order fulfilment process in a partner company was made. No major refinements of the tools took place but interviews were held with people across the entire order fulfilment process, and different sets of disturbance, flexibility, buffering and decision categories were used.

The company blends a number of raw materials and stores the result in either a pot, for immediate use on the fill line, or in a drum, which can be stored in the warehouse. The product has a long shelf life. Blended material from a pot or a drum is taken by the fill line and inserted into tubes that have been injection moulded in house. There is a buffer store of tubes between injection moulding and fill. Finally the filled tubes are assembled with a nozzle, a label and a plunger, and packed into boxes. These are in turn shipped to the warehouse on pallets. The process flow diagram for sealant manufacture is shown in figure 5. It does not include warehousing and final dispatch, as the company is a make to stock organisation and maintains fixed (over the medium term) levels of finished goods stock. Customer orders are satisfied on demand from this stock. It is unusual for these stock levels to be reduced to zero, but not unknown.

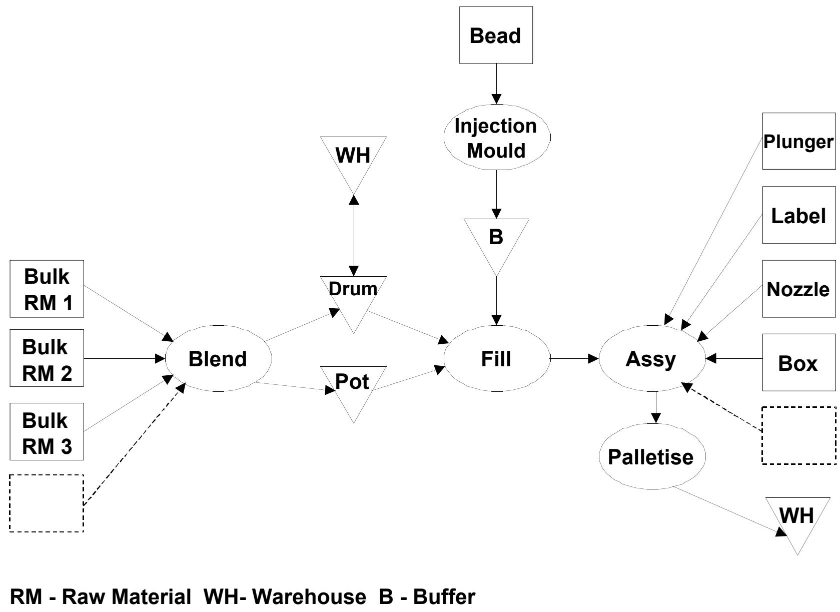

Figure 5 - Process flow diagram for the bathroom sealant manufacturer

Orders for production are generated when finished goods stock in the warehouse falls below a set minimum safety stock level. These levels are set on the basis of historic demand. This accounts for day to day order generation but the overall manufacturing planning for the year is derived from annual sales forecasts. The company has experienced serious problems in keeping its major customers satisfied when a single customer has placed unanticipated large orders. These reduce the warehouse stock to zero before the company can respond.

Overview of Response Assessment

The assessment was carried out over a one week period in 2001. No disturbances were captured that did not affect production but all those that were had been experienced by departments outside production. Care had to be taken in nomenclature as systems and standards changed along the supply chain. Disturbances were found to fall into three categories, examples of which are give in figure 6 below. The first category was a failure in the process (for example a machine breakdown) the second an upstream failure in the supply chain, and the third an abnormal variation in the level of customer demand.

Two goal hierarchies were identified. The first was to maintain excellent levels of customer service. During the period of the investigation, the company achieved a service level to the customer of over 98%. The second goal was to minimise cost in the operation. The goal hierarchies are shown in figure 6.

The customer services department, which falls outside of the production operation, has a clear set of goals that contribute significantly to the overall achievement of on-time in-full delivery to the customer, and to the second major goal of minimising cost through efficient organisation of transport. It is clear that these two goals may well conflict, for example, when in order to achieve delivery on time to a customer special transport arrangements may need to be arranged.

