BEHAVIOUR-BASED CONTROL FOR UNCERTAINTY MANAGEMENT IN MANUFACTURING EXECUTION SYSTEMS

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Abstract:

This paper focuses on disturbances handling and uncertainty management in Manufacturing Execution Systems (MES). In real manufacturing environment there are a lot of disturbances such as priority tasks, machine breakdowns, missing materials, absence of labour, quality issues, job lateness, unexpected events, data management and acquisition errors. Behaviour Based Control (BBC) is a type of adaptive control strategy for uncertainty management. In this paper a new structural and functional model for MES uncertainty management will be presented. An attempt will be made to demonstrate the usability of BBC in the field of MES. Some typical modules which have to be used to support the process management on shop floor level are discussed: 1. Process monitoring; 2. Alarm management and automatic corrections; 3. Diagnostics and action selection; 4. Decision support and cockpit task management components. The structural model which describes the component structure and the joints of components in the proposed system is also presented.

Keywords:

Uncertainty management, MES, Behaviour Based Control, Cockpit task management

1. INTRODUCTION

Recently disturbances handling and uncertainty management became more and more important functional requirement for Manufacturing Execution System (MES) on Shop Floor Control (SFC) level. This fact applies to “customized mass production”, too. Customization is a production activity when a firm produces goods or services to meet demands of individual or important customer or shopping centers with near mass production efficiency and cost. Mass production is one of the great well known paradigms. Today mass production is very common all over the world for a lot of goods. Mass production technology has automated manufacturing and/or assembly lines, specialized skilled workers, big lot size, automated quality checking, automated packing operations, and relatively high stock level of materials. The lot size generally as high as possible. Frequently, there is a stable supply chain system for materials and product components.

In customized mass production the firms plan their production partially for external direct orders, arriving from logistic or shopping centers but to meet delivery dates they have to make forecast for manufacturing semi finished products and buying materials having long external lead time. The efficiency of automated manufacturing or assembly lines depend on the lot size, the set up frequency, the utilization rate and the size of queues. In the real manufacturing practice there are a lot of uncertainties that have complicated effect on realization of predicted schedule in shop floor level. If some of the materials and components did not arrive on time, machine lines break down, skilled workforce is missing, specification or volume of initial market demand changed will not achievable and the warehouse stock level will be too high or too low. At present, satisfying customer demand from inventory is more and more expensive. To hold reserve manufacturing capacity causes long return of invested money. Therefore the importance of flexible and integrated software tools supporting decisions on planning and control level is very high.

2. MES IN CUSTOMIZED MASS PRODUCTION

In customized mass production MES is responsible for short time scheduling, resources allocation, dispatching and monitoring production activities from order launch to finished goods. In an ideal world the manufacturing and transportation processes are flowing as planned. However in a real manufacturing environment there are a lot of disturbances, therefore the performance of production system is changing dynamically. Supervising the production performance requires the up date monitoring of the status of the production orders (PO), jobs and pallets created by the scheduler or dispatchers, machines and machine lines, materials picked up, setup activities, assembly operations, test and packaging operations and destination of finished products.
At shop floor level MES systems are used to track down the real status of process elements and objects (physical and virtual ones as well) online. The most important MES functional components are shown in Fig. 1.

