A Responsive Audit for Production and Order fulfillment Process

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Abstract
In the late 1990s responsiveness became a key differentiator for manufacturing companies aiming to better support their customers with more timely deliveries and more appropriately customized products. In addition, significant internal improvements in cost and stock reductions can be achieved through a more responsive operation. It has been argued by the authors that it is possible to comprehensively audit the impact of response and to systematically assess response capabilities. This paper reports on a responsiveness auditing tool that has been developed and applied within a range of industries. The audit provides a framework for examining the ability of a production operation to respond to external and internal production disruptions or response needs. It has been developed to help manufacturing companies assess and improve their ability to respond to those influences on operational performance, which they cannot readily control. The paper begins with a set of clarifying definitions which position (production) responsiveness in line with established concepts of agility and flexibility. It then introduces the audit process as a means of allowing a production operation to systematically assess response capabilities and the impact of responding or not responding. It then demonstrates how the audit can be used as a means of directing response improvement actions. Case study examples are used as a means of illustrating the developments. The paper concludes by considering the extension of the audit to the entire order fulfillment process.

Keywords

Responsiveness, agility, flexibility, production, audit, disturbance

INTRODUCTION

There is enormous pressure on all manufacturing businesses today to be more agile in the way they operate. Customers and markets demand increased product customisation, greater product variety and frequent changes in batch sizes. Coupled with the pressure of shortening delivery lead times and expectation of increased delivery reliability and decreasing costs, these demands require a complete change from the steady, reliable but relatively inflexible production practices of the past. This paper introduces an audit, which focuses specifically on assessing the contribution that production can make in responding to these increasing pressures. This paper is a companion paper to Matson and McFarlane (1999) in which a number of the individual tools making up the audit were introduced and is an extension of McFarlane et al. (2002) introducing some of the features of the audit processes. We acknowledge that there are many response issues that impact outside the production domain, but understanding the ability of production to respond (profitably) to disturbances and knowing in which areas response capabilities need to be improved is extremely important. In addition to the production domain issues, we conclude the paper by briefly addressing some responsiveness issues relevant to the overall order fulfillment process as introduced in Kritchanchai and MacCarthy (1999).

The production responsiveness audit described in this paper provides a framework for examining the ability of a production operation to respond to:

- Current external and internal production disruptions or response needs
- Future sources of external and internal production disruptions or response needs
- Particular response issues of importance to the business (e.g. rush orders)

The audit is a means for collecting and structuring information about the most critical of these disruptions or response needs in terms of:

- An estimate of the impact of each on specific production goals
- The available capabilities within production for addressing the disruptions or response needs

From this data, and the subsequent assessment procedure, recommendations can be made (in conjunction with existing plant / operations improvement programmes) on:

- Making better use of available response capabilities
- Additional capabilities that are required to address particular disruptions or response needs
- A prioritisation of disruptions and response needs in terms of relative impact (in terms of reduced production performance) as an input to the prioritisation of improvement activities.

The responsiveness audit has been developed to help manufacturing companies assess and improve their ability to respond to those influences on operational performance which they cannot readily control (e.g. variations in product demand or mix, raw material delivery or quality fluctuations or machine breakdowns).

The audit is designed to draw upon, integrate and structure the existing knowledge and experience of production personnel via interviews and workshops. It is designed to generate improvement projects and focused studies addressing specific responsiveness needs relating directly to the company's operating goals and environment. Although designed as a stand-alone tool that is generally applicable in most production environments, it is particularly helpful in situations where the company has a particular response-related objective in mind. Under these circumstances the audit can be used as a means of focussing on this objective. To illustrate, three scenarios in which the audit might be appropriately deployed are outlined in Table 1.

Table 1 Response Assessment Scenarios

Situation	Use of the Audit
(1) Company X producing components observes a potentially profitable opening for responding to customers requiring a) replacement parts at very short notice and b) products in smaller and varying batch sizes.	*The audit would be used in this case to assess the likely impact of these two scenarios against a background of existing production conditions. It would provide a framework for assessing the potential costs and whether core capabilities exist for managing these challenges*
(2) Company Y is asked to begin an improvement programme, which is focussed on achieving an increase in production flexibility for a range of reasons. Where should it begin, and in what priority order should improvements be made?	*The audit will help the company to clarify exactly what it is wanting to achieve by an improved flexibility - i.e. flexibility is a process characteristic which can provide good response capabilities if it appropriately deployed. The audit differentiates between flexibilities associated with:* - *plant: physical equipment and operations* - *information: sources and use made of data and knowledge* - *control and decision: readiness with which these elements can adapt to suit changing requirements* *and improvement areas are identified accordingly*
(3) Company Z is finding that it is unable to meet increasingly tight production targets owing to unreliable equipment and frequent routing blockages	*The audit provides a means for highlighting exactly which equipment or routing issues are affecting production targets and (quantitatively) by how much. It also provides a (limited) analysis for the key problem areas in determining whether equipment, problem recognition or decision making improvements would make the most significant impact.*

The audit is not intended to be a lengthy or totally rigorous assessment of production facilities responsiveness. It is intended to provide a relatively quick qualitative snapshot of the key response capabilities that are available, how well they are used, and whether they should be improved. It is likely that on completion of the audit a more focused analysis may be required before a commitment to capital expenditure be made or a major operational change be undertaken. The underlying assumption associated with the audit is that all the information required resides with plant personnel and the simple role of the audit is to extract and present this information in a meaningful way.

PRODUCTION RESPONSIVENESS

To position the audit development with regard to existing developments in the literature, we now examine the definition and scope of production responsiveness.

Definition

Lehtonen et al. (1999) defined quick responsiveness as the following: "*Quick response in production and inventory control is the ability to plan, manufacture and deliver the full product range within a delivery time that is acceptable to the customer*". Production responsiveness is viewed here as just one aspect of the responsiveness of a manufacturing organisation seen as a whole (Matson and McFarlane, 1999). It is concerned with how one part of a manufacturing company (the production system) responds to one class of events (those affecting its operational performance). We now clarify the way in which this terminology is used in the present paper. The main functions, which are either internal to, or directly linked to the production operations of a manufacturing company, are outlined in Figure 1. The production system is viewed here as a combination of the materials supply, production planning, scheduling, control and manufacturing functions. Together, these functions must respond to demands set either directly by customer orders (in a make to order company), or to production orders generated by an inventory control function (in a make to stock company). Figure 1 can be interpreted in the context of both make to stock and make to order companies by excluding the italicised text for the case of a make to order company. The dashed lines indicate information flows and the solid lines material flows.

