Lifecycle Engineering of Future Automation Systems in the Automotive Powertrain Sector

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***Abstract*— This paper provides a brief insight into some of the key issues related to meeting the future requirements for automation systems in an agile manufacturing context. In particular the needs of the automotive powertrain sector are considered, and a new Technology Cycle Plan initiative by the Ford Motor Company is described, which aims to fundamentally enhance the capabilities of Ford's automation systems in a lifecycle engineering context. Ongoing research at Loughborough University, which has shown the potential value of adopting a lifecycle engineering approach to automation, is briefly reviewed, and the opportunities for more virtual engineering and greater functional modularity in future automation systems are highlighted. Attention is also drawn to the importance of establishing effective partnerships between the major players in the automation supply chain, e.g., the controls vendors, digital engineering tool vendors, machine builders and end-users, in the realisation of the enhanced automation systems of the future.**

I. Introduction

In the last decade the effects of rapidly changing customer demands and also industrial globalisation have been evident within the automotive industry. As product lifecycles grow shorter, manufacturing systems need to be created that can effectively support frequent product change. Efficiently engineering more flexible and configurable automation systems is now becoming essential to the competitiveness of automotive powertrain manufacturing [1]-[6].

Ford Motor Company, Powertrain Operations (PTO) has recently launched a global Technology Cycle Plan (TCP) initiative with the aim of improving their manufacturing competitiveness by enhancing their automation technology and methods. The primary focus of this study is in the area of assembly automation since it is in assembly, rather than in machining operations, where it is most difficult to accommodate frequent product change efficiently and hence where there is the greatest potential for cost and time savings.

Through this TCP activity Ford aims 1) to assess the current state of automation technology, 2) to determine the capabilities its future automation systems should embody, and 3) to instigate an action plan to facilitate the necessary changes to its automation capabilities.

In common with many large global companies in the automotive sector, Ford's strategy for automation systems has traditionally been relatively fragmented, and because it is a product-oriented company, its manufacturing automation has often not been adequately represented at senior management level.

The aims of the TCP initiative are to achieve a more proactive approach to the engineering and lifecycle support of automation systems, making them easier to design, install, (re)configure and maintain, and also to promote technologies and methods that are under the end-user's control.

Key aspects of this initiative include not only automation technology but the integrated and ongoing training and support of staff through the engineering lifecycle. Better integration with business systems and the provision of traceability in all aspects of the engineering and lifecycle support processes are also vitally important. Improved interfaces are required with business systems in the context both of local production support and of remote support from supply chain partners.

Key challenges identified through internal studies at Ford are to:

- Facilitate shorter system build times and achieve rapid flawless launch.
- Provide flexible, lean facilities with low levels of complexity.
- Install systems that 'fit' with the skills available to operate and maintain them.
- Reduce lifecycle and investment costs.
- Provide an engineering system that can deliver tried and tested solutions within an increasingly complex and diverse supply chain.
- Decrease dramatically the MTTR (mean time to repair) for automation systems.
- Encourage innovation whilst at the same time reducing risk.

In the case of the adoption of remote support services, important security and safety issues are raised as previously private systems are opened up to enable external monitoring and assistance, e.g., for maintenance and training activities.

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II. The Current Engineering Process

As illustrated in Figure 1, the current machine development process, whilst well established and using well proven methods, is still essentially paper-based and uses an ad-hoc collection of often poorly integrated tools to take customer requirements and translate them into the desired system. Customer product specifications are typically interpreted by process engineers to produce a suitable machine configuration, and process cycle charts are written to specify the necessary timing of machine movements, which are later interpreted by programmers to produce structured control software. This is typically implemented in either ladder logic or sequential function charts. Associated operator interface screens and machine diagnostics and monitoring applications are finally added [6], [7].