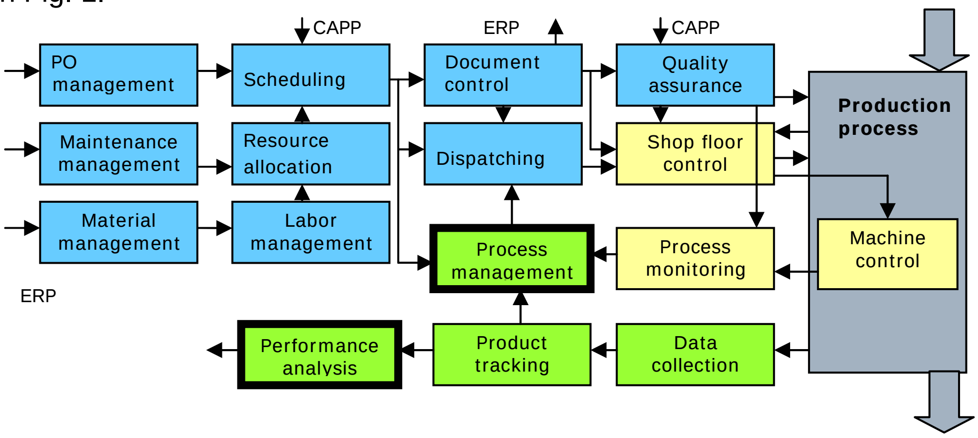

Figure 1. MES functions in mass production

By means of MES system the performance of production must be assessed. If any deviance from normal (planned) status is detected, an alert is generated and the appropriate action has to be done. Control theory provides a lot of successful control policy to extend the simple “feed back and eliminate error” based algorithm. Table 1 summarizes the most widely used classical control policies for eliminating disturbances on automatic controlled technology.
In the case of production control system feedback it is also very important to manage uncertainty. The production management gets a set of production orders with documents: BOM-s, technology routings, detailed schedule and quality requirements. Proactive production planning and scheduling is based on the centralised knowledge consisting of the system models, resource and material statuses and the data of independent orders. Production planning and scheduling defines what actions have to do to achieve the defined production goal. The proactive approach is successful when the environment and goal do not change, and the model is reliable.
Reactive control can uses planned and built in actions real time (on line), which are triggered by certain process events and conditions defined. Internal model can respect the stochastic nature of the process being controlled, too.
Adaptive control is an extended control algorithm in which controls parameters varies in real time, to allow the controller to remain effective in varying environment. Advanced systems may use historical data for the purpose of learning system properties.
Behaviour Based Control is a type of adaptive control strategy for uncertainty management. It observes the general status of the controlled process, end compare it with the planned status. The state space may distribute to finite number of situation domains. Situations and demanded activities related to state variable domains by complex nonlinear mapping functions.

	Proactive	Reactive	Adaptive	Learning	Behaviour based
Model	known	stochastic	incomplete	unknown	known
Goal	defined	defined	varying	varying	varying
Disturbance	negligible	probability	strong	strong	situation based

Table 1: Theoretic types of control systems

2. RELATED WORKS

There exists a lot of literature dealing with the Manufacturing Execution Systems functionality [8] but uncertainty management functions have not shown wide-spreading appearance yet. The main terms are defined in [2] for general engineering system modeling. Uncertainty in manufacturing systems appears as an unexpected complex behavior of the production process. Behavior is an emergent property of a system through being in interaction with the environment [8]. In conventional control strategies the system samples the controlled process via observable state variables and matches them to a planned model. When a perfect match is found the system starts the next planned action which best fits to achieving the system goal. BBC is a new paradigm which uses a finite number of different models. First implementation of the BBC was introduced by Brooks in 1986 in robotics [1]. To create robust control, the subsumption architecture is applied as an instance of a behavior based method [14].
In many cases for behaviour recognition Artificial Neural Networks are used, in which neurons of several layers are connected [9]. The relationship between the input and output variables is stored in the network in the form of weights, thresholds and activating functions. Also the layout of the ANN, i.e. the number of layers, the number of neurons in each layer and how the layers are connected is of great importance. During learning phase the weights and thresholds are set to minimize the difference between the expected and computed output. As one can see the model of the process is hidden. After recognition the actual situation the controller behaviour is changing and corrective action generating by expert system [7]. Behaviour-based approach inherits the properties of proactive, reactive and adaptive approach of control systems. BBC shows similarity to reactive systems, but contains certain greater freedom to interpret the situation and to find the required response activities.

3. BBC IN SHOP LOOR LEVEL PRODUCTION CONTROL

Behaviour-based controllers consist of a finite collection of behaviour oriented activity set.. They are selected actions or control laws that avoid risk of damage and achieve and/or maintain defined goal. Behaviours can be implemented either in software or hardware components; as a processing element or a procedure. Each behaviour based component can take inputs from the process sensors and/or from human operators and higher hierarchical system. BBC may send outputs to execute certain action or call other behaviour components. Thus, a behaviour-based controller is a structured network of such interacting control components. Behaviours themselves can have state sequences, and can form activity representations. Unlike reactive systems, behaviour-based systems are not limited in their defined or learnt capabilities, although learning requires feedback (e.g. reinforcement).
The most widely used AI techniques for BBC are as follows:

- expert systems,
- fuzzy methods,
- artificial neural networks,
- human-machine interaction by cockpit screens,
- rapid simulation techniques.

For manufacturing applications we suggest a new structure, which contains uncertainty management tools at MES level as an extended observing, data collecting and process management function.
For customised mass production companies which use a lot of automated production lines, a new conceptual structural and functional model for MES uncertainty management is provided in this paper. An attempt is made to demonstrate the usability of Behaviour-Based Control in the field of

MES. There are some typical models which can be used to support the process management on shop floor level. The models contains: 1. Process monitoring, 2. Alarm management and automatic corrections; 3. Diagnostics and action selection component; 4. Decision support and cockpit task management components for human activities. The structural model which describes the component structure and the joints of components in the proposed system is shown on Fig 2.

