Assessing and Improving The Responsiveness of Manufacturing Production Systems

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Summary

In a market where rapid changes in demand, product mix and volumes are now commonplace and where the requirement for a production operation to be reliable in terms of quality and delivery performance is now a base-level expectation, an appropriate set of response capabilities is critical. This paper presents a link between agility, responsiveness and flexibility in the context of production operations and examines key issues associated with determining the most appropriate manner for improving production responsiveness, and, in particular, consideres the role of flexible decision making and control strategies in this context.

1. Introduction

1.1 Background

The material presented in this paper is based on the results of a two year investigation established in 1997[1] with the intention of examining the issue of responsiveness as it impacts on a production operation, and in particular, investigating the role of new control and decision making strategies in delivering improved response. The paper reviews the definition of responsiveness in a production context and compares this to related issues of organisational agility and system flexibility. Methods for assessing the responsiveness of a production operation are introduced and work seeking to improve responsiveness through changes to control and decision making are described.

1.2 Defining Production Responsiveness

For the purposes of this paper, the production system is viewed as a combination of the materials supply, production planning, scheduling, control and material transformation 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).

A working definition of production responsiveness adopted in the two year project is as follows (Matson and McFarlane 1998; Matson and McFarlane 1999a):

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. The reader is referred to previous papers for further details on this definition.

1.3 Agility, Responsiveness and Flexibility

In this section we briefly relate responsiveness to the concepts of agility and flexibility that are frequently discussed in the literature.

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1.3.1 Agility and Response

Agility is described in (Goldman et al. 1995) 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. The link between agility and responsiveness is outlined in Figure 1. What is clear from this diagram is that effective response is a critical attribute, and represents the *reactive* capabilities of an agile organisation

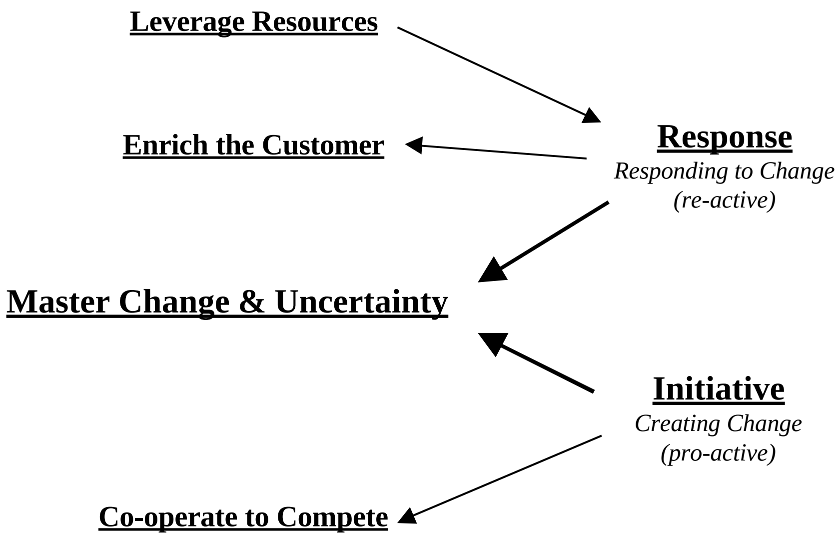

Figure 1 Contributors to Agility

1.3.2 System Flexibility

Flexibility has been dealt with many different authors in the literature, but 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. To this end we follow the perspective of (Slack 1990) who 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):

> *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 and Buzacott 1996), total system flexibility is a complicated function of many system attributes, including machine and subsystem flexibilities. 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[2]. In particular, we will discuss the additional need for appropriate situation appraisal and decision making in achieving good response in the next section.

2. Assessing Responsiveness

2.1 Specifications for Responsiveness Improvement

In order to be able to specify appropriate ways to improve responsiveness, it is important to be able to identify - for a particular disturbance - the different response capabilities required by a production operation. Figure 2 outlines the response capabilities identified in this research (Matson and McFarlane 1998). A suitable combination of the qualities is critical for effectively responding to a disturbance which alters the normal operating pattern of the plant. (In particular note that flexibility is perceived as being *only one* of the capabilities needed for effective response.) A simple quantification methodology has been developed for assessing both a) the extent of available response capabilities and b) the level to which these are currently exploited (Matson and McFarlane 1999a). In particular, the methodology identifies situations where improvements can be achieved through more effective decision making or control without the need for any infrastructural change. The methodology has been incorporated into the Responsiveness Audit, which is outlined in the next section.

