Holonic Production Control
to
Support Mass Customisation

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1. Overview

Effective, flexible production processes are a key capability for (cost) effective mass customisation (Pine, 1995, Feitzinger, 1997, Mehunu, 2001). This paper is specifically concerned with the *control* of production systems required to support a mass customisation environment. In particular, we will examine needs for such control, and will argue that the class of so-called *holonic manufacturing control* systems (Suda, 1989, Christensen, 1994) meet these needs and hence could successfully support mass customisation. We will discuss experience with both the design and operation of these control systems and the manner in which they should integrate with other aspects of overall manufacturing system design.

2. Control Requirements for Mass Customised Production

Requirements for successful mass customisation have been analysed in numerous publications (see for example Radder, 1999, Mehunu, 2001 and the references therein). In general they refer to the ability to be able to produce a wide range of products, in relatively low volumes, at little or no notice in a cost and quality effective manner. Duray (2000) differentiates between *standard, tailored* and *pure* customisation in terms of the level of product anticipation that can be applied, and we are particularly interested in the latter here – namely the "preparation for the unpreparable" – control strategies for yet-to-be-determined products.

In terms of production operations, the impact of mass customisation is in requirements for systems with both a high degree of system *flexibility* and *reconfigurability*. High flexibility to allow for known product ranges or variations to be manufactured within single production configurations, and reconfigurability in order to be able to readily and simply change production functionality to meet new requirements. While the physical degrees of freedom of the physical operations and the reconfigurability of these systems are clearly important, this paper will focus predominantly on aspects associated with the decision making and control associated with mass customisation operations. In previous work, a number of the characteristics for production control systems needed to support flexibility and reconfigurability have been identified (Bussmann, 1999, McFarlane, 2000):

- Low and late commitment to tasks
- Adaptability of production control strategy
- Adaptability in the execution of the production control strategy
- Complexity of the introduction of a new product
- Complexity of the introduction of a new production resource

(We note that these requirements align closely with the specifications for agile software in a mass customisation context in Pine, 1998)

3. Holonic Control Systems Approaches

Holonic control represents a methodology for the design of flexible, reconfigurable control systems in the manufacturing supply chain. Importantly, it represents the <u>only</u> methodology for control system design and operation that manages disruptions and changes as *business as usual.* Numerous authors have introduced the main concepts behind holonic control (Suda, 1989, Christensen, 1994, Valckenaers, 1997, Brennan, 1998, Fischer, 1999, Fletcher, 1999, McFarlane, 2001) and this paper will only briefly review these. This is extremely relevant to the *purest* form of mass customisation (Duray, 2000) in which each new order can represent a complete change of conditions to that of the previous order.

The holonic control approach is based around the concept of autonomous, distributed decision making in which there is no fixed hierarchical relationship between control functions such as machine control, shop floor control, scheduling and planning. These control functions in fact *emerge* through the interaction between distributed decision making nodes which correspond directly to the physical quantities involved in the production environment such as machine (resources), products and orders. Figure 1 provides an illustration of this type of interaction which shows a pool of resource holons responding to an order for several products by forming a temporary production route and then adjusting that production route for a subsequent product when there is a resource failure.

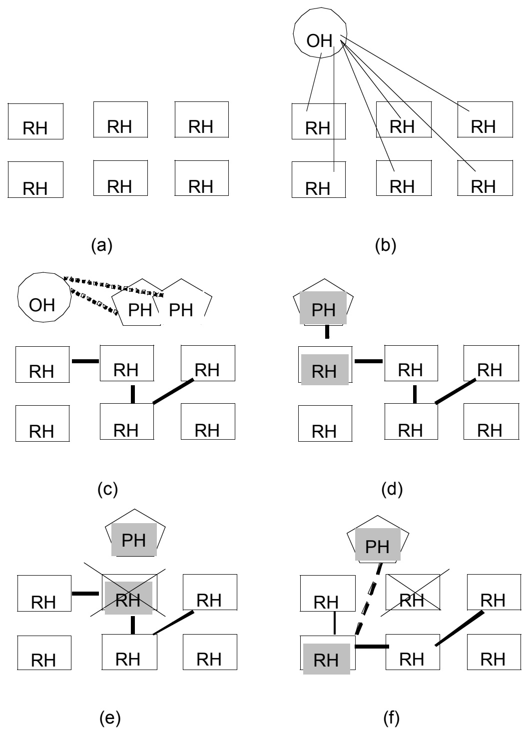

Figure 1 Holonic Interactions in Production Control

The holonic control approach directly complements more conventional approaches for computer control system development based on Computer Integrated Manufacturing methods (CIM). CIM approaches tend to focus on developing systematic and well defined control functions which can ably support steady, mass production operations in a consistent and at times optimal manner. The control functions – planning & scheduling, shop floor control and machine control are hierarchically organized in a relatively rigid manner. Tables 1 and 2 outline the main differences between conventional and holonic manufacturing control system design and operation. These features are more or less general to any of the holonic system developments proposed in the literature.

