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Tools for Assessing the Responsiveness of Existing Production Operations

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- ABSTRACT -

A set of audit tools is being prepared for assessing the response capability of a production operation, as part of an EPSRC[1] funded investigation into improving the responsiveness of manufacturing production systems. These tools are based on the idea that the ability to respond is linked to i) the nature of the disturbances or changes requiring a response, ii) their impact on production goals and iii) the decision processes which initiate system responses to disturbances.

1. INTRODUCTION

It is often stated that the most critical capability for a manufacturing company today is its ability to manage change. It is therefore surprising that production performance is still frequently assessed based on "steady-state" operating conditions. This paper focuses entirely on production performance under "non steady-state" operating conditions - far less comfortable or easy to assess but in all probability more critical to the ongoing success of an operation.

1.1 Aim of Responsiveness Analysis

The principal aim of the responsiveness assessment method reported in this paper is to provide an indication as to how greatly a production operation is affected by internal/external disturbances and how well it uses its existing infrastructure to respond. We note here that disturbances may not necessarily be of a negative nature in terms of the overall business, but they can often place additional pressures on production. Companies' responses to disturbances are often not systematic and may not take into account the full effects of a response on high-level production goals. Rather they are commonly made on the basis of localised information and low-level goals. The responsiveness analysis procedure aims to help a company evaluate its current ability to handle non-steady-state conditions and to decide appropriate actions for improving its responsiveness. For example, it is intended that the procedure will assist a company to answer the following questions:

- What is the effect of last minute order changes on the effectiveness and quality of production operations?
- What is the overall impact of breakdowns on production schedules and what decision making processes need to be changed as a consequence?
- What is the effect of short term raw material unavailability in terms of meeting production delivery and cost targets?

1.2 A Responsiveness Analysis Tool

In order to address these type of questions, a methodology for assessing production responsiveness is being developed based on the following key steps:

1. The identification of critical production goals and their decomposition or division across production units or operations (i.e. identifying how different parts of the company contribute to them).
2. An examination and classification of existing disturbance / change conditions.
3. Assessing disturbance impact and response effectiveness in terms of production performance.

These steps are integrated into an auditing tool, as described in Section 4, which provides a company with a methodology for assessing and prioritising critical problem issues, and setting action plans. The scope of the assessment discussed is confined to production operations, thus other manufacturing responsiveness issues associated with product and process development are excluded. Only qualitative methods are discussed, although extensions to include quantitative approaches are under development.

A second outcome of the audit tool is an assessment of existing plant capabilities which have potential to

[1] Engineering and Physical Sciences Research Council

be used to respond to disturbances, but which may currently be overlooked or under-utilised.

In addition to providing a useful assessment tool, the audit also generates a goal-oriented process description, coupled to critical disturbance modes, which should provide a basis for the development of more responsive decision making and control systems.

2. PRODUCTION RESPONSIVENESS

2.1 Defining Production Responsiveness

The production-related operations of a manufacturing company are outlined in Figure 2.1. Production system responsiveness is viewed here as one aspect of the responsiveness of a manufacturing organisation seen as a whole (see McFarlane et al, 1997). 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).