The current machine build process is almost entirely sequential and heavily segmented organisationally into different engineering disciplines. For example, new project tendering is followed by mechanical, fluid power, electrical, and commissioning activities once the contract is secured (see Figure 1 and the upper part of Figure 2). Whilst very effective automation systems are created using this approach, fundamental problems are identified with it, particularly in the context of manufacturing agility. In particular there may be:

- Loss of information through the design process between engineering activities,
- Poor reuse (with each new production line being implemented with little of the engineering carried over from previous implementations, resulting in new systems similar in concept but different in detail for no good reason),
- Failure to meet customer requirements due to flaws in the engineering solution that are only manifested in the commissioning phase, resulting in very expensive modifications and delays in delivery and
- Increased cost and time due to repetition of work and lack of process visibility both within and between different functional departments.

Engineering environments need to support better the lifecycle of automated machines, encompassing all aspects of the build process (e.g., mechanical, electrical and control systems realisation) in an integrated manner and tracking and coordinating supply chain activities [8].

III. Future Automation Requirements

Research at Loughborough through an ongoing series of major UK and EU research projects is investigating the requirements, design and potential for implementation of new modular automation systems better able to meet the lifecycle needs of the products they manufacture by exhibiting improvements in key lifecycle performance characteristics [9]-[13]. For example:

- Better machine scalability, i.e., allowing machine changes to be made more efficiently by simply adding or removing individual components at will.
- Greater modularity and support for postponed machine build, i.e., allowing sub-assemblies, from single components up to major sub-sections, to be built and tested separately and then combined quickly and easily in accordance with a well defined machine architecture.
- Easier process definition, i.e., provision of high-level graphical representations of machine behaviour in a processes-related manner, which will allow process engineers to make system changes more easily.
- Implicit support for e-service/maintenance, i.e., provision of embedded support for remote machine diagnostics and monitoring.

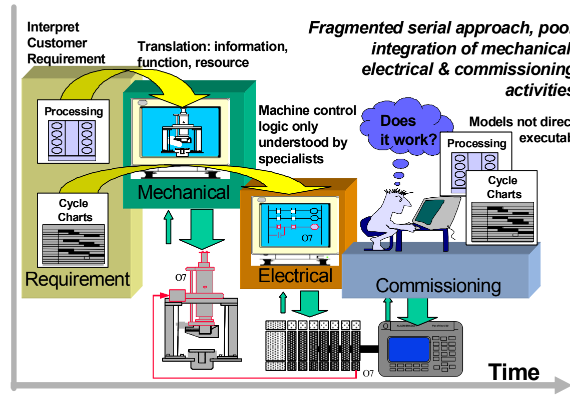

Fig. 1. Current Machine Build Process.

In order to realise a modular reconfigurable automation system with the desired capabilities, it is vitally important to be able, reliably and repeatably, to construct and compose systems that can meet and adapt readily to ever changing user application requirements. Such systems need to be generally applicable to a broad spectrum of applications and yet be capable of easy and precise tailoring to specific applications. The objective is not only to support application design, simulation and monitoring of automation systems from the control perspective (control dimension) but also to support the integration of control devices with higher-level business process systems

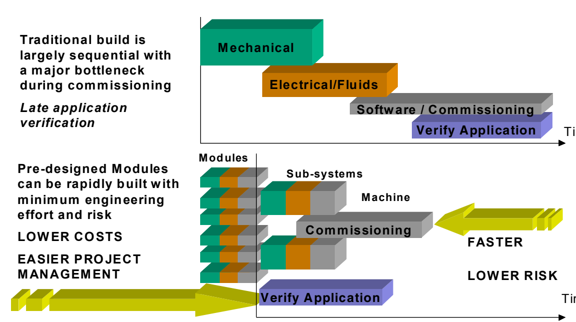

Fig. 2. Comparison of traditional methods (above) with the future approach (below)