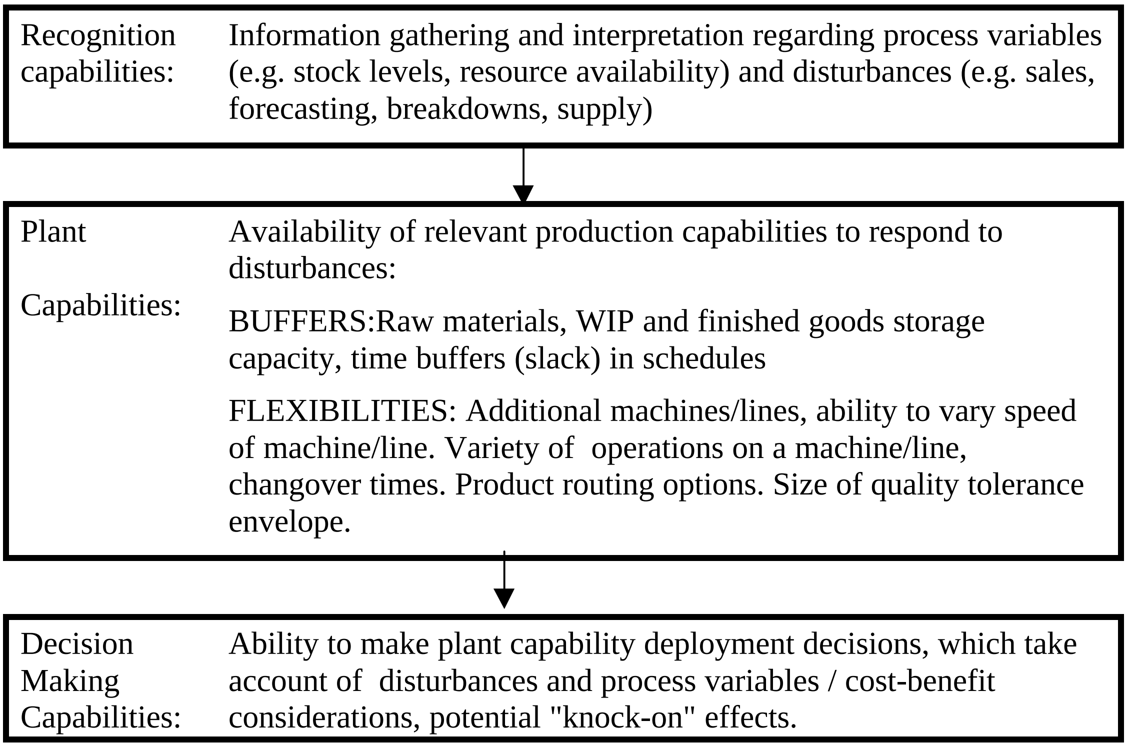

Figure 2 Contributors to Production Responsiveness

The *cost* of responding is also a critical issue for many manufacturers. That is, determining whether the additional effort and expense associated with managing an unplanned or uncontrollable events is worthwhile. For example, an industrial case study has examined the

[2] It could perhaps be argued that the above definition of system flexibility is almost equivalent to responsiveness to demand-side disturbances. Once new production requirements are known, then the system must be flexed to meet that new requirement. However, production responsiveness is concerned with the overall actual service level and production cost deviations resulting after a change in demand. An explanation of this follows. If current flexibility capabilities match the changes customer requirements, clearly responsiveness will be good. However if there are mismatches between the plant capabilities and requirements then responsiveness will be poor. Thus, the intrinsic system capability to flex must be distinguished from the ability of the system to respond to the particular disturbances concerned.

cost trade off between increasing production responsiveness and simply maintaining larger finished goods stock holding. A production frequency selection method has been developed which integrates demand and forecast error data with known production conditions and enables estimates of the most appropriate production frequency to be made.