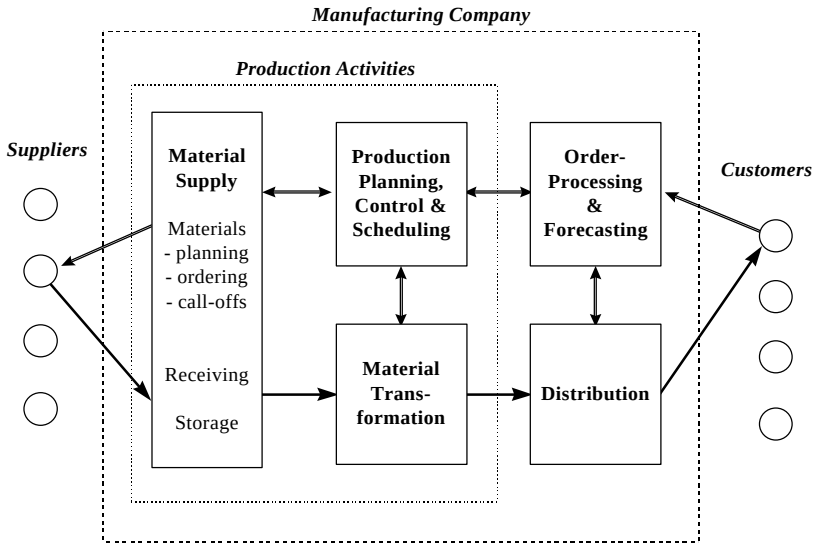

Figure 2.1 - Delineation of Production Activities showing material and information flows.

At present, there appears to be no generally agreed definition of responsiveness in the manufacturing literature. The following working definition is proposed (see Barclay et al, 1996):

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

This definition hinges on an understanding of the following terms which are explored subsequently (see also Matson & McFarlane, 1997).

- the nature of production goals and how they are interrelated
- the type of disturbances encountered
- the ability to respond - mechanisms and measures

2.2 Link to Existing Work

In this section we briefly review some related concepts reported in the literature. A more detailed review can be found in Matson and McFarlane (1997).

2.2.1 Agile Manufacturing

Agility is described by Goldman et al, (1995) as the ability of a company to operate “profitably in a competitive environment of continually, and unpredictably, changing customer opportunities”. Whilst responsiveness is concerned with the manner and effect of any response a company makes to changing conditions, it should be noted that the ability to respond to events is only one aspect of agility. As described by Goldman et al, (1995), an agile company may also set out to influence the various environments in which it operates by means of many different activities, including marketing, co-operative alliances, new product and process development.

2.2.2 System Flexibility and Robustness

Flexibility has received much attention as a manufacturing research topic in the last decade or so. The various forms of machine and subsystem flexibilities found within a production system often represent means responding to disturbances. However, the concept of 'total system flexibility', introduced by Slack, (1990), is more immediately relevant to responsiveness, which is also a 'total system' property:

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

While system flexibility constitutes a possible means for responding to disturbances, a flexible system is not necessarily responsive, since the system must also be able to judiciously employ its flexibility in response to disturbances.

Correa and Slack, (1996) recognised the importance of another type of total system behaviour which complements the concept of total system flexibility, which they call 'system robustness flexibility'. The following definition is put forward to summarise this concept:

> *System Robustness is the ability of a production system to maintain its goals in the face of disturbances originating from suppliers or within the production system.*

System robustness represents a particular type of responsiveness, whereby the system guards against negative impacts of supply and internal disturbances. There are two reasons why system robustness is not equivalent to responsiveness: 1) a response may be appropriate when the impact of a disturbance is positive 2) responsiveness to customer disturbances is not incorporated.

3. DISTURBANCE ANALYSIS

3.1 Defining and Classifying Disturbances

Disturbances can be found at the supply and customer interfaces of a production system, as well as internally and in its environment. Barclay et al, (1996) introduce the concept of "responsiveness drivers" which are described as "the events or influencing factors to which the company has to respond". Correa and Slack, (1996) refer to "stimuli" or "unplanned changes" affecting production, which occur "independently of the system's intentions".

> *A disturbance is a change (internal or external) affecting the performance of a production system, which is either outside its control or has not been planned.*

3.2 Disturbance Classification by Source

To help identify and describe disturbances during the audit process, a classification of common disturbance sources has been developed. The list is intended to ensure that a comprehensive picture of the main issues facing the company is obtained. The reference list of disturbances is broken up into three broad areas: upstream, internal and downstream (Caputo, (1996) presents a similar list).

1. Upstream disturbances

   Materials quality problems, supplier production problems, materials delivery delays, material property variations, incorrect deliveries.

2. Internal disturbances

   2.1 Information, control and decision-making

   Control and communication system failures, operator errors and omissions, recording / communication errors, materials ordering errors, materials stock control problems.

   2.2 Production Equipment and Labour

   Machine breakdowns, variability in machine performance (quality, cost, production rate), unavailability of labour

   2.3 Material Handling and Flow

   Blockages, handling equipment failure.