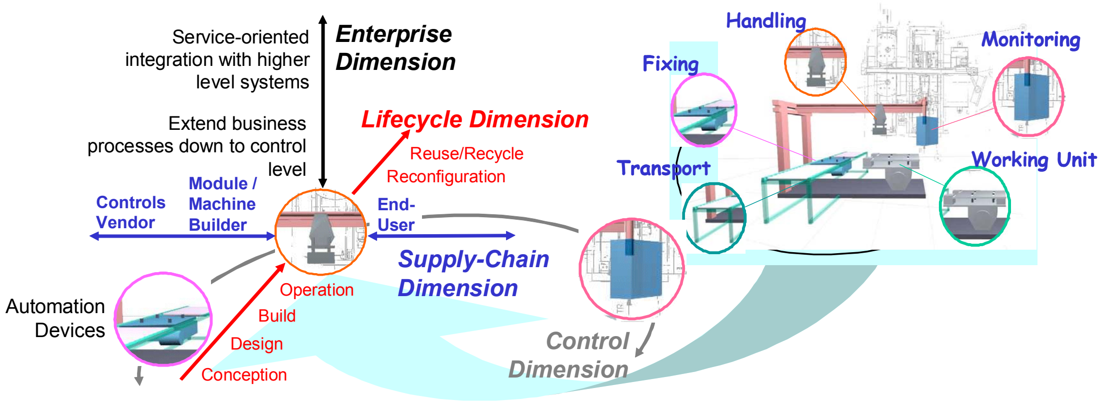

Fig. 3. Concept of a modular automation system and its integration needs

(enterprise dimension). In addition, the integration of service support from supply chain partners (value/supply-chain dimension) needs to be provided. And all of this needs to take place within a lifecycle engineering context (lifecycle dimension). Figure 3 presents an example of a modular automation system for automotive engine assembly composed of mechatronic modules and highlights its support and integration needs. An integrated engineering environment is needed to support the multi-perspective needs of different classes of application users in an efficient manner. The approach adopted at Loughborough is to identify reusable, configurable components, the aim being to mask complexity, maximize reuse and build domain-specific libraries of configurable modules and associated services, minimising the need for new custom components for each new application. Previous studies in several industrial sectors have shown that a relatively small library of modules, specifically tailored to the needs of a given automation user, could meet 80-90% of the user's needs. In particular, support for internal functionality needs to be provided in terms of component behaviour, and support for external functionality needs to be provided in terms of how modules, each offering specific service capabilities, are composed and, at the higher level, orchestrated to meet the overall application need [9], [12].

A complete discussion of the future requirements for a new approach to the engineering of automation systems is beyond the scope of this paper. Two aspects of such a system will however be highlighted. These are the growing importance of virtual engineering and the need for appropriate machine modularity.

IV. Progress Towards Virtual Engineering

The upper part of Figure 4 shows the typical current state of the engineering process in terms of the split between physical and virtual engineering. In the product engineering domain digital engineering approaches now dominate much of the product design and realisation phases. In manufacturing engineering, particularly in an automation context, physical engineering predominates with relatively little virtual engineering support. As indicated in the lower part of Figure 4 end-users such as Ford wish to migrate to a much higher degree of virtual engineering support for the engineering of the manufacturing automation systems and beyond this to virtual environments, which can be used both to verify automation systems before they are physically launched and to provide ongoing production support capabilities.

Currently the launch of a new manufacturing system and its subsequent operation is totally reliant on in-house end-user skills or on-site vendor support. The future strategy will allow remote expert assistance with the capability to visualize the plant floor status remotely with no additional work.

Digital product design is now a very well established field of engineering, enabling visualisation, design optimisation and performance prediction well before physical engineering of production prototypes, thereby compressing the product lifecycle. In the manufacturing domain, digital manufacturing is already being utilised strongly in both CNC machining and robotic application domains. In the field of assembly automation its use is much less well established particularly in the domain of special purpose machinery.

The development of virtual engineering environments to support machine builders are emerging from two principle directions: 1) CAD vendors extending their capabilities into the manufacturing domain for PLM, e.g., Delmia and Tecnomatix [14]; and 2) control vendors producing