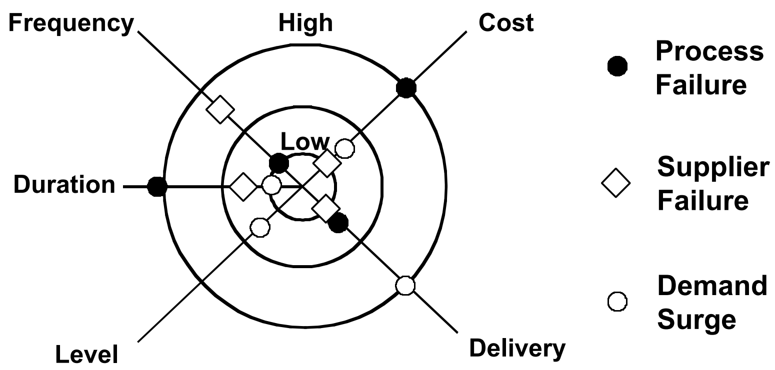

Figure 6. Populated disturbance characteristic diagram from the bathroom sealant manufacturer

The captured disturbances were mapped onto a diagram as in figure 6 above. From the left hand side it can be seen that process failures were infrequent but when they occurred lasted for some time. Supplier failures were far more frequent, but short lived. Demand surges also did not occur often and their level of disruption was moderate. The impact of the three types of disturbance on the goals of cost and delivery are recorded on the right hand side.

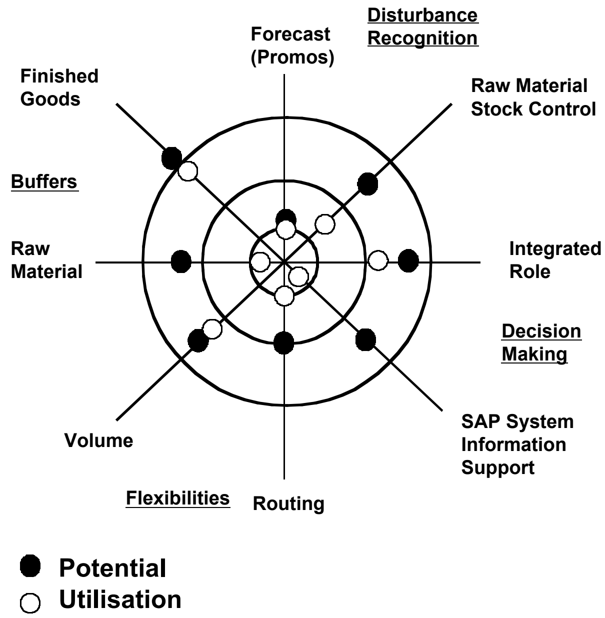

Figure 7. Populated response capability diagram from the bathroom sealant manufacturer

Response capabilities were identified and plotted on the diagram, see figure 7 above. The black circles mark the potential for each capability and the white circle how well the company was using that capability. For example the company had an excellent ERP system to aid with decision making but its level of utilisation was poor.

The test of the extended tools was a success and they worked in their extended mode with some provisos. Care still needed to be exercised if disturbances that did not affect production were discovered. The tools would not work with major structural changes to markets or products and the introduction of new products was still beyond their scope.

Quantifying Response

Requirements

Response characteristics are hard to quantify as they are typically not directly cost related. However, developing measures that allow comparison of response capabilities across different industries is useful as it will help enable the transfer of best practice from one sector to another. Previous work at Cambridge (Matson, 1999) has tried to quantify response capabilities by attaching values to the axes on the disturbance characteristics diagram and the response capability diagram, and a so called response capability index was calculated for each class of disturbances. We note that some of the judgements used in determining these indices were subjective and the results therefore are at best indicative and certainly not appropriate for cross sectional comparison.

For any measures to be useful they need to be able to be compared from company to company and from industry to industry. Ratios such as the coefficient of variation (CV) have been proposed as a measure of lumpiness in demand (Bobko, 1985). The concept of ratio type metrics was considered for the axes of the diagrams. Such metrics would have the advantage of being normalised and expressible as a decimal or percentage of an ideal value.

The problem associated with creating such a set of metrics is that if disturbances, goals and capabilities are unique to each manufacturing organisation then a proliferation of measures would be created which would not help with inter company comparisons. However from this work and previous studies trends in data types have emerged and it may be possible to classify disturbances, goals and capabilities in a generic way.