2.2 Responsiveness Auditing

An auditing tool has been developed - (Matson and McFarlane 1999a), (Matson and McFarlane 1998) - which enables an objective assessment to be made of both the *impact* of different operational disturbances and the *response capabilities* available for dealing with those disturbances. The Production Responsiveness Audit is designed to enable a company to perform a prioritised self assessment of available response capabilities that are not fully utilised at present and/or additional capabilities that are required to address individual disruptions / response needs. The basic audit process is outlined in Figure 3 on the next page which indicates that a typical audit proceeds as a series of short interviews for determining either current or future disturbances (response issues) and plant information followed by a workshop in which these disturbances are assessed and prioritised in terms of impact and the current capabilities available for dealing with them. A feedback discussion session then establishes improvement actions. The audit is not intended to be a lengthy or totally rigorous assessment of a production facilities responsiveness but is intended to provide as outcomes:

- a structured and collective view of the plants ability to handle important response issues
- prioritisation of response issues in terms of impact on the business
- for key response issues, the audit identifies whether:

  Benefits can be achieved by better exploitation of existing facilities

  OR

  Infrastructural improvements are required
- identified target improvement areas

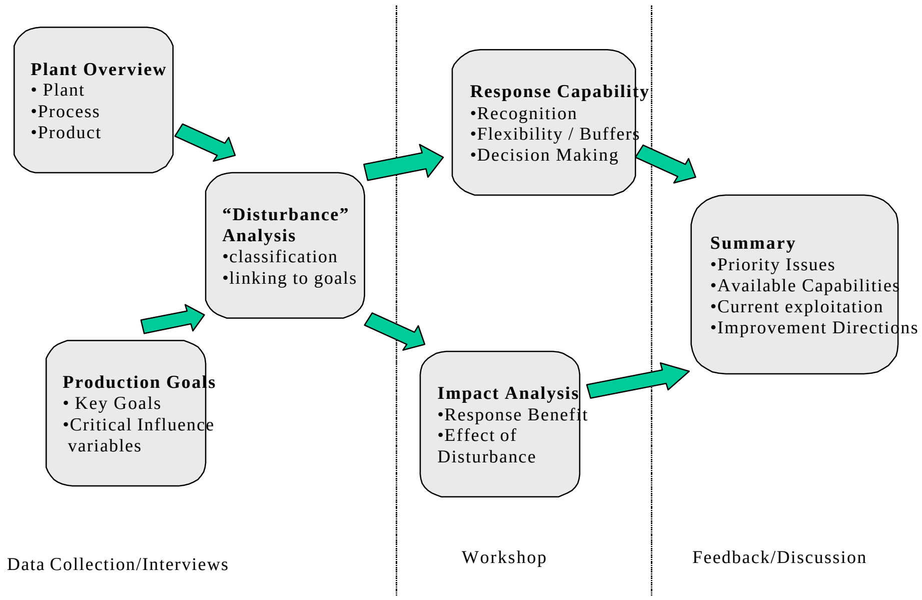

Figure 3 Production Responsiveness Audit Process

It is likely that on completion of the audit a more focussed analysis may be required before a commitment to capital expenditure or a major operational change be undertaken. <u>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.</u> A number of trials of the audit were carried out during its development at production sites of Allied Steel and Wire, Britvic, and Alcatel.

3. Improving Production Responsiveness

3.1 Improving Response Through Co-operative Control And Decision Making Strategies

In Section 3.2 it was indicated that improved production response can often be achieved *without* infrastructural change. One common limitation on the ability to exploit the responsive capabilities of the existing infrastructure (i.e. flexibilities and/or buffers that are already available) is the use of excessively rigid decision making and/or control strategies which are unable to adapt to dynamically changing conditions. This project has investigated a class of decision making and control strategies based on the *co-operative* interaction between distributed process elements (McFarlane and Matson 1998). These strategies have two key features compared to conventional approaches (refer to Figure 4):
(i) a more *localised* rather than centralised deployment of processing power for decision making (e.g. for functions such as planning and scheduling)
(ii) an *interactive* rather command/response approach to information exchange (in order to support distributed decision making)