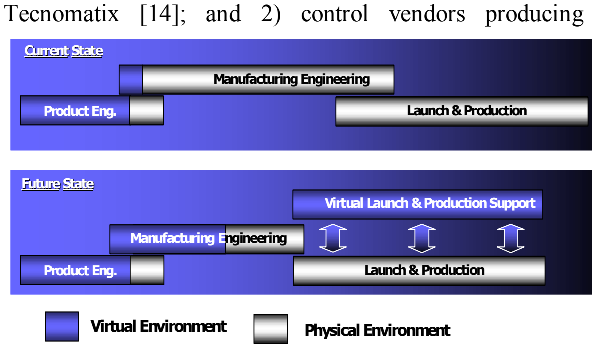

Fig. 4. Concept of virtual and physical engineering environments

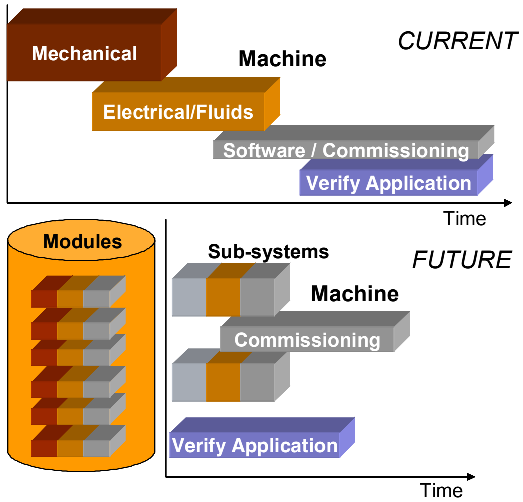

Fig. 5. From a monolithic approach to a modular approach

engineering support tools with lifecycle support capabilities, e.g., Siemens, Schneider and Rockwell Automation, with perhaps the most notable example of such an engineering tool currently being Enterprise Controls from Rockwell [15].

To take an example of a CAD vendor, with Delmia PLM the process engineer is focused on process definition and on being able to design and simulate the process of the production system. Delmia Automation extends this capability to control. The control engineer designs and simulates the control of the production system in the same virtual environment. Delmia Automation is able to generate control programs for the target PLC and then to allow the validation of the PLC program connected to the virtual equipment [14].

In the long term, the aim must be to bring much more of the engineering lifecycle into the virtual environment to compress timescales and reduce risk.

V. Modularity and Lifecycle Engineering Models

There is the potential to achieve substantial gains in terms of more rapid build and reconfiguration of automation systems through the adoption of a more modular approach to automation system engineering.

As shown in Figure 5 a modular approach has the potential to move from the late verification of complete automation systems to the construction of automation systems from proven mechanism modules, allowing opportunities for early system verification within a virtual environment [12].

An effective solution to the lifecycle engineering of modular automated machines needs to provide:

- a set of mechatronic modules at an appropriate level of granularity for the intended application domain to enable efficient machine build and re-use of designs,
- a system architecture that reflects the specific needs of the application domain and
- an engineering environment and common engineering model that can effectively support the supply chain partners throughout the machine's lifecycle.

A. Modular Decomposition

It is obviously important to choose an appropriate level of granularity within a modular system architecture that aims to support reuse and reconfiguration of automated machinery. Loughborough's research has shown that it is important to define carefully how much functionality each element in the system should provide. A pragmatic approach is to create a system of the coarsest granularity that still offers the ability to provide all the necessary system variants, i.e., to minimise the number of modules required within a given system whilst still being able to build any desired machine configuration. Determining the optimum level of modularity for any system requires consideration and trade-off of many factors. As described by Gain, a design method supports effective modularity if it evidences [16]:

- Decomposability -- a systematic mechanism for decomposing the problem
- Composability -- ability to reuse modules in a new system
- Understandability -- the module can be understood as a standalone unit
- Continuity -- minimising change-induced side effects
- Protection -- minimising error-induced side effects

Correct modularity makes systems easier to build, reconfigure and repair. It also makes systems intellectually more manageable, i.e., reduces the skill level needed to support a given system throughout its lifecycle. Changeability is an important metric for modularity, i.e., the modular decomposition of a system needs to be evaluated in terms of what changes it can accommodate. Good machine-modularity will be characterised by minimal interaction between modules (coupling) and maximal interaction within modules (cohesion); indeed there are many parallels with component-based software engineering [16]. Granularity is an important issue since having too many modules has the potential to make integration over-complicated. Figure 6 presents a highly simplistic view of some modularity trade-offs. In practice a much more in-depth analysis is required focusing on a study of the functional modularity of the system, e.g., what functionality is to be reused and in what combinations.