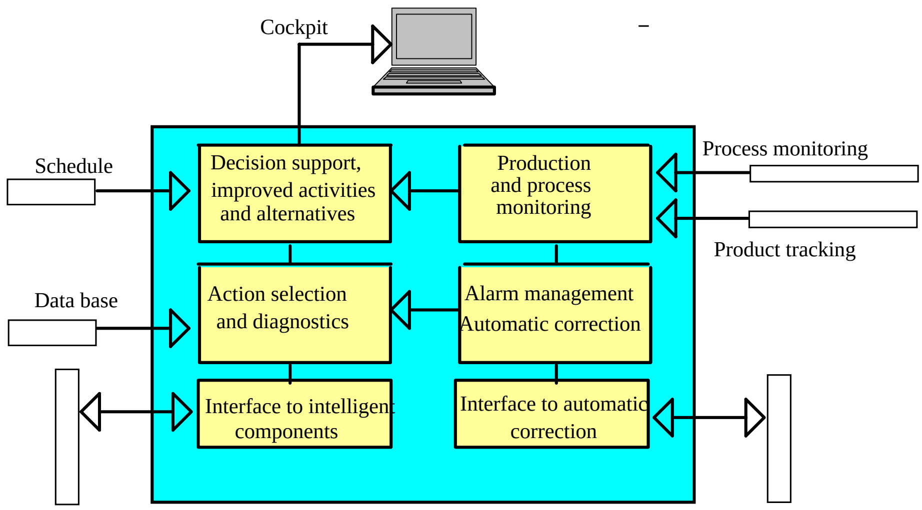

Fig 2. Structure of BBC based uncertainty management.

As a case study a production system with automatic assembly lines will be investigated. The natural structure of the automated assembly system is organized as **plant→shop-→machine-group→machine-line→machine-station** hierarchy. The uncertainty management can support all the hierarchy level above. The information model of the new MES components based on entities-relationship form. The BBC component of the model at the manufacturing process level classifies processes into behavioral patterns, such as normal, deviant or critical, evaluates action plans corresponding to the situation, selects actions and executes them automatically. The successfulness of BBC depends on adequate model.

4. COCKPIT TASK MANAGEMENT

CTM was born as an aviation technology to support pilots in supervising and managing highly automated aircrafts. In the viewpoint of CTM a goal is a desired state of the aircraft, such as taking off, flying or landing, and a task is a process to achieve these goals. The function of the cockpit management system is to initiate, monitor, prioritize and terminate tasks [4]. The system supports:

- controlling the airplane, hence flight control;
- navigation: determining where the airplane is, where to go and how to get there;
- communication: communicating with air traffic control;
- system management: configuring and correcting fuel, power plant, electrical, hydraulic and life support systems.

The ultimate goal of a CTM in aviation is to ensure the safe operation of an aircraft and to avoid human errors. In contrast to this, the role of the human is the supervision of the whole system to manage uncertain situations behind the abilities of the control system. The task management system is able to classify situations, execute automatic corrections or provide the pilot with information and action plan alternatives to resolve problems. CTM can tightly joint to BBC as a tool for human decision support.

Sayal [11] developed a business process cockpit to analyze, monitor and manage execution of various business processes at a large multinational corporation. The function of the system is to transform raw data and specific technical information to a customized schematic form to be analyzed by business and IT managers, who have no knowledge about the specific process technology. The purpose of the system is to enable locating problems, supporting route cause analysis and issuing alerts or warnings with suitable action plans toward the organizational hierarchy of the corporation. The business process cockpit fills in the same role as the CTM in aviation. Sensing and classifying the behavior of the complex monitored system, the cockpit evaluates feasible action plans and acts or collaborates with the supervisor in order to resolve problem issues.

In mass manufacturing three main sources of uncertainty may appear: market, manufacturing process and supply chain uncertainty. In conventional production management these problems are addressed by hierarchical control, reserved capacity and safety buffers. The main disadvantage of these approaches is that they fail to consider the level of uncertainness of the current market environment and the significance of feedback from the manufacturing process level. In the long run, these approaches weaken the competitiveness and profitableness of the manufacturer.

4. UNCERTANITY AND PERFORMANCE MANAGEMENT

To make a competent decision in manufacturing systems two matters have to be considered: the current and the planned status of manufacturing resources and material flow. Any decisions that are made without this criterion may lead to decreasing of production performance. Moreover, invariability of such status information among the decision makers has to be guaranteed in order to achieve collaborative actions to resolve problems. In case all participants of a decision making system comprehend situations invariably and each participant possesses a well defined scope of responsibility and boundaries of autonomy, the automation and synchronization of decision mechanisms can be achieved with high efficiency. To achieve advanced decision mechanisms in uncertainty management the combination of BBC and CTM is addressed.

The production management uses CTM to monitor material flow and manage allocation of jobs to orders, job scheduling, equipment maintenance and product quality. Supply chain management applies CTM for managing time window setting for supplied materials delivery and monitoring material flow towards the supply chain. Action steps that CTM is requested to manage automatically can be, for instance, the handling of a production line halt:

- issue line recovery alert;
- request and monitor recovery duration;
- request for redefinition of time windows for the supply chain;
- request for reschedule and reallocation of jobs and orders;
- estimate delays in delivery and issue warning.

