A Production Responsiveness Audit

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Abstract

In the late 1990s responsiveness has become a key differentiator for manufacturing companies aiming to better support their customers with more timely deliveries and more appropriately customised products. In addition, significant internal improvements in cost and stock reductions can be achieved through a more responsive operation.

This paper firstly reports on a responsiveness auditing tool that has been developed and refined over the last four years and used within a range of industries. The audit provides a framework for examining the ability of a production operation to respond to current 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 in 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. Finally, the paper introduces current developments in which the audit is being extended to apply to the entire order fulfillment process.

Key Words
Responsiveness, agility, flexibility, production, audit, disturbance

1. 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. 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 overall order fulfillment domain.

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:

- Enhanced 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 prioritising 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. variation 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 focussed 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 given 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 <u>can</u> 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 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 focussed 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.

2. 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.

2.1. A Working Definition of Production Responsiveness

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

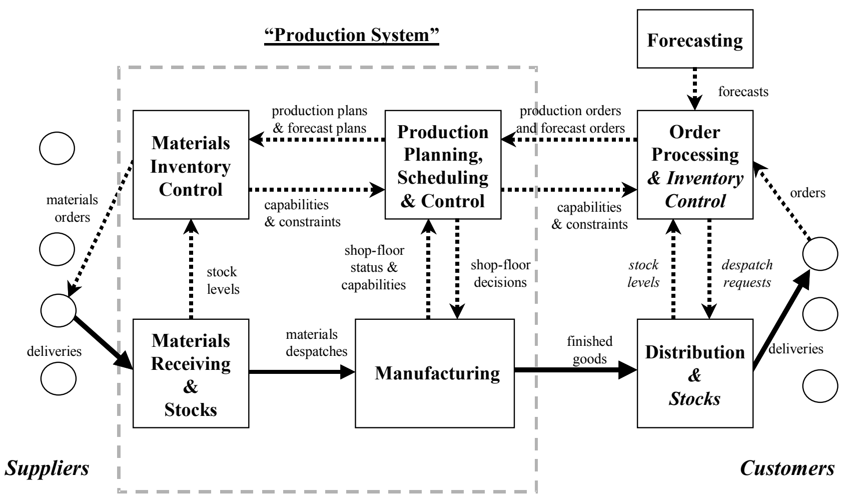

Figure 1. Delineation of Production Activities (Overall order fulfillment processes)

At present, there appears to be 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 disturbance*s* 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. The reader is referred to a previous companion paper (Matson and McFarlane, 1999) for further details on this definition.

2.2. Linking Responsiveness to Agility, Flexibility and RoPUstness

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 relationship between responsiveness and agility, flexibility and robustness.

2.2.1. Agility

Agility is described by (Goldman et al. 1995, Kidd, 1994) 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.

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". The link between agility and responsiveness is outlined in Figure 2.

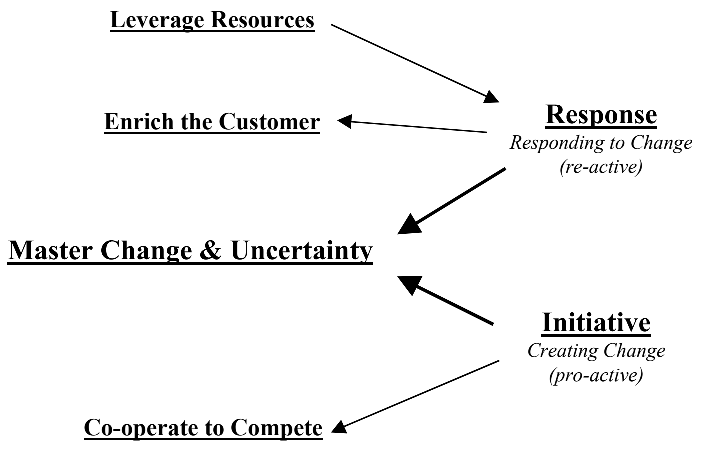

Figure 2. ContriPUtors to Agility

2.2.2. 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). 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*.

2.2.3 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.