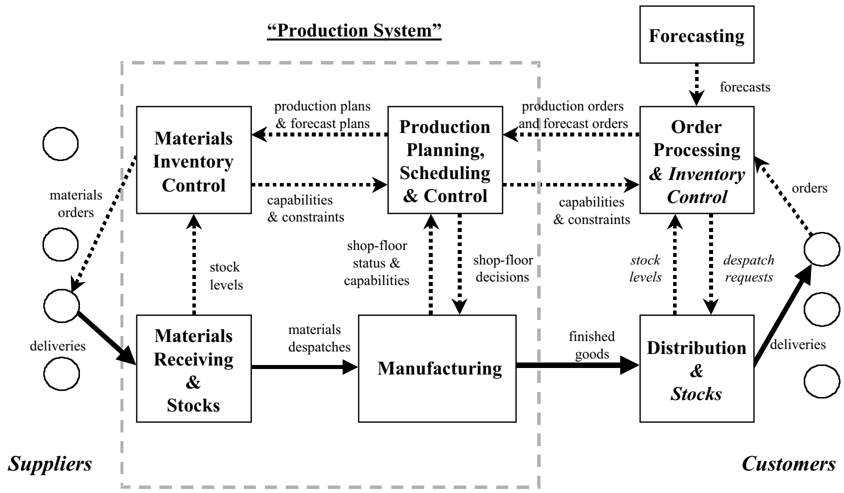

Figure 1. Delineation of Production Activities (Overall order fulfillment processes)

At present, there is no generally agreed definition of responsiveness in the manufacturing literature. The following working definition of production responsiveness proposed in Matson and McFarlane (1999) is used here.

Responsiveness is the ability of a production system to respond to disturbances (originating inside or outside the manufacturing organisation) which impact upon production goals.

Typical disturbances might include, for example, the receipt of rush orders, machine breakdowns or degradations or variations in raw material supply. We note that disturbances may be internal or external and importantly their effect may be either positive or negative.

Linking Responsiveness to Agility, Flexibility and Robustness

In this section we briefly review some concepts related to production responsiveness that have been reported in the literature, as a means of positioning the focus of the audit process. In particular, we seek to clarify the relationships between: responsiveness and agility; responsiveness and flexibility; responsiveness and robustness.

Responsiveness and Agility

Agility is described by (Goldman et al. 1995, Kidd, 1994, Christopher, 2000) as the ability of a company to operate "profitably in a competitive environment of continually, and unpredictably, changing customer opportunities". Four key imperatives have been associated with agile companies: a) enrich the customer, b) master change and uncertainty, c) leverage resources and d) co-operate to compete. More recently, Gunasekaran and Yusuf (2002) also defined agility in manufacturing as follows: "*The capability of an organization, by proactively establishing virtual manufacturing with an efficient product development system, to (i) meet the challenging market requirements, (ii) maximize customer service level and (iii) minimize the cost of goods, with an objective of being competitive in a global market and for an increased chance of long-term survival and profit potential. This must be supported by flexible people, process and technologies*".

Responsiveness clearly contributes to fulfilling the agility imperative of mastering change and uncertainty. However, agility is also concerned with making full use of the influence a company has over the sources of change and uncertainty, to pro-actively remove them or drive them to support the organisation's goals. As described by (Goldman et al, 1995), an agile company may pro-actively influence the various environments in which it operates by means of many different activities, including marketing, co-operative alliances, new product and process development. In contrast, responsiveness is about taking actions in response to actual or potential changes which the system either cannot control or has not planned. Van Hoek et al. (2001) distinguished agility with lean. Lean is "how to eliminate waste" while "agility is all about customer responsiveness and mastering market turbulence". Extensive literature survey on agile manufacturing systems were presented by Sanchez and Nagi (2001). The link between agility and responsiveness is outlined in Figure 2, following the definition of agility provided in Goldman et al. (1995) and Harrison (2000).

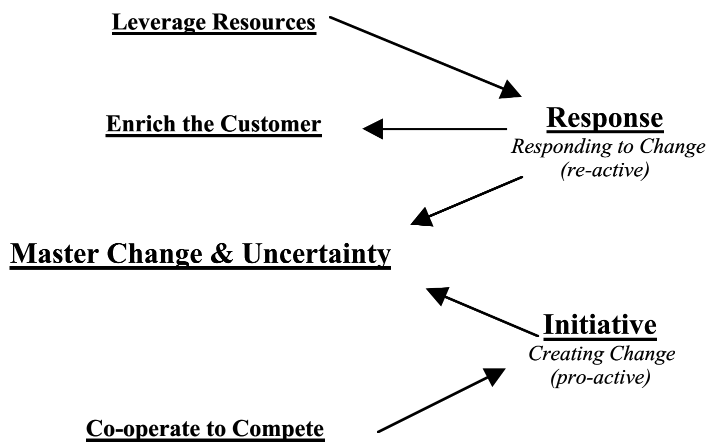

Figure 2. Four contributors to agility and response

Responsiveness and Flexibility

Flexibility has received much attention as a manufacturing research topic in the last decade or so. Despite the fact that the word is used in many different senses, there is a general consensus in the literature that flexibility is valuable in dealing with change (Gupta and Buzacott, 1996; Slack, 1990; Upton, 1984; Sethi and Sethi, 1990). As such, it is important to consider the relationship between responsiveness and flexibility. This paper adopts the view expressed in Gupta and Buzacott (1996), that ‘flexibility contributes to the overall ability of a firm to cope with changes without suffering significant loss of performance’. Flexibility is viewed in this paper as an inherent production system property, which has meaning without the need to make reference to system performance or the need of the system to deal with change. Slack (1990) comments that flexibility ‘is desirable not as an end in itself but as a means to other ends’. The following definition is based on a definition of ‘Function or Total System Flexibility’, given in Slack (1990) although we note that other compatible variations exist in Gupat and Buzacott (1996) and Upton (1994).

System Flexibility is the ability of a production system to change the mix, volume and timing of its outputs.