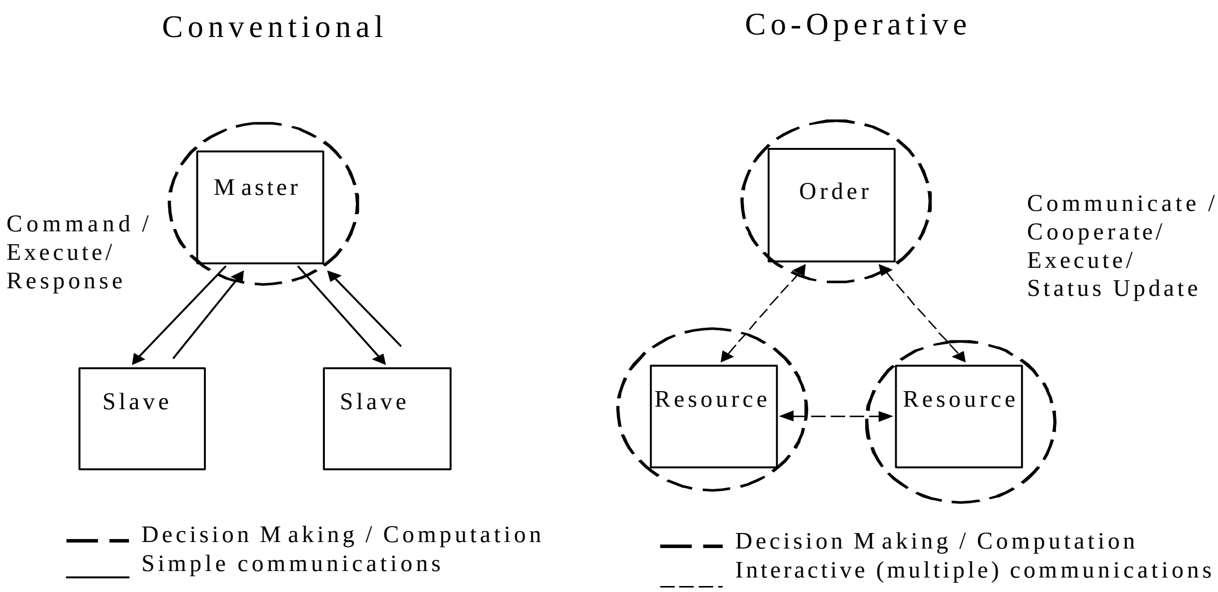

Figure 4 Conventional vs Co-operative Interaction Between Process Elements

Additionally, the elements or nodes involved in such strategies are typically based on physical objects in the production environment such as resources, products and customer orders, where each of these elements is equiped with the necessary computer or human based reasoning capabilities in order to be able to negotiate its role in the manufacturing operation proposed.

The key benefits of such approaches are an increased ability to exploit dynamic shop-floor data (associated with process units) in decision making and a more flexible and robust approach to the allocation of tasks in, for example, scheduling, manufacturing execution and process optimisation. In such as strategy, for example, individual production resources would not be assigned tasks, but rather would negotiate to determine the role they play in processing an order. A particular concern in the development of these highly interactive solution procedures is that they are stable and converge to an acceptable solution within a specified time period. A preliminary study has been performed (McFarlane 1998) and this topic is the subject of ongoing research.

In (Matson and McFarlane 1999b; Matson et al. 1999) a case study for improved response in a steel making plant is considered. A co-operative decision making strategy is developed for co-ordinating different steel making tasks whose durations are uncertain and where the necessary information for making the decisions is dynamically varying and distributed over different process areas. In particular, the problem of determining when to commence a steel treatment operations in advance of the commencement of a downstream casting operations has been considered, and a simple co-operative strategy for minimising plant downtime has been developed and delivered to the collaborating company in the form of an operator-based Standard Operating Practice (SOP) (Matson et al. 1999). (The existing approaches based on predetermined operating practices is conservative and leads to excessive mill downtime.) In a separate project co-operative control strategies are being deployed in a car painting plant (MASCADA 1998).

3.2 Building Blocks for Development of Holonic Manufacturing Systems

The final part of this research into imrpoving responsiveness has examined the contribution of the overall information, computing and control systems to providing improved response characteristics, and has considered alternative approaches to developing computer systems infrastructures. This work has particularly focussed on the rationale for and development of so called *Holonic Manufacturing Systems (HMSs)* (Christensen 1994; Suda 1989; Suda 1990) which provides an alternative perspective to more conventional Computer Integrated Manufacturing (CIM) approach to information, computing and control system design and operation. A factory built as a holonic manufacturing system, comprises a number of modular units or *holons*, where each unit contains physical equipment required to perform a production operation and also the human resources and computing, control and communications to support the operation. It is proposed that a plant constructed and operated in this way, be highly reconfigurable and readily adapted and hence provide support for longer term response issues. A detailed explanation for the rationale behind such systems and the link to the responsiveness requirements of a modern manufacturing business is provided in (Bussmann and McFarlane 1999). In (McFarlane and Bussmann 2000) the role of holonic systems in supporting different manufacturing control requirements is discussed. Further research in this area has involved the specification and development of a laboratory assembly cell (Chirn and McFarlane 1999; Chirn and McFarlane 2000) for testing holonic systems software architectures in conjunction with co-operative control strategies (Cirocco et al. 1999).

4. Acknowledgements

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