2.2.4. Requirements for Production Responsiveness

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

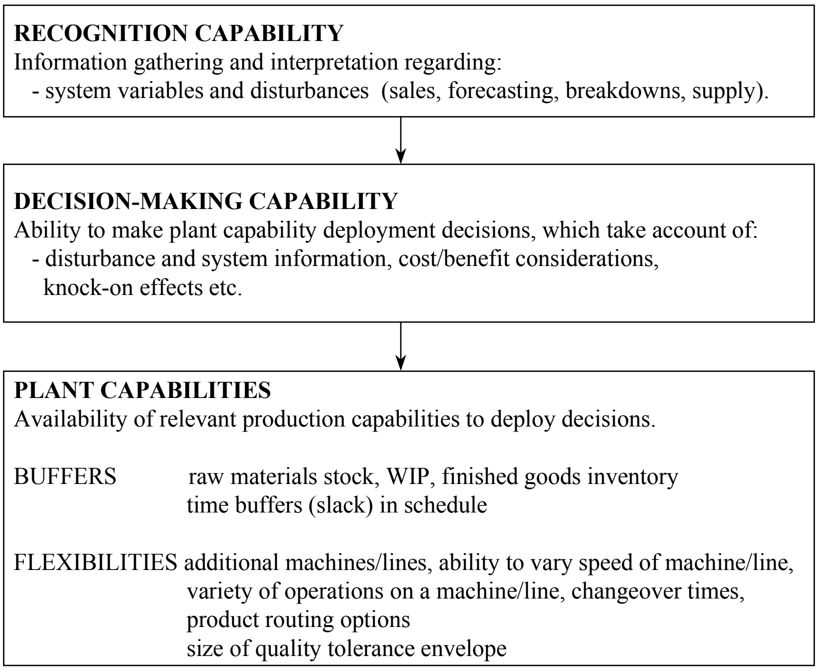

Figure 3. Factors Influencing Production Responsiveness

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.

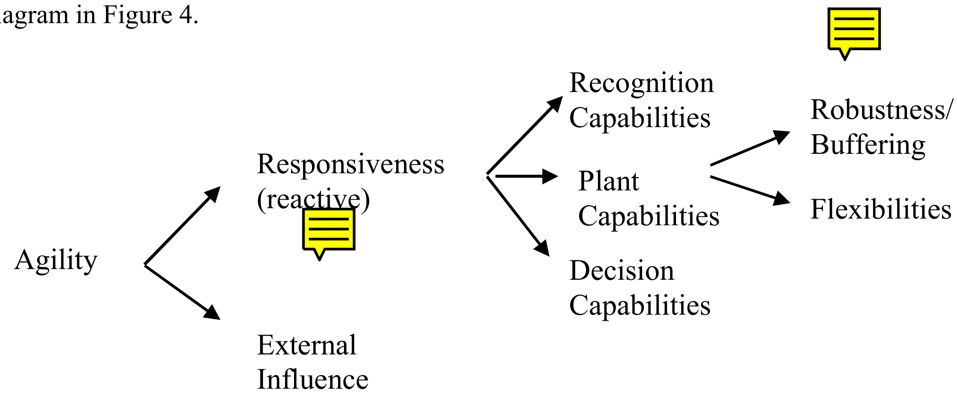

Figure 4. Linking of Different Change Management Characteristics

3. THE AUDIT PROCESS

In this section the audit process and necessary support tools required to undertake the audit are described. As we 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):

- *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.
- *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.
- *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.
- *Impact Analysis: A* detailed impact analysis was performed for a number of disturbances as a means of estimating the effect of order variations.
- *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 utilised
- *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 given 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