As noted by Slack (1990) and Gupta (1996), system flexibility is a complicated function of many system attributes, including machine and subsystem flexibilities. Also, we note that while system flexibility constitutes a possible means for responding to disturbances (both internal - e.g. machine breakdowns - and external - e.g. demand variation, rush-orders) it is not synonymous with responsiveness, since the system must also be able to judiciously use its flexibility in response to disturbances - i.e. decide when to flex its outputs and by how much. We also note that system flexibility does not refer to the ability of the production system to manage supply side or internal disturbances, which is covered by the complementary property of *robustness*. More researches can be referenced from the followings: Toni and Tonchia (1998); Shewchuck and Moodie (1998)

Responsiveness and Robustness

Correa and Slack (1996) recognise the importance of another type of total system behaviour, which they call ‘system robustness flexibility’. The following definition is put forward to summarise this concept, which we call here simply ‘system robustness’: *System Robustness is the ability of a production system to maintain performance in the presence of disturbances originating from suppliers or from within the production system.*

System robustness is a particular type of responsiveness, whereby the system guards against negative impacts of supply and internal disturbances. Note that in contrast with flexibility, system robustness is defined with direct reference to both disturbances and goals. Note also the relatedness of this definition to production responsiveness. Upton has described this type of behaviour as a type of ‘flexibility’, however as explained in the previous section, the authors have chosen to use the term ‘flexibility’ in the current paper in a very specific sense which precludes the robustness interpretation. There are a number of different ways in which system robustness can be achieved, including the use of system flexibility (e.g. in making up for a period of plant down-time). Other strategies include the use of raw materials stocks and work in progress to guard against materials delays and machine breakdowns, and the use of routing flexibility to compensate for machine breakdowns. In many respects, responsiveness (as defined earlier) can be seen as an extension of the idea of system robustness. However, there are two reasons why system robustness is not equivalent to responsiveness:

- A response may be appropriate even when the impact of a disturbance is positive.

  (e.g. the early arrival of materials may allow a favourable re-scheduling of production).

- Responsiveness to customer disturbances is not incorporated in the definition.

  (e.g. maintaining profitability in the face of demand variations is a key responsiveness requirement of many companies).

The contention of this work is that both system flexibility and system robustness need to be viewed within a broader framework, and that the provisional definition of responsiveness put forward is a step towards this.

Production Responsiveness Capabilities

The diagram in Figure 3 attempts to highlight the necessary requirements for "good" responsiveness.

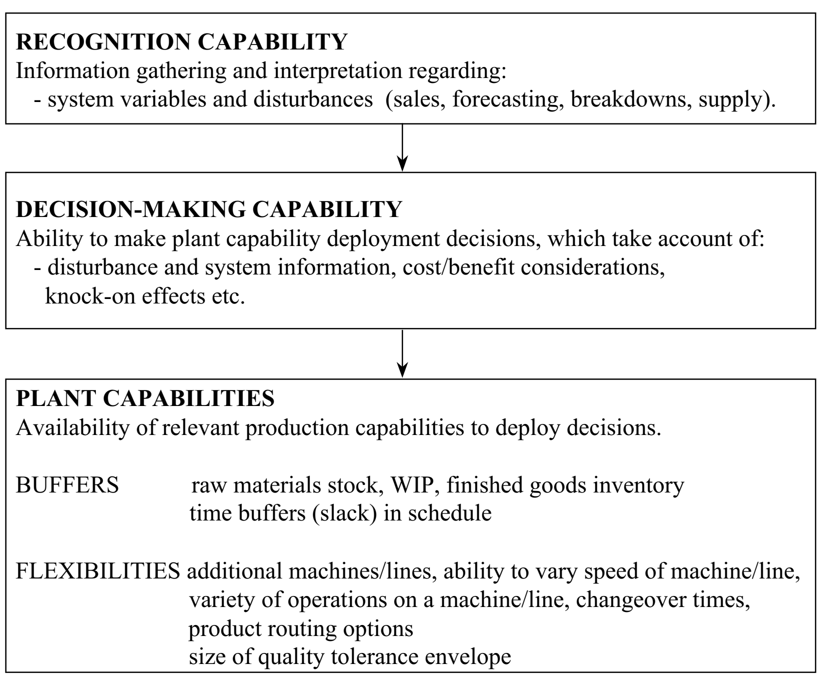

Figure 3. Factors Influencing Production Responsiveness

The degree and quality of information available concerning the occurrence and nature of disturbances has a major effect on responsiveness, in that it greatly influences the achievable quality of response decisions (see Caputo, 1996). In addition to a combination of flexible process capabilities and buffers, it is important that a) disturbances and plant conditions are recognised and evaluated effectively and b) appropriate decisions are made regarding the use of the available flexibilities and in the face of disturbances. Figure 3 forms the basis of the audit to be described in the next section. We can therefore summarise the connections between the concepts discussed in this section in terms of the diagram in Figure 4.

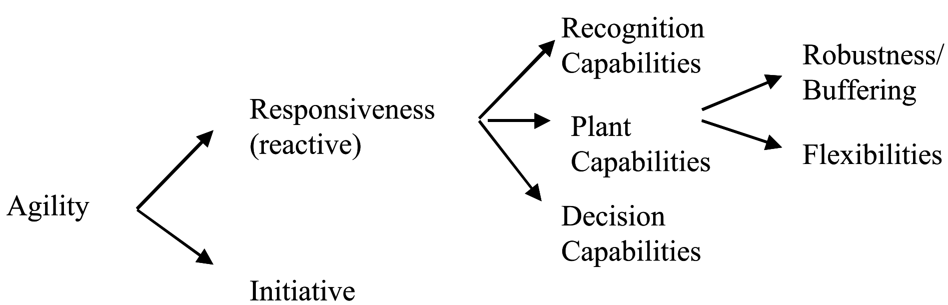

Figure 4. Linking of Different Change Management Characteristics

THE AUDIT PROCESS

In order to make a systematic assessment of production responsiveness an auditing process has been developed which integrates a number of different focus while auditing approaches for flexibilities (Slack, 1990) and human resource (Harrison, 2000) have appeared in the literature, this is the first systematic methodology for assessing production responsiveness that the authors are aware of.

