Impact of Moderation through the Distributed Virtual Enterprise Life Cycle

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Abstract. The increasing application of the Virtual Enterprises (VE) model of partners collaborating to exploit a single product through its life cycle implies complex requirements for communication and collaboration. Distributed decision making from concept design, through product and manufacturing system design, volume production and on into obsolescence engenders significant risk of highly expensive conflicts in collaborative decision making. This paper explores the opportunity to apply intelligent, hybrid, knowledge based software Moderators, already demonstrated in the domains of product and manufacturing systems design, to support and enhance collaboration throughout the product and virtual enterprise life cycle.

1 The Virtual Enterprise

The concept of a Virtual Enterprise (VE) was proposed by Onosato and Iwata [1] in response to a changing industrial environment, where product lines have a significantly shorter lifetime. For example from the early 1960s for a period of some 30 years the design of home telephones was virtually unchanged: companies could be established to manufacture one stable product and know that there was a stable market. However with the advent of mobile telephones, and their status as fashion accessories, the marketable life of a product line once launched is measured in, at best, months. Indeed the life cycle from product concept to obsolescence is likely to be less than a year.

To meet this challenge, supply chains take the form of collaborating consortia of specialist partners who come together to provide the expertise necessary to exploit

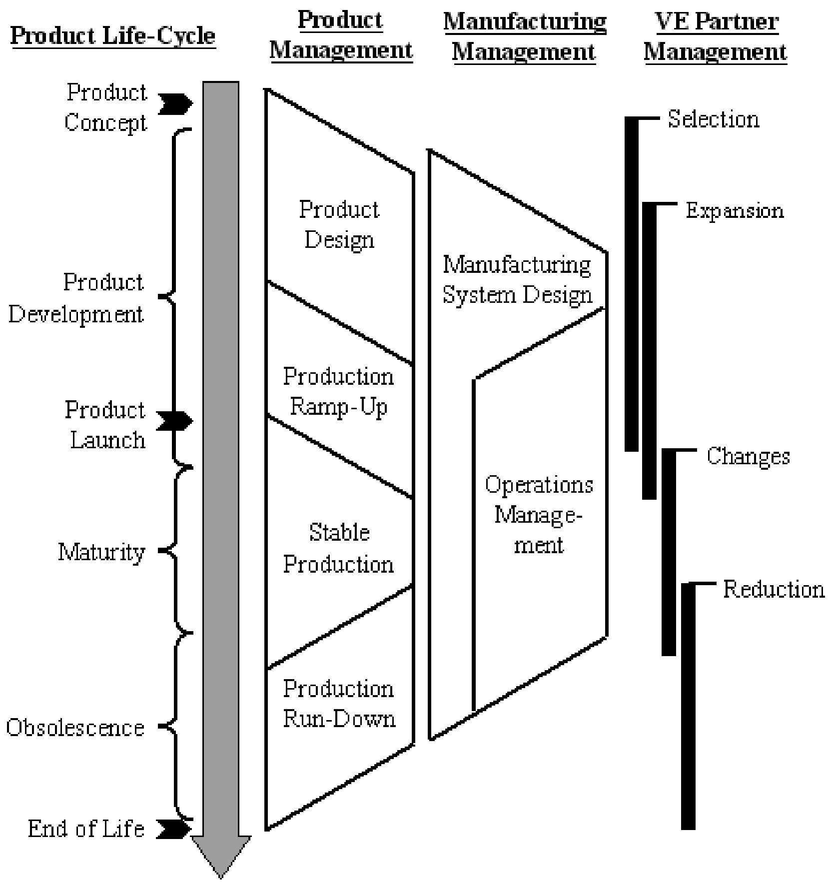

Fig. 1. The Virtual Enterprise Life-Cycle

just one product, and it is such a consortium which is termed a Virtual Enterprise. A number of features distinguish this particular kind of supply chain:

- Collaboration on the selected product is close, well-co-ordinated and open, so as have the agility to maximise the exploitation of the product.
- Partners may not collaborate on any other products. Indeed it is probable that they will be competitors on other products. This implies a need for confidentiality, militating against the need for openness noted above, complicating collaboration issues.
- The life-cycle of a VE is limited to that of the product, as in Figure 1, and partners have no obligation beyond that.
- Partners may be added to the VE or leave it as the product life-cycle progresses;
- The VE will include contributors responsible for products and manufacturing engineering the early stages at least, as these activities must be concur-

rent with one another and with the formation of the VE consortium. Indeed selection of VE partners is a major aspect of manufacturing engineering.