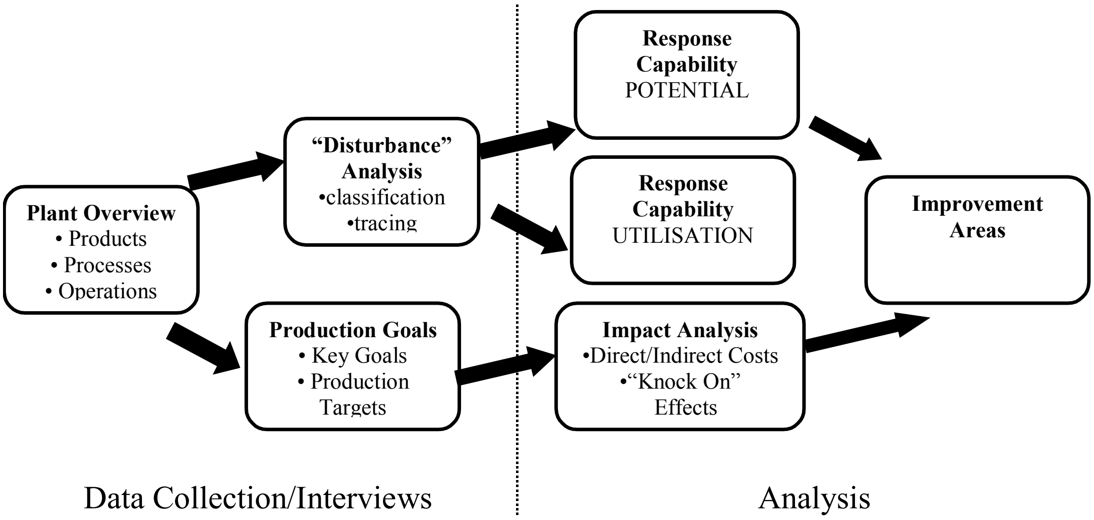

Figure 5. Overview of Audit Process

3.1. 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.

3.2. Collection / Clarification of Production Goals

A systematic approach for assessing the impact of disturbances is by 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 identify the main production goals and generate a simple tree-diagram of the production variables that affect them. This leads to a set of goal map diagrams, which can generally based around cost and delivery. Examples of two typical goal maps are given in Figures 6 and 7.