In this section the audit process and necessary support tools required to undertake the audit are described. As previously pointed out, the assessment is not intended to be a lengthy or totally rigorous analysis of the responsiveness of a production facility. It is intended to provide a relatively quick snapshot of the key issues associated with improving response capabilities. The underlying assumption associated with the assessment is that all the information required resides with plant personnel and the simple role of the assessment is to extract and present this information in a meaningful way. The production responsiveness audit typically consists of the following steps (refer to Figure 5):

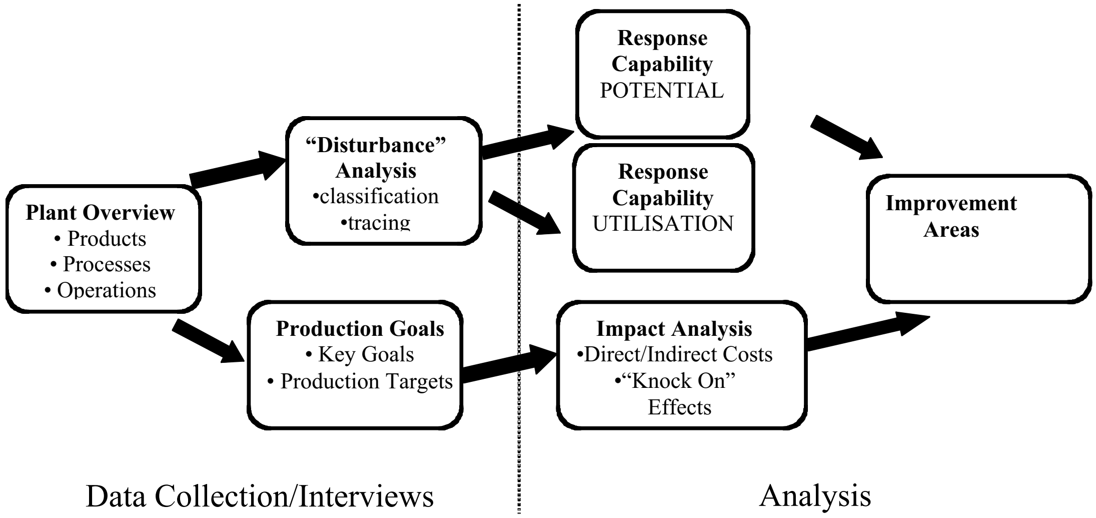

Figure 5. Overview of Audit Process

1. *Familiarisation with Operations:* This involves a process overview, plant tour and initial observations about facilities in terms of physical layout, computer systems, flexibilities, buffers, decision & control approaches used.
2. *Collection / Clarification of Production Goals:* Using existing information, production data and by interview identify the main production goals and generate an understanding of the main production variables that affect them.
3. *Disturbance Collection / Selection:* An identification of the main order variations ("disturbances") was performed, followed by a suitable classification and a tracing of a number of recent examples.
4. *Impact Analysis: A* detailed impact analysis was performed for a number of disturbances as a means of estimating the effect of order variations.
5. *Response Capability Assessment:* The capabilities required to successfully manage the difference disturbance types were assessed using a simple charting process which

evaluates both the response potential of the existing systems/infrastructure in place and the degree to which these capabilities are currently utilized.

6. *Improvement Strategy:* Improvement directions were identified from the response capability charts and specific actions recommended.

Depending on the application, the audit can be used in a number of different orientations, and in this paper, cases studies from two orientations will be described which are:

- An overall investigation of existing factory response issues and capabilities
- An investigation of capabilities for responding to a particular response challenge

Additionally, the audit process could also be applied in an investigation of capabilities for responding to potential / future response challenges and hence provide support for determining the limits to agility that the production operations is capable of supporting. The different stages are now described in more detail in the following sections.

Familiarisation with Operations

A significant amount of relevant information can be gained from an initial overview of the operations, followed by plant tour, during which the facilitators make initial observations in terms of:

- Physical Overview: physical plant layout, product mix (variety, volumes and frequency of changeovers), process configuration (e.g. single/multiple lines, cellular)
- Computer and communication systems: local process unit control, central control systems, data collection, performance monitoring, database capabilities, human interfaces, and communication services.
- Flexibilities: routings, equipment, people skills, product tolerances, production times
- Buffers: raw materials, WIP, finished goods, unscheduled time, machine capacities

- Decision and Control: planning and scheduling systems, shop floor control, process optimisation, decision making processes.

In addition to guiding the disturbance identification process, this data is a useful input in the response capability section. By the end of this step, the facilitator will have a working knowledge of the plant, processes and products.

Collection / Clarification of Production Goals

A systematic approach for assessing the impact of disturbances is by directly examining their effect on production goals. For this reason, the next step involves a mapping of the main contributors to the goals that drive the plant. [1] Using existing information, production data and by interview the main production goals are identified and a simple tree-diagram are generated based on the production variables that affect them. This leads to a set of *goal map diagrams*, which are generally based around cost and delivery. Examples of two typical goal maps are given in Figures 6 and 7.

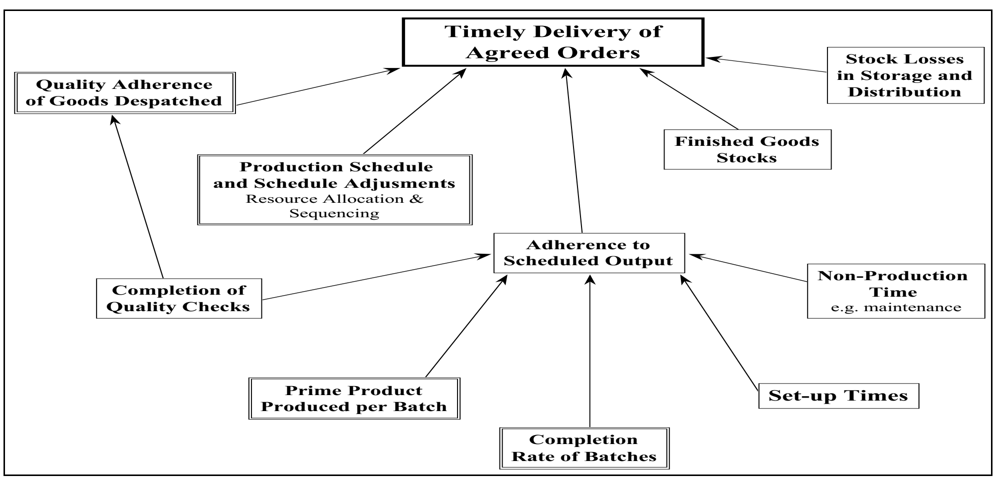

Figure 6. Generic Goal Map Diagrams for Delivery

[1] In some companies this process may already have been achieved as part of an in house performance measurement process.