2 Moderation of Distributed VE Design Activity

Where a single site manufacturing system is developed there is the opportunity for all members of the manufacturing system engineering (MSE) team to collaborate closely with one another, and where concurrent engineering principles are embraced, to collaborate closely with the product design team. Indeed it is probable that the members of both teams are co-located, precisely to ensure communication and mutual understanding. This is problematical in the distributed VE: the MSE expertise contributed by a partner is concentrated in the partner's own personnel, who are by definition physically separated from other partners' experts, and although modern electronic communication helps interaction between MSE team members in the distributed partners, there are still problems of terminology, language and even time-zones which lead to MSE design conflict. MSE design decisions will be made by distributed groups of manufacturing engineers, some working on the VE as a whole, some with interests at the local, VE partner level, and some primarily concerned with logistics.

At the same time the very drivers for the creation of a VE demand rapid and efficient collaboration in the MSE design process. The product must be brought to market rapidly, or the market opportunity will be lost to competing products, whilst the life-cycle of the product is so short that there is no opportunity to develop the manufacturing system after product launch to improve subsequent profitability: the product will be obsolete to soon.

The MISSION project (IMS/ESPRIT Project 29656) demonstrated that information modelling methods can be used to address the problems of both maintaining a shared model [2] of the MSE design and of reducing the potential damage caused by inadvertent design conflicts being introduced by distributed engineers. Global manufacturing system design was enhanced in the MISSION project by the application of a Manufacturing Systems Engineering Moderator (MSEM) [3]. This hybrid knowledge based software uses its own knowledge about the knowledge used by each contributor to the developing VE design to analyse both the results of modelling and the decisions based thereon, to detect potential conflicts as they arise.

2.1 An Example of Manufacturing Systems Engineering Moderation

An example of Moderation presented in the MISSION Final Report [4], demonstrated simulation of the entire manufacturing system (MS) at a point in the project where considerable detail had been added to the MS design. Earlier design work had used only estimates of VE partners' performance in global simulations, and performance predictions so generated were added to the MSE database, being adequate to meet strategic requirements. However the new more precise simulation generates new performance predictions, which are in their turn added to the database.

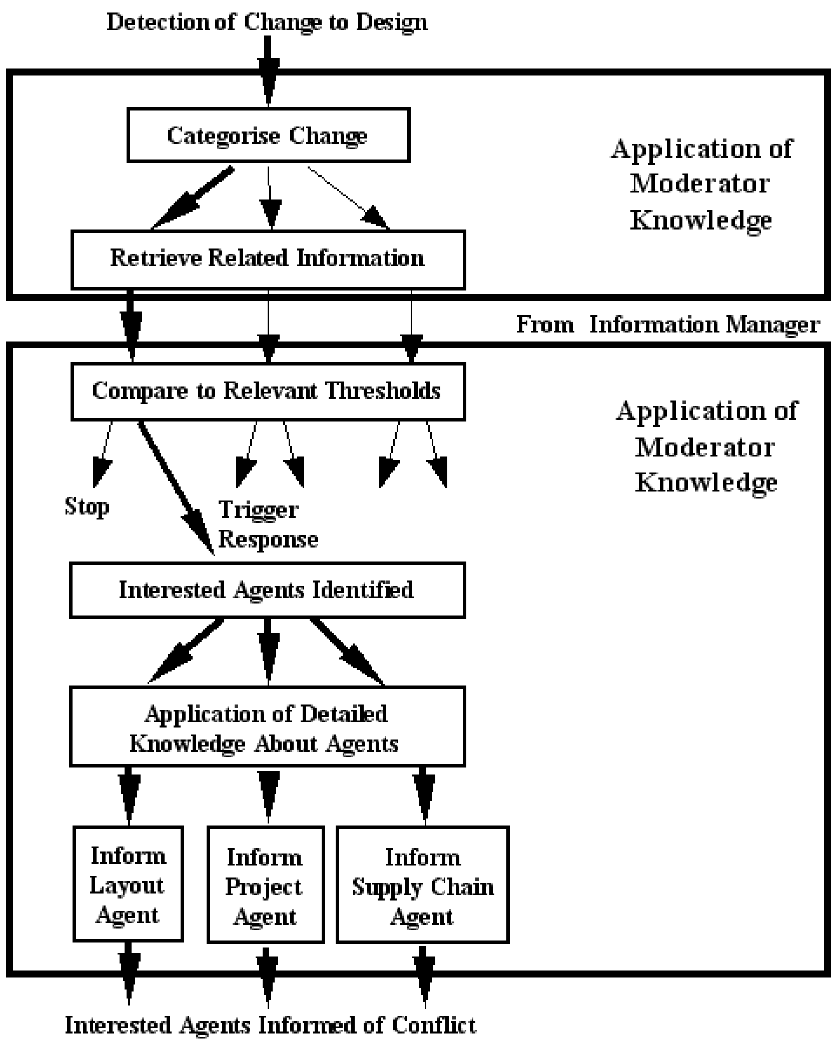

Fig.2. Manufacturing Systems Engineering Moderation

The MSEM monitors all changes to the design database as they occur. MSEM processing is illustrated in Figure 2. System design changes are identified as changes to its predicted performance, so any previously accepted predictions are first retrieved from the MS design database, allowing the nature and magnitude of the changes to be compared with thresholds derived from MSEM knowledge of the interests of MSE partners. If no thresholds are reached, then the MSEM takes no further action. Otherwise, for example if the confidence limits on predicted work in progress have broadened indicating that excessive variation may occur, the MSEM again uses its own knowledge of partners interests to determine who to inform of the potential design conflict, in this case the Project Agent, responsible for overall project outcomes, and the Supply Chain Agent, responsible for MS performance against strategic targets.