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

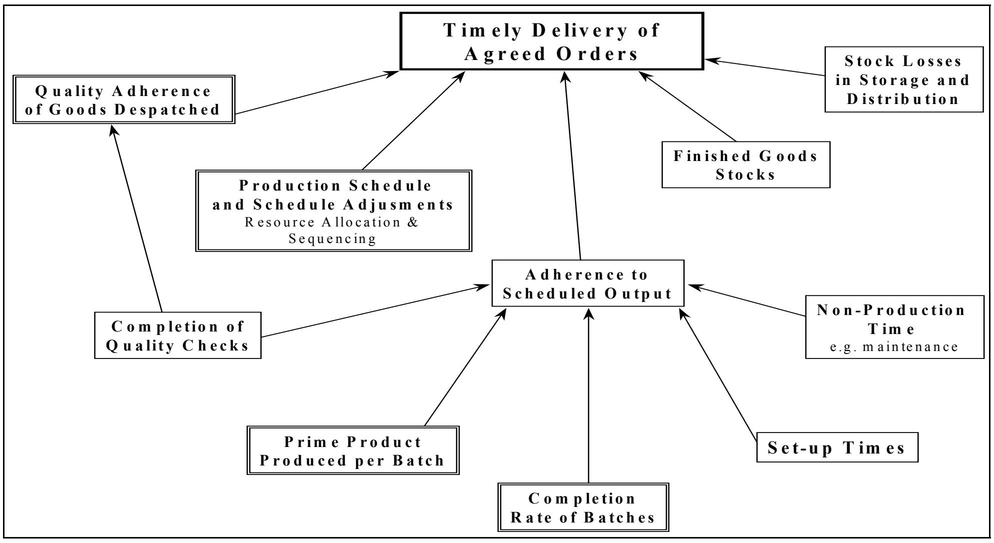

Figure 6. Generic Goal Map Diagrams for Delivery

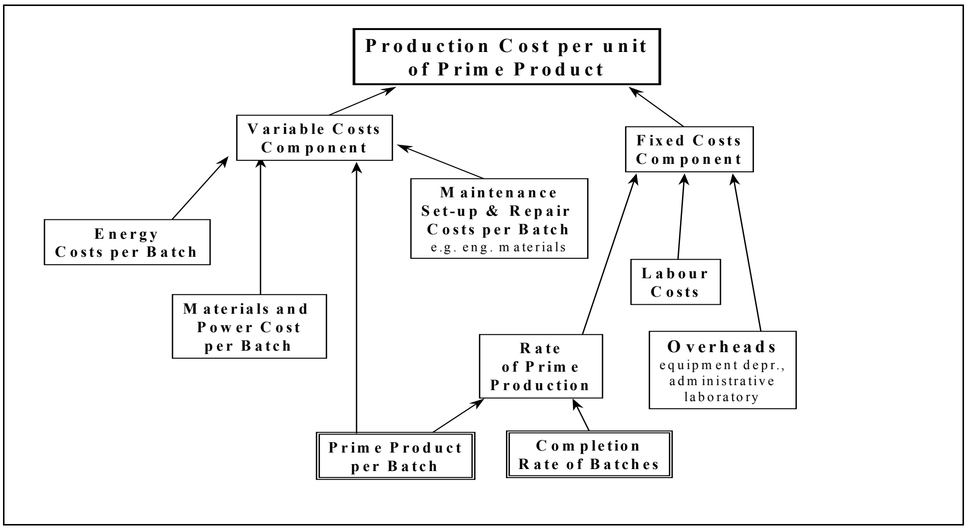

Figure 7. Generic Goal Map Diagrams for Cost

The goal maps are used as a guide for identifying and tracing the impact of disturbances during the next two steps of the audit.

3.3. Disturbance Collection / Selection

This step may occur either after or in parallel to the previous step. An identification of the key 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 tables for collecting together disturbances as they are contributed through interview or workshop. The first table simply classifies the physical source of the different disturbances, while the second –Table 3- provides an initial assessment of the way in which each disturbance affects the production goals identified in the previous section.

Table 2. Disturbance Classification Based on Physical Location

Location	Supply	Production - Area 1	Production - Area 2	Production - Area - 3	Plant-Wide Systems	Demand
Disturbances						

Table 3. Disturbance Classification Based on Production Goals Influenced

Goal	Goal 1: Cost	Goal 2: Delivery
Disturbances		

The tables can be used in the following way. Tables 2 and 3 are completed by facilitators during interviews, and then in a brief meeting, plant personnel are asked to highlight the most *important* disturbance in each column in Tables 2 and 3. They are then asked to select the most *important* disturbance from these highlighted disturbances. That disturbance is then removed from Table 2 and the process repeated until 3-5 disturbances have been identified[2]. This screening process is clearly subjective, but where necessary either Figure 6 or Figure 7 can be used to clarify the likely effect of the disturbance on plant goals.

3.4. 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[3]

The Disturbance Responsiveness Chart, illustrated in Figure 8, is used to capture the audit 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). 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.

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.

[2] Experience has shown that the analysis of greater than 5 disturbances is unhelpful as it reduces the focus on the main issues the plant is facing.

[3] We also note that the tools described in sections 3.4, 3.5 have previously been described in Matson and McFarlane (1999).

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.

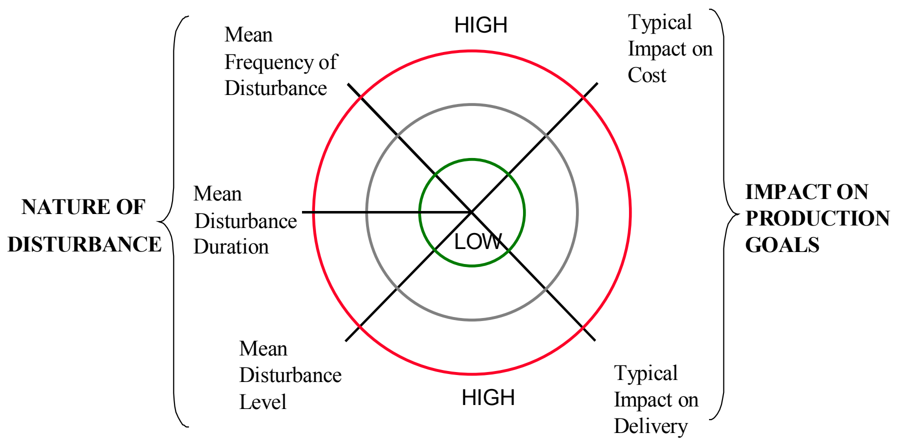

Figure 8. Disturbance Responsiveness Chart

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[4]

3.5. 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
- **PUffers -** 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 simple captures response capabilities. Importantly, we note that this tool must in fact 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.

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.

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

(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.

(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).

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.