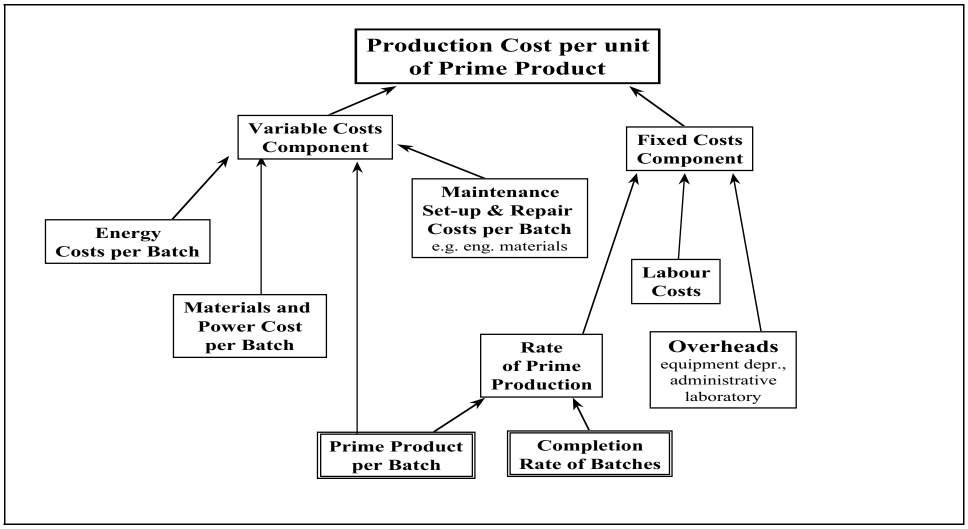

Figure 7. Generic Goal Map Diagrams for Cost

The goal maps are used as a guide for identifying and tracing the impact of disturbances during the next two steps of the audit (In an extended form, these maps also include relative weightings on the arcs linking goals and sub goals).

Disturbance Classification

This step may occur either after or in parallel to the previous step. Next, an identification of the key disturbances (disruptions or response issues) is required, and simple tools are presented below to support this activity. This process provides a rough estimate of the contributions of the particular disturbances to the different production goals.

Audit Tool: Disturbance Mapping

This tool comprises two simple classifications of disturbances as they are contributed through interview or workshop. The first simply classifies the physical source of the different disturbances, typically supply-end, and demand-end while the second provides an initial assessment of the way in which each disturbance affects the production goals identified in the previous section. Typically, this process yields 3~5 key disturbance types through a series of structured interviews. A more thorough analysis is then made at the next stage.

Impact Analysis

For those critical disturbances identified as being particularly important in the previous section (and hence likely to warrant improvement actions), a more detailed analysis is performed. Either by interview or by workshop session, information on the following is collected for an average incidence of each type of disturbance:

- **Level** - Extent of the individual type of disturbance
- **Duration** - average impact period
- **Frequency of occurrence**
- **Effect on production goals** - qualitative estimate in terms of £, hours, tonnes etc

A chart is generated to represent this data, and an approximate calculation is used to provide an *impact rating* for the disturbance. The goal maps developed in Figures 6 and 7 are again used as a resource for guiding the assessments made by the participants.

Audit Tool: Disturbance Responsiveness Charting[2]

The Disturbance Responsiveness Chart, illustrated in Figure 8, is used to capture the audit workshop participants' assessment of the characteristics of the disturbance and of the impact that the particular class of disturbance has on the plant when it occurs (note that high impact means low responsiveness). When impact is known to be highly dependent on the particular production conditions at the time of the disturbance, it may be necessary to fill out separate charts for the same disturbance for each scenario. The following information is collected in the chart:

Mean frequency of disturbances – this is an indication of how frequently this class of disturbance occurs and is normally measured in terms of incidences per time unit – e.g. per day, hour, shift etc.

[2] We also note that the tools described in sections 3.4, 3.5, 3.6 have previously been described.

Mean disturbance duration – for disturbances, which affect production over intervals of time (e.g. machine breakdowns), this measures the disturbance's mean duration.

Mean disturbance level – for disturbances which cannot be characterised in terms of duration, this measures the mean level of the disturbance class in appropriate units e.g. lateness of raw material delivery, change in materials price.

Impact on Goal 1,2,… – these dimensions measure how a disturbance of this class, with stated mean level and/or duration, affects the plant's achievement of its goals. A separate dimension is added for each overall production goal and should be measured in units appropriate for that goal.

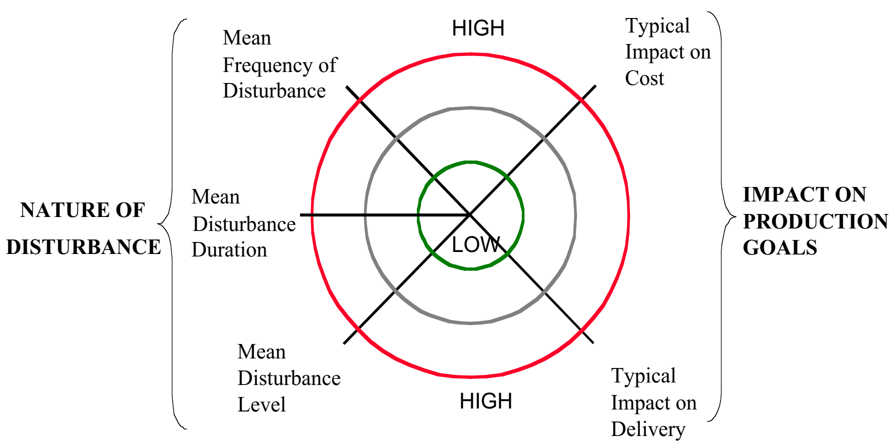

Figure 8. Disturbance Responsiveness Chart

Scales for the frequency and goal dimensions on the disturbance responsiveness chart should be consistent across the different disturbance classes. This is to aid comparison of different disturbance impacts. Note that for a given disturbance class and goal, the following calculation is made:

Average Disturbance Impact per unit time

≅

Impact on Goal (at mean duration and level) x Frequency of Disturbance

This number provides a basis for comparing different classes of disturbances[3]

Response Capability Assessment

The capabilities required to successfully manage each of the critical disturbance types are assessed using a simple charting process. Capabilities assessed are linked to the following general categories:

- **Recognition** - access to appropriate data, information
- **Buffers -** product buffers, slack in production schedules, machine capacities
- **Flexibilities -** routings, equipment, people, product tolerances
- **Decision Making -** appropriate knowledge, decision making or control support

To support this assessment, the following charting tool is recommended which simply captures response capabilities.