As has been noted above disturbances fall into three categories. These are an upstream failure in the supply chain, a failure in the production system and an abnormal variation in the level of customer demand. Similarly goals fall into two types. The first is customer service and is usually measured by on-time in-full delivery and the second is cost. Finally the response capabilities can be divided into a sequence of three operations that deal with the problem. The first is recognition of the disturbance, the second is the process of deciding how to deal with the disturbance and the third is deploying a capability to actually treat the problem.

Proposed Measures

This leads to a matrix of disturbance classes and diagram axes that contain the proposed metrics as in table 1 below:

	Disturbance Characteristic Diagram Axes				
Disturbance Class	**Frequency**	**Duration**	**Level**	**Impact on Costs**	**Impact on Delivery**
Supplier Failure	$=\left(\frac{\text{Freq. of failure}}{\text{Freq. of delivery}}\right)$	$=\left(\frac{\text{Length of delay}}{\text{Order lead time}}\right)$	Not applicable	$=\left(\frac{\text{Increased cost}}{\text{Periodic cost}}\right)$	Change in on-time in-full delivery
Process Failure	$=\left(\frac{\text{Freq. of failure}}{\text{Process frequency}}\right)$	$=\left(\frac{\text{Length of failure}}{\text{Process Interval}}\right)$	Not applicable	$=\left(\frac{\text{Increased cost}}{\text{Periodic cost}}\right)$	Change in on-time in-full delivery
Order Variation	$=\left(\frac{\text{Freq. of variation}}{\text{Freq. of delivery}}\right)$	Not applicable	Coefficient of variation, CV	$=\left(\frac{\text{Increased cost}}{\text{Periodic cost}}\right)$	Change in on-time in-full delivery

Table 1 – Generic disturbance characteristic measures

The terms used in these metrics are summarised in table 2 below:

Term	Definition	Units
Freq. of failure	How often a supplier or process failure occurs on average	$Days^{-1}$
Freq. of delivery	How often a supplier delivers to the company or the company delivers to the customer on average	$Days^{-1}$
Length of delay	How long the shortage lasted for	Days
Order lead time	Normal lead time for ordering this raw material or component	Days
Increased cost	How much extra cost the disturbance generated	Currency
Periodic cost	The average operating cost of the business over a normal management accounting period – probably a month	Currency
Process frequency	The rate at which jobs move between operations on average in the absence of disturbances	$Days^{-1}$
Length of failure	Duration of a process failure	Days
Process interval	The inverse of the process frequency	Days
Freq. of variation	How often abnormal customer orders are placed	$Days^{-1}$
Coefficient of variation	The ratio of the standard deviation of the requirements per period to the average requirements per period	Dimensionless
Change in on-time in-full delivery	Self explanatory	Percentage

Table 2 – Components of generic disturbance characteristic measures

Two further useful measures not included in these tables are a) *the time taken to respond* and b) *the cost of maintaining each response capability*. The latter in particular is is a critical item for future consideration:

Response Time: The time taken to respond must include recognition, decision and deployment times. This could be normalised by dividing it by the average order lead-time. Values much less than 1 would indicate rapid effective reaction to disturbances with little effect on delivery performance. Disturbances with values greater than 1 would show that the delivery performance of the company is being compromised.

Response Cost: No capability comes free. The cost of maintaining buffer stocks or a flexible workforce can be measured and is of importance to the business in understanding which capability to deploy in the face of a disturbance and the effect this action might have on its cost goal.

The proposed measures require a large amount of data to be available in a company for them to be collected. The question of data sufficiency was tested in our second case study. The tools were used in a pressure transducer manufacturer and an assessment made of the data available. There was sufficient data to enable the calculation of all the metrics, but the study had to be cut short for operational reasons and no disturbances were able to be fully captured. A subsequent audit of a small to medium sized enterprise (SME) that is not one of the partners in PROCHART has raised some questions on data availability in smaller companies.

Conclusions

A set of audit tools for assessing response has been developed, extended and successfully applied to the whole order fulfilment process. A set of measures for assessing the impact of a disturbance has been proposed, and measures for the effectiveness of a response capability discussed. Adequate data to support the measures has been found in a large business but problems could be encountered with data sufficiency in some SMEs.

Further work will be carried out in testing data sufficiency and the utility of the metrics proposed in the partner companies and in the wider manufacturing community. The authors would like to acknowledge with gratitude the time and effort put in by the partner companies and the financial support of the EPSRC.

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