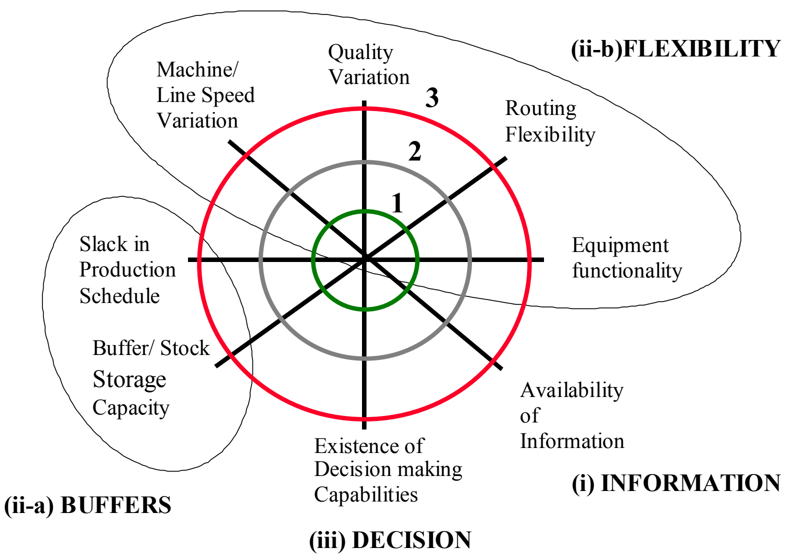

Figure 9. Disturbance Response Capability Chart

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.
- As described above, the chart is used in two modes in order to assess both *potential* and *utilised* capabilities Hence 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 utilisation of the available resources

3.6. 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. There are two steps in setting improvement actions:

For each of the different axes in Figure 9, comparing both the potential and utilisation rating can lead to the following conclusion regarding follow up actions:

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.

This will be illustrated in the next section.

4. ILLUSTRATIVE EXAMPLE

4.1. Responsive Capability Analysis

In this section we briefly illustrate the charting tools and responsive capability analysis described in the previous section using a case study of a mechanical component manufacturer. The company consists of several several self-contained production units (PUs) 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 PU. The PU 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.

Figure 12 illustrates an overlaying of the potential and the utilization response capability assessments for this production unit in dealing with short-term customer order variations[5]. This chart was generated based on the procedures in section 3. The rationale for 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. Potential *flexibilities* were identified at three different levels in the operation, machine, cell and production unit and also in the ST operation. Potential *PU flexibilities* were identified as being able to subcontract work, possibly to other PUs. 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 with the company.

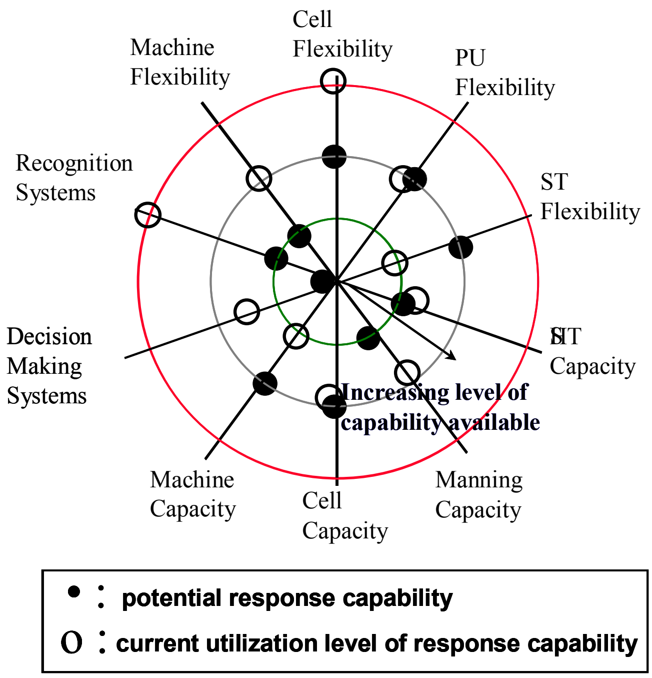

Figure 12. Superimposed Potential and Utilisation Charts

4.2. 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.

[5] We classified order variations into two types, short term and long term. Short-term order variations are characterised by their unpredictable nature, their need for a reactive response, and a typical time scale for recognition, decision making and adjustment process of a few days. This did not mean that the effects of a short term order variation were over in a day or two. It seemed likely that often it would take a week or possible two or more for things to get back to "normal" -whatever that is. Long term order variations tended to arrive with some prior warning and typically be seasonal trends or increasing ramps in required output. These variations allowed for a more proactive response to the problem and had characteristic time scales of a few months.