Audit Tool: Disturbance Response Capability Charting

This tool assesses three categories of response capabilities with respect to the specified classes of disturbances: A score of either 1, 2 or 3 is assigned to each category with increasing utility of plant capabilities in dealing with the disturbance. In the case of recognition and decision-making capabilities, a score between 1 and 3 is assigned according to the degree to which they could potentially contribute to a timely and appropriate response. Where a capability is simply not present or irrelevant to the disturbance concerned, then a score should not be recorded.

(i) Recognition Capability

- Availability of Information – this dimension measures how readily the required information is available to make a favourable response to the disturbance class. This is a function of data gathering / processing and interpretation relating both to system variables/states and disturbances.

[3] We also note that an adjusted but similar calculation can be made for continuous as opposed to event based disturbances

(ii) Plant Response Capabilities

(a) Buffers

- Limits on Storage Capacity – Given the maximum available capacity of the raw material, WIP and finished goods buffers, to what extent could these buffers be used to deal with the class of disturbance being considered?
- Limits on Slack Time in Production Schedules – Given a typical production schedule, to what extent could the available slack be used for dealing with the class of disturbance being considered?

(b) Flexibility

- Limits on quality variation – Given the size of the quality tolerance range over which a product will still remain satisfactory/saleable, to what extent can this flexibility be used for dealing with the class of disturbances being considered?
- Limits on re-routing flexibility – Given the existing possibilities of re-routing the path of a product or batch through an alternative line or sequence of machines, this dimension measures the extent to which these routing options could be used to help manage the disturbance class.
- Limit to equipment/line functionality – Given the range of different production operations, which equipment/lines can perform, and the speed at which they can changeover between these operations, this dimension measures the extent to which these capabilities could be used to deal with the disturbance class.
- Limits on machine/line speed ranges – Given the available ranges of machine/line speeds, to what extent could these be used to deal with the disturbance class?

(iii) Decision Making Capability

This dimension captures the availability of capabilities such as relevant process knowledge, communication and computing support required to support decision making about appropriate use of available plant buffers and flexibilities specified in (ii). Note that this dimension excludes the algorithm or procedure used to make decisions and focuses rather on the infrastructure relevant to the decision being made.

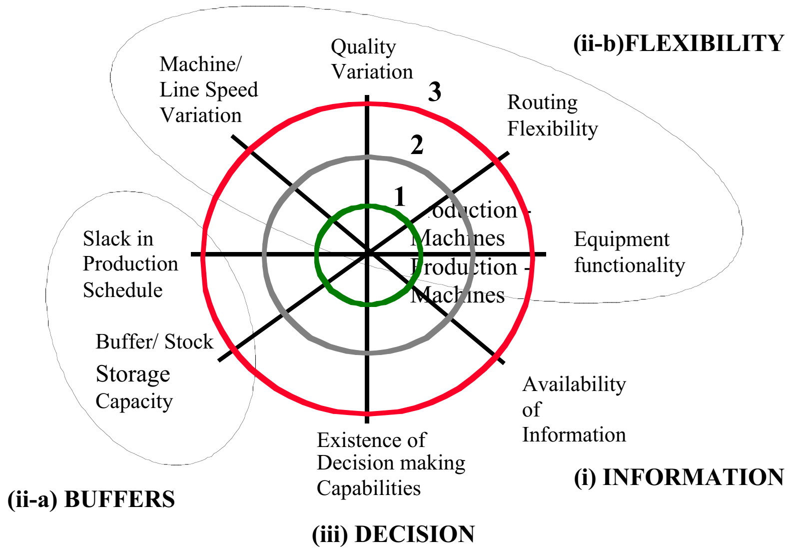

Figure 9. Disturbance Response Capability Chart

Figure 9 demonstrates how these dimensions can be combined into a diagram for assessing the response capabilities available for dealing with a class of disturbances. Those points furthest from the centre of the chart refer to capabilities, which can be readily used to respond, and the points nearest to the centre refer to capabilities, which can only make a limited contribution to the handling of the disturbance. The decision axis (iii) should be assessed last, as an understanding of the information and plant response capabilities is implicit in its completion.

We note several important points about the use of the Disturbance Response Capability Chart:

- It is possible to generate a single *capability index* by averaging each of the different ratings (1- 3) on the axes in the chart.
- Importantly, in fact we note that this tool must be used twice for each disturbance class: Once, to assess the potential capabilities existing in the plant and secondly, to assess the degree to which these capabilities are actually utilised. There are often significant differences.
- As the chart is used in two modes in order to assess both *potential* and *utilised* capabilities there are two capability indices that are relevant in this analysis:

- *Process Capability Index*: a measure of the potential effectiveness of the available resources in dealing with the disturbance class
- *Capability Utilisation Index*: a measure of the current utilisation of the available resources

As will be discussed in the case study these indices can be considerably different. The former, a reflection of the system infrastructure, the latter a refection of system behavior.

Setting Improvement Actions

Once response capabilities have been assessed both from a potential and utilisation point of view, this information can be used to identify directions for improvement in conjunction with process understanding to recommend possible change areas in the shop floor. Figure 10 illustrates the potential combinations of potential and utilize capabilities. Potential and Utilisation capability data can be used either to assess overall capabilities or the individual capabilities in Figure 9. Each of the condition types in Figure 10, implies a different improvement strategy.

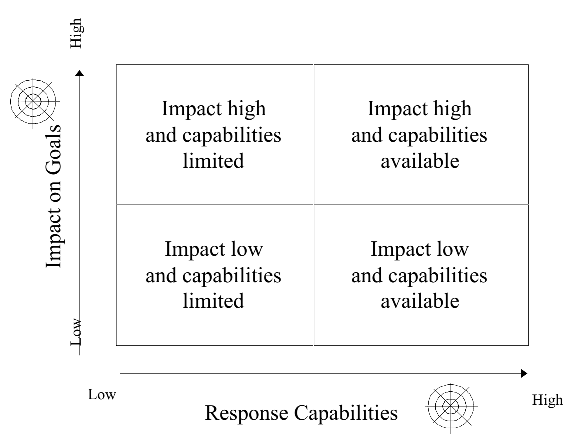

Figure 10 The Responsiveness Summary Chart

For each of the different axes in Figure 9, comparing both potential and utilization rating can lead to the following conclusion regarding follow up actions (See, Audit Tool: Response Improvement Strategy).

Audit Tool: Response Improvement Strategy

- Condition 1: Potential – high, Utilisation - high

  This implies that good response capabilities exist for the type of plant being considered and are being well exploited.

- Condition 2: Potential – high, Utilisation – low

  This implies that good response capabilities exist for the type of plant being considered but that there is significant opportunity for improved utilisation.