2.2 Manufacturing Engineering Moderator Implementation

The Manufacturing Systems Engineering Moderator functions as a background process monitoring decisions as they are recorded in the MS design database, and coming to the notice of partners in the design process only when potential design conflicts are detected. It is implemented as a hybrid knowledge based system, as a combination of artificial intelligence paradigms that are needed to achieve conflict detection across MSE domains.

It is also essential that an MSEM has capability to dynamically add to its knowledge base, both to reflect the discovery of new expertise that the enterprise gains about the process of MSE, and to reflect the current state of an individual project. To achieve this the MSEM is implemented as knowledge objects in an objected oriented database, structured as three main modules: a Moderation Module which drives the process of moderation and maintains information on current project status; a Design Agent Module containing sub-modules, each of which stores and applies knowledge about the areas of interest of one the MSE collaborators; and a knowledge acquisition module.

3 The Application of Moderation Throughout the VE Life-Cycle

We see from the above that there is significant potential benefit in applying a combination of simulation and moderation in the design phase of the VE life cycle, and this is summarised on Figure 3. The same issues are relevant to any subsequent changes to the manufacturing system design during the life of the VE.

However, this same approach of intelligent moderation working with simulation has potential application at subsequent stages of the VE life cycle, as suggested in Figure 4. Here we see that the potential for decision conflict remains through the life cycle, both in operations management of the MS to meet current, changing demands, and in terms of planning to respond to the product life-cycle. Intelligent moderation uses operational information, together with its knowledge about the distributed, specialist contributors to the VE to identify conflicting decisions where these may be critical to current and future VE performance. Moderation knowledge can also be applied to external information, such as market conditions, to identify where this may conflict with existing or proposed VE activity. These applications, their benefits to industry and the research issues to be addressed to achieve these benefits may be summarised as follows.