3 Downstream disturbances

   Make to order:

   Rush orders, changes to orders (quantity, due date), quantity and mix variations (e.g. due to demand variations in customer's business), customer production problems.

   Make to stock:

   Demand variations (e.g. due to seasonality, marketing activity, competitor activity), forecasting errors, finished goods delivery delays, lost stock, poor stock monitoring.

3.3 Assessing Disturbance Impact

Having obtained a list of significant production disturbances, their actual or potential impact on production goals must be assessed. In order to appreciate the impact of disturbances on production operations, it is of value to understand the immediate point of impact of each disturbance on the system. The immediate impact may be localised (e.g. machine failure) or distributed (e.g. power failure). It should be noted that disturbances with a localised immediate impact may be propagated through the system, by subsequent material and information processing.

3.4 Responding to Disturbances

The ability of a production system to respond is ultimately measured by the total overall effect which the disturbances have on the system's achievement of its goals. This overall effect incorporates both the initial impact of the disturbance, together with the effects of any responses. When the impact of a disturbance on a goal is negative, responsiveness is associated with an absorption of the effect. When the impact on a particular goal is positive, responsiveness is associated with the degree of operational enhancement which results. Thus responsiveness is also about detecting and exploiting opportunities created by disturbances.

Disturbance Detection and Monitoring

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. Caputo, (1996) notes that it is possible to deal with uncertainties by reducing them or by accepting and withstanding them.

Factors Affecting Responsiveness

The following areas have been identified as being of importance in the development of more responsive manufacturing systems:

- human/organisational
- equipment/processes
- decision, control and information systems

The selection of appropriate methods for improving responsiveness will form part of the final audit.

4. AUDIT FRAMEWORK

The aim of this section is to provide a brief introduction to the auditing methodology under development at University of Cambridge for obtaining a comprehensive and systematic assessment of a company's i) current ability to manage change in its production environment and ii) existing capabilities which may potentially be used to manage change in new ways. The critical point about the audit is that it is specifically targeted at non steady-state conditions, in contrast to many other production assessment tools which apply primarily to steady-state operating behaviour. This in fact presents an immediate problem as there is typically very little systematic production data available for these conditions.

4.1 Aims and Benefits

The aims of the audit - which is developed as a series of interviews, interactive workshops and data analyses - are as follows:

1. To provide a unified[2] identification and classification of the principal disturbances affecting production from both internal and external sources.
2. To establish a link between these disturbances and the overall goals of production, using both quantitative and qualitative information.
3. To systematically assess disturbances in terms of their effect on production goals and to establish prioritised improvement actions based on this assessment.

The complexity of responsiveness analysis lies in the accurate determination of the link between different disturbances and goals and in dealing with potential overlaps and conflicts that may exist between goals and their contributing sub goals. Additionally, underlying these aims is an assessment of the current production capacities and flexibilities which can greatly influence the response capability of the production operation.

[2] Often opinions of individual personnel may differ significantly

4.2 Outline of Audit Procedure

Production operations are generally subject to many disturbances and an exhaustive quantitative assessment of responsiveness is generally not possible, nor sensible. Thus a large component of the audit is necessarily of a qualitative nature, involving discussions with and amongst plant personnel. The qualitative component of the audit is intended to unify the different interpretations and perspectives of production employees regarding disturbance impact and response capabilities. It should also highlight areas where there are conflicting or ambiguous assessments.

1. Process Mapping

Familiarisation with the products, markets, plant, organisation and IT infrastructure.

2. Main Goals

The main goals of the operation are identified, usually in terms of cost, quality and delivery.

3. Disturbance Identification

The classification of disturbance sources in section 3.2 facilitates this process.

4. Goal Mapping

Clarify the role of each production unit / individual in achieving goals. Identify where co-ordination between units is required to achieve goals. Figure 4.1 shows the influences on quality adherence in an industrial partner's factory.