The BBC component of the model at the manufacturing process level classifies processes into behavioral patterns, such as normal, deviant, critical, or dangers. Evaluates action plans corresponding to the situation, selects actions and executes them automatically. The successfulness of BBC depends on adequate model evaluation, action plan warehouse and action selection method. The architecture of the uncertainty management in the manufacturing control can be seen in Fig 3.

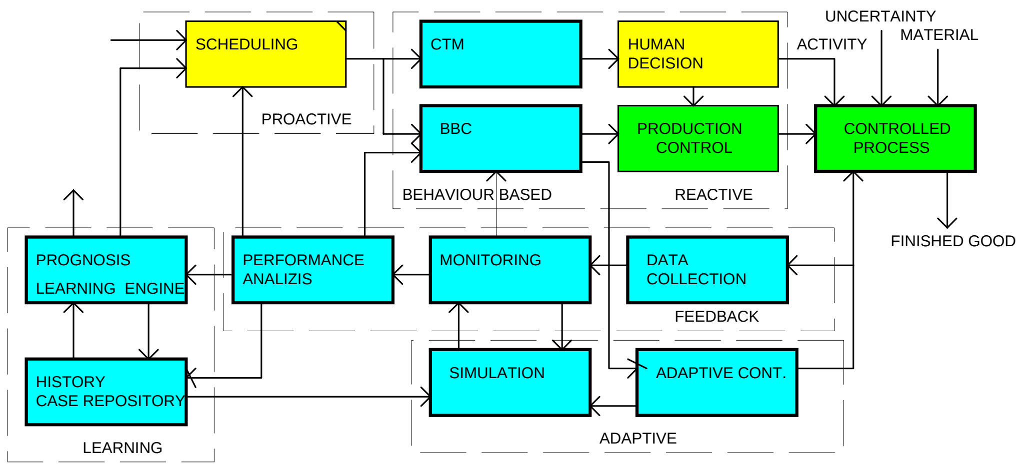

Figure 3. Structure of uncertainty management components.

The operator, to recover normal process behavior, uses CTM for defining quick action plans and executes them to reestablish material flow. Depending on situations jobs can be delayed by critical process behaviors. In this case, the operator has to cooperate with the dispatcher on how to minimizing the impact of the delay. The dispatcher attempts to reschedule jobs in the related area to minimize conflicts. However, it may also happen that delays cannot be reduced to an acceptable level or the material flow cannot be recovered due to quality problems. In this case the production planner has to reassign jobs to orders and revise priorities. In such decision making mechanism the planner has to consult with the sales management to reconsider priorities of customer's orders and the supply chain manager to provide supplied materials in a different order.

Behaviors of the system controller considering model competency can be categorized into four main types:

- proactive: competency of models is high, goals are well defined;
- reactive: competency is based on stochastic models, goals of the control depends on situations;
- adaptive: models are incomplete, uncertainty of controlling the process in order to achieve the defined goal is high, the control has to evaluate proper actions;
- learning: models to handle situations are unknown, goals are changing depending on the evaluated models.

In proactive mode the MES gives plans and schedules of tasks created by models and optimization methods to achieve the desired quality of order execution. In reactive mode the MES also has to take certain situations into consideration and to provide action plans with goals to achieve the purpose of the system. Using the system monitor, situation can easily be assigned to predefined action sequences. The adaptive control verifies models by comparing the output of the simulation model with the output of the controlled process. The responsibility of the adaptive mode is to evaluate what has to be changed to achieve a goal. Learning is needed when the expected output and the real output not only differ, but adverse. In such situations current behavior has to be analyzed in details, fundamental models reconsidered and corrected. The synthesis of these behaviors will result in a model and data warehouse that is highly competent to manage uncertainty in the internal and external environment.

The model gives new directions for developing next generation MES to successfully manage uncertainty in manufacturing systems.

5. CONCLUSIONS

This paper presented uncertainty management for manufacturing system in the viewpoint of advanced shop floor control. The combination of cockpit task management (CTM) and behavior based control (BBC) has been addressed as and approach to the problem. First, main criteria to manage uncertainty in production systems have been discussed referring to various related literatures. CTM has been introduced as the communication component in the system to ensure supporting human decisions and management information flow. CTM provides interface to the control system from the top-down.

BBC handles disturbances bottom-up way from situation recognition. BBC classifies the behavior of the controlled process, evaluates own capabilities and executes automatic corrections or delivers control data through the CTM.

Artificial intelligence approaches are utilized to keep the competency of the model warehouse in the addressed uncertain environment. Five control components for MES have been defined: proactive, reactive, feedback, adaptive and learning ones. The implementation of these components is proposed to provide adequate uncertainty management in the practice of a Hungarian company.

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