- Condition 3: Potential – low

  There is limited opportunity for improvement without some structural or system level improvement to the operations.

- Condition 4: Potential – low, Utilisation-high

  This implies that for an exceptional reason, utilisation is in fact exceeding available response potential as it has been assessed. This can be often be the case in the area of recognition and decision making where individuals are demonstrating significant initiative which exceeds expectation.

We have now presented the complete audit process which results in a qualitative assessment of the responsiveness of a production operation. We note that quantitative extensions and their facilitation of response benchmarking is the subject of on going research Shaw et al. (2002).

ILLUSTRATIVE EXAMPLE

Responsive Capability Analysis

Next, a section of the audit process described in the previous section is illustrated using a case study of a mechanical component manufacturer. The company consists of several several self-contained production units and this analysis considers one of these.

This production unit works on a "pull" system, however it suffers from the frequent demand fluctuation and unreliable forecasting. The company especially suffers from order variation. The production unit in question consists of a number of single unit flow cells each typically machining several different parts.

Some parts require a specialist treatment (ST) operation in addition to the machining which is not performed within the Business Unit (BU). The BU had been investigating the possibility of releasing spare capacity within the cells by reorganizing to a more functional layout. A production responsiveness audit was carried out for the production unit. Goal and disturbance, impact analysis were carried out according to the steps in the previous section, although in this case impact analysis was omitted out the key focus was on capability assessment.

Figure 11 illustrates an overlaying of the potential and the utilization response capability assessments for this production unit in dealing with short-term customer order variations[4]. This chart was generated based on the procedures in section 3. The rationalefor the assessments are summarised as follows: For *recognition* of the problem the only ways in which this could be done was by fax and/or telephone calls from the customer hence potential (without any IT support) was limited, although utilization was assessed as very good. Potential *flexibilities* were identified at three different levels in the operation, machine, cell and

[4] Two demand-end disturbance types were considered. In addition to the short-term variations, response to longer term (unplanned) trends was also assessed.

production unit and also in the ST operation. Potential *BU flexibilities* were identified as being able to subcontract work, possibly to other BUs. ST was also potentially able to be flexible, being capable of processing any part. Potential *capacity or buffering* for dealing with short term order variations was identified at the machine and cell levels. A number of machines also had spare capacity. *Cell capacity* was flexed by using extra shifts. Manning was proving to be a serious constraint. Recruiting, training and retaining enough personnel was a problem and numbers of agency staff had to be used. Special treatment capacity was also becoming difficult to flex. The scoring of each factor was done in a qualitative but systematic manner in conclusion with the company personnel.

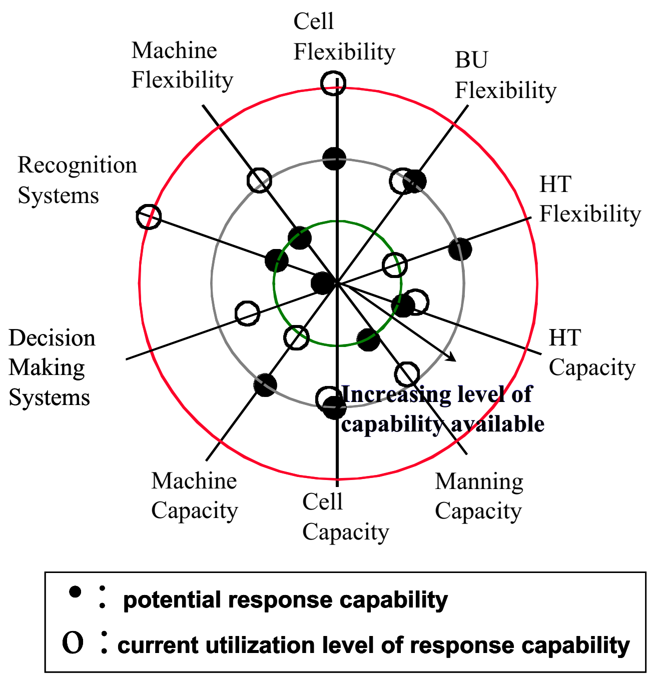

Figure 11. Superimposed Potential and Utilisation Charts

Interpretation of the Response Capability Chart and Setting Improvement Actions

In this section we provide recommendations on responsiveness improvement areas based on the capability assessment outlined in the previous section.

Interpreting the response capability charts

Figure 11 can be interpreted in terms of a number of different types of conditions:

Condition 1: Potential – high, Utilisation - high

This implies that good response capabilities exist for the type of plant being considered and are being well exploited. This is the case for the cell and BU level flexibilities.

Condition 2: Potential – high, Utilisation – low

This implies that good response capabilities exist for the type of plant being considered but that there is significant opportunity for improved utilisation. For this BU, this is the case for the exploitation of special treatment flexibilities and machine capacities.

Condition 3: Potential – low

There is limited opportunity for improvement without some structural or system level improvement to the operations. This is the case for current recognition and decision-making systems, manning capacity levels and machine flexibilities.

Condition 4: Potential – low, Utilisation-high

This implies that for an exceptional reason, utilisation is in fact exceeding available response potential as it has been assessed. This is the case in the area of recognition and to a certain extent decision making where individuals are demonstrating significant initiative (albeit ad hoc) in order to preempt the impact of order variations.

Improvement Areas Recommendations

On the basis of the response capability potential analysis, there appeared to be at least two critical areas where improvements to existing systems would make a significant impact on response capabilities.

Utilisation Improvements

On the basis of the *response capability utilisation* analysis, there were also areas where improvements to existing systems would make a significant impact on response capabilities:

- Better exploitation of Cell/BU capacity: improving the use of available buffering in conjunction with a rigorous programme aimed at reducing change over times
- Special Treatment (HT) Flexibility/Capacity: It is increasingly critical to schedule this section of the operations as a bottleneck in order to best exploit the capacity (and flexibility) that does exist.

Structural / Systems Improvements

On the basis of the *response capability potential* analysis, there appeared to be at least two critical areas where improvements to existing systems would make a significant impact on response capabilities:

- Machine Flexibilities and Capacities: It was recommended that Production Units group small volume similar process parts as a means of determining the scope of the proposed "flexible cell”
- Recognition and Decision Making Systems: The introduction of one or more standard processes is required to reduce the number of order variation. Clearly, better early warning data from the

customer or the introduction of collaborative planning, forecasting and replenishment (CPFR) would significant enhance this process.