B. A Common Engineering Model

The importance of the correct level of modularity and the potential for the definition of a reuse library of mechanisms lead to the need for an engineering model that can contain and support all the information required for the complete engineering lifecycle from the perspectives of not only the end-user, e.g., Ford, but also their supply-chain partners.

Figure 7 shows that one part of such a common lifecycle engineering model will be the mechanism modules

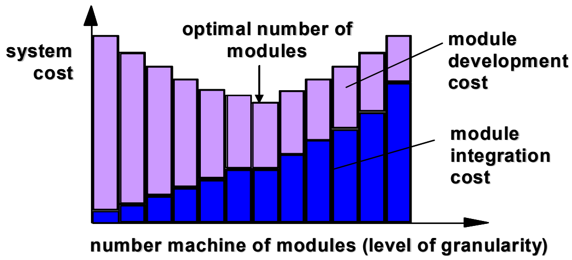

Fig. 6. Optimising modularity: a simplistic view (Adapted from Gain, 2004)

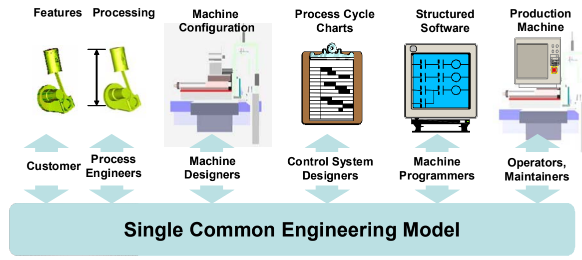

Fig. 8. Engineering model accessible to all supply chain partners

composing the given machine. These mechanisms will be configurable mechatronic modules with both physical and virtual representations. Such a system encourages the reuse of standard mechanism modules from a standard library. A mechanism module can be reused physically and in terms of its design. It typically embodies mechanical, electrical and control engineering [13].

Figure 8 shows that such an engineering model will be accessible throughout the lifecycle of the machine by all supply chain partners. Currently the end-user has little control over (or visibility of) the machine mechanical configuration. This is left to the machine builders only to be verified late in the engineering process when the physical system is commissioned. The utilisation of pre-defined modules of known performance, reliability and maintainability is very attractive, and the machine build process is compressed [16].

This can also result in much improved levels of commonality across plant installations both locally and globally. The change-control process for the automation system can be managed properly; only approved modules can be used and progressively discarded as new ones are introduced so that an optimum "minimum set" of modules is achieved.

Modules can be defined based on appropriate levels of flexibility, e.g., enforcing levels of automation complexity that are appropriate from the end-user perspective, matched to staff capabilities and system operational characteristics with regard to safely, security, complexity and standardisation.

VI. Conclusions and Future Work

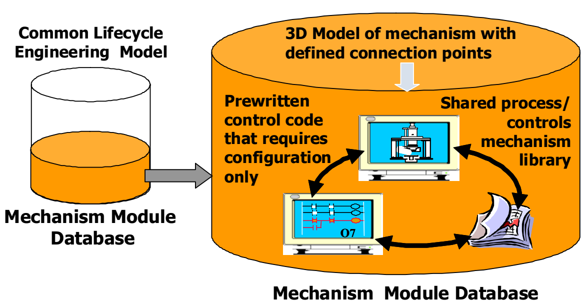

Fig. 7. Mechanism modules within engineering model

This paper has provided a brief insight into some of the issues related to improving the capabilities of automation systems in an agile manufacturing context. In particular the needs of the automotive powertrain sector have been considered along with a new TCP initiative by the Ford Motor Company to fundamentally enhance the capabilities of its automation system in a lifecycle engineering context.

Research at Loughborough University has shown the potential value in adopting a lifecycle engineering approach to automation systems and the need for effective partnerships between the major partners in the supply chain, e.g., the controls vendors, engineering tool vendors, machine builders and end-users such as Ford.

The realisation of future automation systems will increasingly cut across traditional organisational boundaries. Closer integration will be required between the business and control system domains and within supply chain partnerships. The creation of intelligent mechatronic modules will increasingly blur the boundaries between mechanical, process and controls engineering. The commissioning of machines will become a process of configuring assemblies of pre-tested modules. An increasing proportion of all these activities will be achieved within a digital engineering environment.

VII. Acknowledgements

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