Conventional Control	Holonic Control
• Solution-oriented design of manufacturing environment (i.e. specific product targets) • Fixed orientations/interactions of resources • Computer Systems Integration defined by hierarchy • Solution specific software for planning, scheduling, execution and control	• Design of a "Pool" of resources with known relevant capabilities (i.e. specific products NOT assumed) • "Unknown" orientation/ interactions of resources • Computer Systems Integration – "plug and play", device discovery • Sofware capabilities for supporting different (distributed) P, S, E, C approaches embedded in resource holons

Table 1 Conventional and Holonic Control - Design Features

Conventional Control	Holonic Control
• Predermined resource functions used • Predetermined production sequences • Follows fixed, predetermined planning, scheduling strategies • Tasks are executed on resources by central assignment	• "Pool" of resources with known capabilities • Production sequence only determined when product recipe interacts with resource capabilities • planning, scheduling, emerge by negotiation between orders & resources • tasks are bid for and negotiated by individual resources

Table 2 Conventional and Holonic Control - Operational Features

The main aim of these two tables is to highlight the fact a) in design, the specification of the control functions for a resource are essentially developed *independent* of any products to be manufactured on the resource and b) in operations, a *latest commitment* strategy to maximise robustness against breakdown and responsiveness to order variation. In this sense, holonic control appears to be extremely well suited to the requirements of a mass customisation environment.

4. Application Experience with Holonic Control Systems

In this section we will outline some experience with the development, implementation and operation of holonic control systems on a laboratory testbed assembly system, and in this way, demonstrate the potential of the approach for dealing with mass customisation. The testbed system, illustrated in Figure 2, has been previously discussed in the context of holonic control design in Chirn (2000), Matson (2000) and Chirn (2002).

This section will overview the key features of the testbed and will then examine the benefits and also practical difficulties and limitations experienced in designing and operating systems based on the holonic control approach. Although the degree of customisability of the items in the testbed is rather limited from a physical perspective, it can be shown that the control system allows all available degrees of freedom to be exploited.

5. Towards a Balanced Design and Operational Strategy for Holonic Control

Based on the experience in Section 4, a balanced strategy for holonic control is proposed which can support the changing needs of mass customisation as *business as usual.*

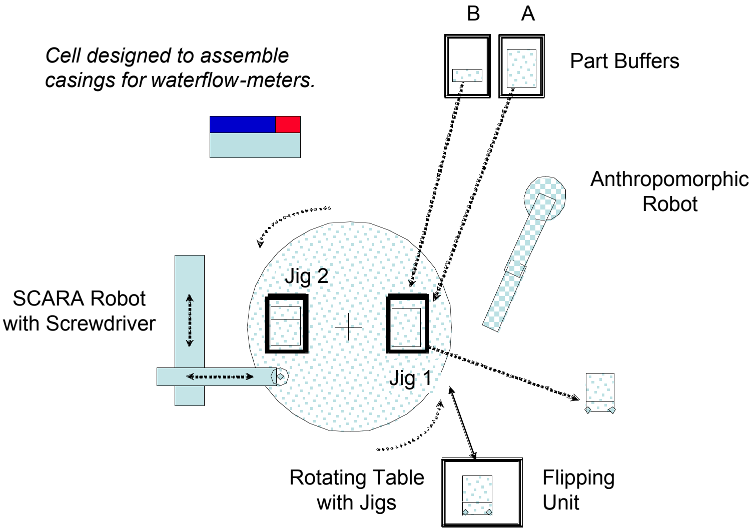

Figure 2 Flexible Assembly Testbed

In particular we will emphasise the need *in design* to a) replace consideration of *product features* with consideration of *resource capabilities* during the system design phase; and in *operation* the requirements to b) accurately track products during their raw material, work-in-progress and finished goods phases and to c) generically describe product production instructions in such a way that they implicitly require particular resource capabilities but don't explicitly refer to particular production resources. More generally we will also emphasise the need to separate requirements for systems architectures from those of the algorithms required to solve the control problems and to consider evaluation metrics that apply to both the system (design) performance as well as the operational performance of the result production operation.

The section will conclude with a design example based on the testbed cell from Section 5.

6. Conclusion

The paper will conclude with an examination of additional issues which need to be considered in conjunction with a holonic control strategy in order to effectively develop a mass customisation environment. These include:

- *flexible resources* (e.g. machines, storage and transportation systems) providing redundancies of function, operation and/or routing
- *flexible networking environments* for both resources and raw materials / products enabling accurate monitoring of highly varied operations
- *flexible and empowered manpower base:* HMS enhances the role of the skilled operator in assisting with disturbance handling
- *flexible business information systems* enabling inter-site interactions between devices, resources and orders to be as flexible as those provided by holonic control systems within an operational site

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