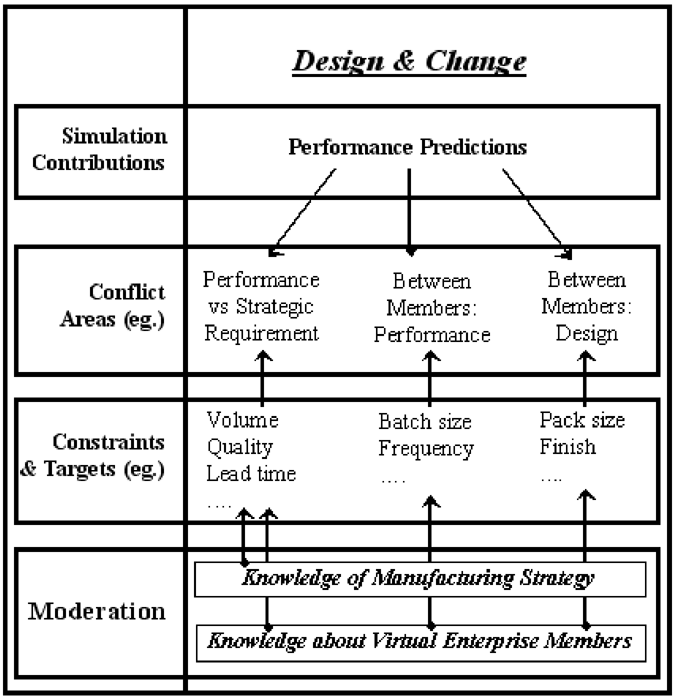

Fig. 3. Moderation Application in Manufacturing System Design

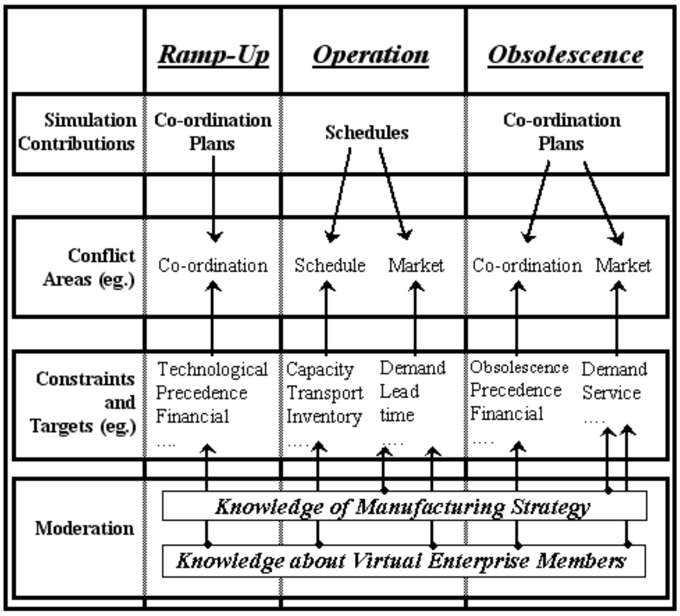

Fig. 4. Moderation in VE Ramp-Up, Operation and Run-Down

3.1 Ramp-Up

In this phase of its life cycle the VE is expanding from prototype production, up to a launch capacity, and then on to planned full production. Partners colaborate to plan and monitor capacity, selecting additional partners as necessary, and consistently expanding the logistics activity. Potential for introducing inadvertent conflict remains, including, for example, differences in technical capabilities (eg. tolerances capabilities) in selected new partners, mismatched expansion rates (eg. component capacity runs ahead of assembly capacity, creating stocks), transport mode conflicts (eg. new partner does not have rail access where existing logistics are based on rail transport).

3.2 Operation

Although at this stage of the life cycle VE demand is relatively stable, it will normally be subject to seasonal and/or random variability. Partners must collaborate to plan to meet varying demand, but distribution offers the potential for conflicting responses (eg. assembly is planned to build to stock in a low demand period whilst component suppliers plan to reduce output). In a more durable VE it is possible that partners may need to be replaced during this phase, re-introducing many of the possible conflicts met during ramp-up. Changes in transport cost structures are particularly likely to conflict with the basis of earlier logistics planning, and moderation may be applicable in triggering response to such externally imposed change.

3.3 Obsolescence

At this stage collaboration to maximise exploitation of the product is especially vulnerable as partners plan exit strategies to meet their own business needs with reduced incentive to consider the VE as a whole. Conflicting plans on shutdown timing are probable. At the same time, depending on product, industry, and perhaps regulation, there is a requirement to ensure implementation of a co-ordinated plan to provide a continuing supply of spares. Conflicting plans in response to a now falling demand are more likely than during operation.

3.4 An Evolving Moderator Knowledge Base

As described above an essential feature of any moderator software is its dynamic knowledge base, able to acquire new knowledge for future moderation, but also able to prioritise the application of its knowledge depending on the state of progress of the project to which it is applied. This means that there is no need for different moderators or even moderator knowledge bases, to be contructed for each stage in the VE life-cycle. Indeed it is perfectly possible that moderator knowledge normally associated with, say, the design phase could on occasion be relevant to run-down: the probability of such a situation is clearly lower, and so the knowledge has lower application priority in this phase.

Thus there is a functional benefit in maintaining a single moderator knowledge base applied to the entire VE life-cycle. Although the underlying functionality of any moderator is generic, its application domain is determined by this knowledge base, so that the owner of a VE Moderator can apply the same core software and knowledge base to all VEs for which he is responsible, whilst adding new knowledge gained from each to the common knowledge base supporting all current and future VEs. Each moderated VE must have its own instantiation only of knowledge specific to that VE and its current status and history.

4 Conclusions

The application of moderation has already been demonstrated in support of manufacturing system design activities. Here we have examined the feasibility of extending this application to the entire life-cycle of a virtual enterprise, and we see that this promises significant benefits in improved performance, and increased agility.

Moderator technology offers a method of first detecting decision conflict arising from the distributed nature of decision-making and the resulting restricted communication of mutual understanding between VE partners, and then driving resolution. In principle a user could operate a single moderator knowledge base, and moderator instances for each virtual enterprise under consideration, each instance holding only information and knowledge peculiar to its VE and its current status.

However research issues remain if this potential is to be realised. These fall into two main categories: the first is the interfacing of moderator software with the software and information bases available to all the members of the VE. These issues are similar to all the known problems of interoperability of heterogeneous systems, and can be addressed in similar ways. There is therefore reason to believe that the issues will be resolved in general in the foreseeable future, and that the general resolution will be applied to moderator interoperation.

The second issues arise out of the need for maintenance of the evolving moderator knowledge base. The moderator structures demonstrated in the past have the capability for adding to and evolving knowledge primarily through a user driven knowledge acquisition module. Such an interface is likely to be a feature of all moderator implementations as it allows the intelligent, explicit editing of the knowledge base needed to ensure that knowledge derived through human observation can be applied. However in the extended environments for moderation envisaged above, there is also scope for automated knowledge generation, for example through knowledge discovery methods [5], [6], and through the development of ontological approaches to knowledge generation and retention [7].

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