TOWARDS A RESPONSIVE AUDIT FOR THE ORDER FULLFILLMENT PROCESSES

We now conclude this paper, by examining some of the issues associated with extending the production responsiveness audit to cover the entire order fulfillment process as described in Figure 5. The following provides a brief introduction to the role, the disturbances, and the goals of each process we are currently focusing.

- (Sales) Order processing: This provides order capturing, quotation and order promises. As in the figure, the order promising is the 'front end' of a company's order fulfillment processes. It is considered that the 'order change' and 'rush order (lumpy order)' are typical disturbances in this level. Typical goals are increasing 'schedule adherence rate' and 'reduction of order promising time'.
- Supply Planning: This provides timely supply of materials for production. Typical disturbances are 'supplier failure' and 'rush order (lumpy order)'. Typical goals are 'increasing on-time-in-full rate' and 'defect free delivery rate'.
- Distribution and Receiving stocks (warehousing): This provides timely delivery of finished goods and keeping materials (e.g. finished goods or raw materials). Typical disturbances are 'transportation failure' and 'rush order (lumpy order)'. Typical goals are 'reduction of transportation costs' and 'reduction of inventory holding costs'.
- Forecasting: This provides accurate, reliable view of market demand (Baseline statistical forecast is generated as a starting point). Typical goal is 'forecast accuracy'. The accuracy of forecasting significantly impacts on the planning and manufacturing.

In order fulfillment level analysis, one has to consider the conflicting objectives among processes and the propagation of the disturbances to the other processes. For example, traditionally sales people are responding to customer request for quotations. Sales operations do not have planning ownership and hence should not promise to customers more than the manufacturing can produce. However in practice this is not always the case since the sales people try to promise more than they can deliver in order to get more customer orders. This kind of behavior results in infeasible promises leading to overloaded manufacturing floor (Goals in both processes will be impacted by wrong decisions). We also note the possibility for potentially complementary situations, in which, for example, a relatively unresponsive production operation (designed for high volume, large batch production) is supplied by highly responsive finished good stock holding leading to a responsiveness order fulfillment process as a whole.

Hence, the extension to order fulfillment auditting is not simply an expansion of scope but involves the need to consider the quantification of a large number of interacting issues (Shaw et al, 2002).

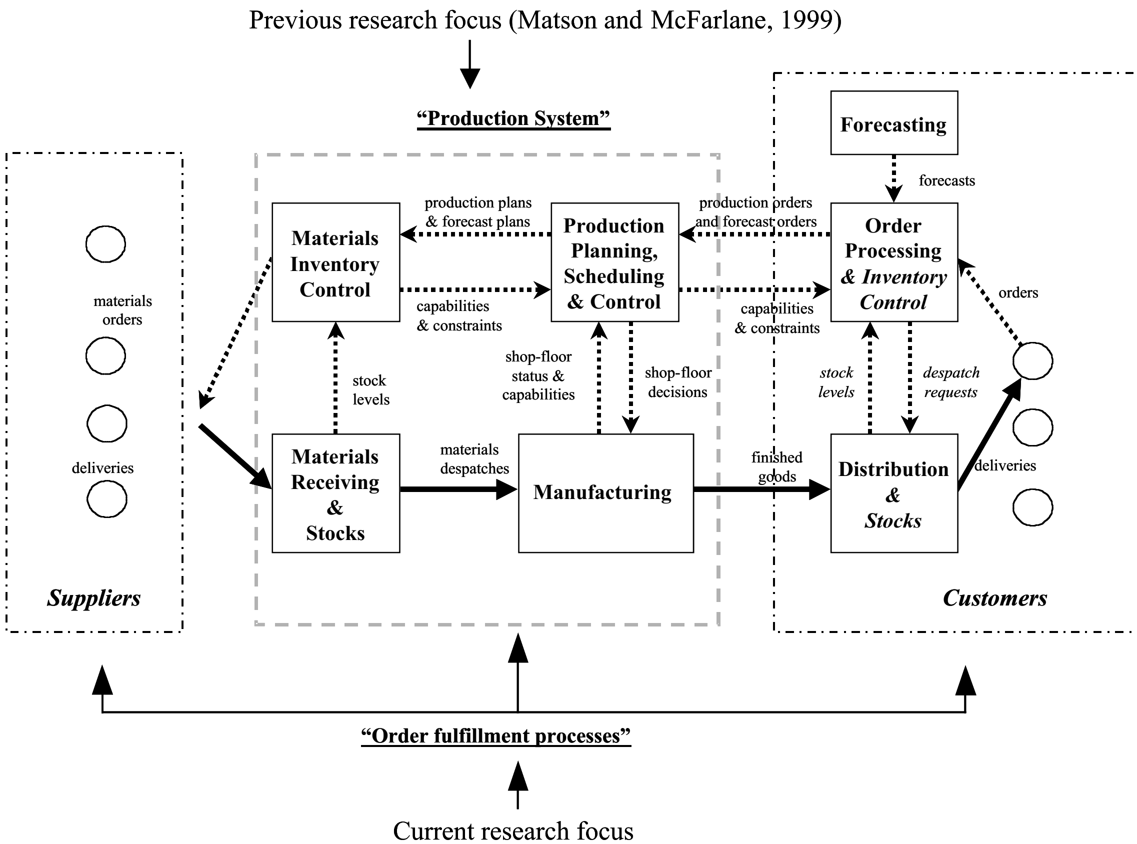

Figure 13. Order fulfillment processes

CONCLUSION

In this paper, we reviewed a number of production responsiveness tools, introduced a responsiveness audit process and illustrated it with a short case study. We have primarily provided a framework for interpreting production system behaviour: the response of the system to disturbances with reference to its goals. As Ohlager (1993) point out, we found that it was very hard to build a general relationship between flexibility and profitability. Although the charts presented in the case study provide quantitative assessments of a sort, they do not in themselves provide information sufficient for a detailed study of response mechanisms. However, the process of completing the charts can indicate which areas to concentrate on and the associated discussions and written responses capture important clues as to how detailed assessment of and improvements to response mechanisms can be made. Several projects using audit tools with the several companies have proven valuable in initiating detailed responsiveness studies relating to stock control in a mechanical component manufacture, a drink manufacturing company and a steel-making company. We also briefly introduced an audit method for order fulfillment processes, which is an extension of our production responsive audit. The area is being pursued as part of our ongoing research with several many industrial partners (refer to, http://www.prochart.org), and additional focus is being placed on developing a more quantified approach.

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