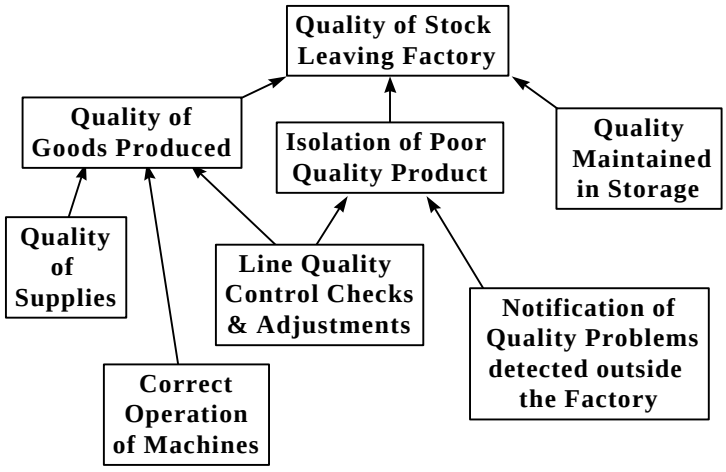

Figure 4.1 Breakdown of Quality Conformance Goal Across Production Operations

5. Disturbance Prioritisation

In the companies studied, the initial number of disturbance-goal links reached well beyond 50. Clearly, some links are of more importance than others in terms of understanding and improving responsiveness, and this number is reduced via a prioritisation of disturbances according to a number of different criteria: severity of impact on each goal, frequency of occurrence, complexity of responding, current ability to respond, degree of systematisation of response (i.e. is a procedure in place for handling the disturbance?)

6. Impact and Response Tracing

This involves detailed impact and response analysis of a few disturbance-goal pairs selected during the disturbance prioritisation step. Tracing is initially qualitative. Quantitative analysis may then follow via data-collection or simulations. Responses are classified into two types, depending on whether they employ robustness or flexibility. These types of robustness and flexibility are not synonymous with the "system" robustness and flexibility described in section 2.2.2. Rather, they refer to specific internal mechanisms which may be employed to contribute to overall system responsiveness.

Within the production system, robustness is synonymous with time and material buffers which, when established, enable rapid response to disturbances. Flexibility is associated with the availability of choices which may be used to respond to disturbances (e.g. machine capacity, changeover times, product routing options, variety of products able to be made by one machine). Both flexibility and robustness vary with time. Flexibility varies with plant condition and closeness of plant to capacity. Robustness depends on current buffer levels, which are a complex function of past plant behaviour and the buffer management strategies used. Both flexibility and robustness come at a cost, and in practice,

various combinations of the two different types of response strategies must be used according to the (changing) circumstances.

7. Identification of Response Potential

During detailed disturbance tracing, existing potential response mechanisms should be identified, as well as current response mechanisms. The following list is intended to act as a checklist for identifying areas where responses should be considered. It should be noted that co-ordination between the these mechanisms may be required to produce an adequate overall system response: maintenance schedules and procedures, machine control (PLCs, N/C, PC-based), process control (DCS, SCADA), WIP buffer management, purchasing decisions and supplies inventory management, panning, scheduling and sequencing, shop floor decision making and communication, operational and quality control procedures.

8. Numerical Responsiveness Measures

Having selected particular disturbance-goal pairs, for which responsiveness improvements are sought, a means of quantifying the responsiveness of the system to the chosen disturbances must be developed. Ideally this should be constructed using existing production performance measures. A numerical measure of responsiveness provides a foundation for empirical or simulation studies. Responsiveness measures should provide an objective means of comparing existing responsiveness with that resulting from new operations management and manufacturing control strategies. A related activity at Cambridge is examining the relevance of so called *holonic manufacturing* methods (see van Brussel, 1994, McFarlane, 1995) in this context.

4.3 Audit Status

The audit has been trialled in a preliminary form within an FMCG-based collaborator's operations, and a revised version will trialled at several further industrial sites in the early part of 1998.

5. CONCLUSION

The approach adopted should result in an extensible framework for deciding priorities for improvement in decision-making and operations management practices. It should also help initiate responsiveness improvement projects by identifying potential response mechanisms and the trade-offs involved in responding to disturbances.

6. REFERENCES

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