4.2.1. Interpreting the response capability charts

Figure 12 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 PU 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 PU, 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.

4.2.2. Improvement Areas

On the basis of the response capability potential analysis, there appears 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/PU 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 appears 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 PU 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.

5. Towards a Responsive Audit for the Order Fulfilment 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 13. 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 fulfilment 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 quotations. The sales people do not have planning ownership and 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 to infeasible promises leading to overloaded manufacturing floor (Goals in both processes will be impacted by wrong decisions).

Hence, the extension to order fulfillment auditting is not simply an expansion of scope but involves the need to consider a large number of interacting issues. In particular, research is focussing on the role of the planning, scheduling and control activities within the business on overall responsiveness.

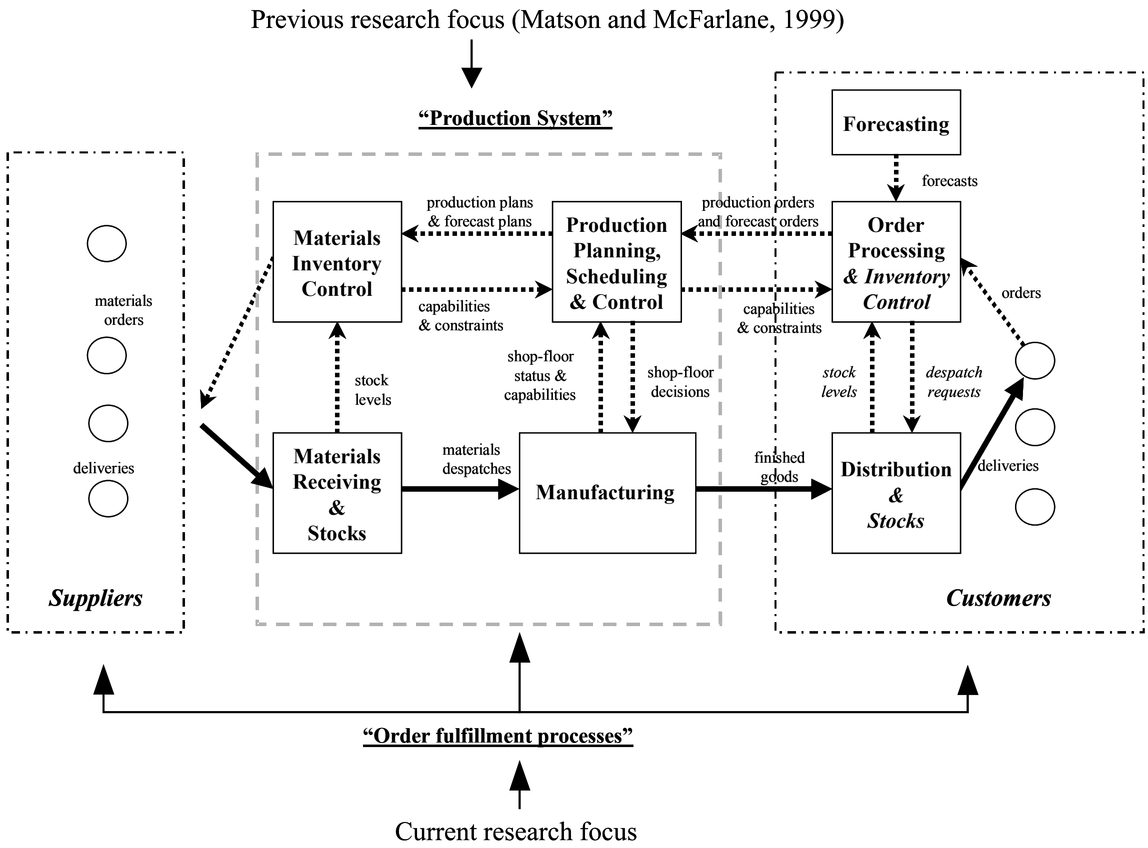

Figure 13. Order fulfillment processes

6. 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. 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 fulfilment 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, www.prochart.org), and additional focus is being placed on developing a more quantified approach.

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