Development of an Intelligent Decision Support System for Metal Forming Industry

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ABSTRACT: *The effect of many internal and external factors, such as machine breakdowns, unacceptable quality, and order problems, needs to be considered in the metal forming processes to control and improve the production efficiency. An intelligent decision support system is developed in this work to integrate subjective information (expert knowledge, empirical models, systematic process analysis etc) and objective information (structural knowledge obtained from industry etc) into one intelligent system. It is able to reduce costs, improve quality, and increase the competitiveness of metal forming process by selection of appropriate settings in currently installed/available machinery and processes.*

Keywords: Intelligent decision support system, metal forming process, integration, subjective information, and objective information

INTRODUCTION

In metal forming and processing industry, there are a great number of functional units to carry out different tasks such as marketing investigation and planning, research and development, engineering product design, facility design, production planning and control, manufacturing, warehousing and product distribution, and etc. Any abnormality occurred during the stages from the marketing planning to product distribution will affect the products of high quality to be reached to customers. As the process involves many parties and personnel within/out the metal forming organisation to be considered, the development of an intelligent decision support system is vital to link the information around the shopfloor to the headquarters of the organisation. This system will assist in the decision making in the product processing during the pre-planning upto post-handling of abnormal conditions.

For a complex manufacturing system like the metal forming processes, it is generally divided into more levels of a hierarchy in which each level has a narrowed responsibility (Wang et al. 1993). The formal hierarchies have been proposed by Computer Aided Manufacturing International (CAM-I) (1984) and by the Automated Manufacturing Research Facility at the National Bureau of Standards (NBS) (Simpson et al. 1982). O'Grady et al (1987) combined both the CAM-I and NBS work and proposed that the control structures can consist of four levels:

- Factory level: This level, which provides inputs for lower level in the hierarchy structure, comprises factory wide computer systems;
- Shopfloor level: This level contains a shopfloor system, which is concerned with overall coordination and control of the major section of the manufacturing system. It comprises serval cells and is central to the production planning and control;
- Cell level: A Cell Control System (CCS) is the central component of this level. The CCS is a micro-/mini- based computer that controls one or more machines and facilities. It can control the individual elements of the cell and to achieve commands from the shopfloor level; and
- Equipment level: It is a level that concerns the monitoring and control of automatic machines or other facilities.

The intelligent decision support system is generally developed at the shopfloor level. To apply it to production planning and control in the modern and automated processes, the intelligent decision support system needs to integrate an expert system with the decision support system. It can interactively make decisions for a combination of different abnormalities. In metal forming processes, the abnormal situations can be classified into five major groups: rush order and order change, job delay and advance, facility breakdown, operation error, and unaccepted quality. In this work, an intelligent decision support system is developed to deal with these abnormalities in the metal forming processes. Different from the decision systems developed previously by other researchers, this intelligent decision support system integrates the expertise from the engineers, operators and managers on the shopfloor.

METAL FORMING PROCESSES AND PRODUCTION STRUCTURE

Metal forming processes are a broad range of processes, generally including hot and cold processes. They are classified into five big catalogues in accordance with the deformation methods (Lange 1985):

- Compressive forming: rolling, free/open-die forming, closed-die forming, indenting, and pushing through an orifice;
- Combined tensile and compressive forming: pulling through a die, deep drawing, spinning, flange forming, and upset bulging;
- Tensile forming: stretching, expanding, and recessing;
- Forming by bending: bending with linear tool motion and bending with rotary tool motion; and
- Forming by shearing: joggling and twisting.

The production structure for a metal forming process is presented in Figure 1. It integrates the dynamic task allocation in the global plan of production. A higher level (global scheduling) has a set of manufacturing orders (global workload capacity, latest finishing time, etc) to the production activity level. The detailed scheduling is incorporated in the real-time control part that focuses on managing the production activity. Thus the detailed scheduling is established dynamically throughout task allocation and production processes.

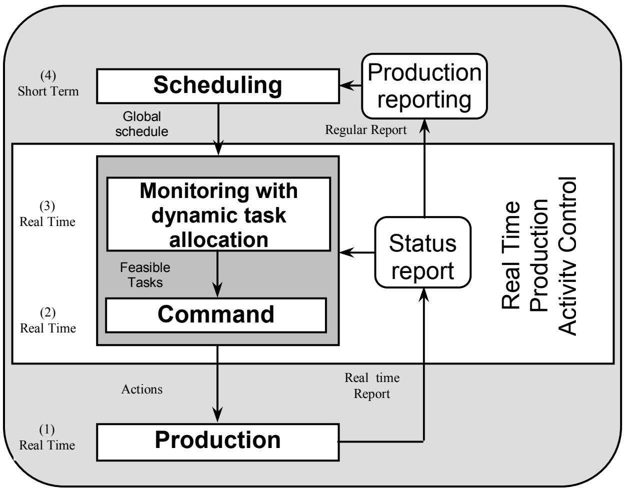

Figure 1: Production structure

There are five challenges making scheduling difficult (Parunak 1991):

- Desirability: It is hard to compute a schedule from an evaluation function and at the same time cope with the wishes of manager. Cooperation of the decision system with the human operator will increase the integration of new special constrains or particular choices whenever needed.
- Stochasticity: To cope with uncertain events such as breakdown or interference is very difficult when detailed scheduling is described before the effective work. On the other hand, dynamic task allocation integrates fault tolerance mechanisms, for example, the breakdown of an entity will not stop but will only alter the global processing of the task allocation. Since this entity will not communicate with others and will never be selected during the time of breakdown, the coming tasks will never be attributed to the deficient entity.
- Tractability: A metal forming enterprise has many independent production parameters, which is so complex that algorithms estimating schedules take too much time to run. The distributed structure automatically splits the complex static NP-hard scheduling calculation into many dynamic real time allocations. However, a decision system can take more data and criteria into account to allocate a task since the decision making (DM) for a single allocation is easier than solving an NP-hard problem.
- Chaos: Chaotic behaviour is a characteristic of every production structure. The sensibility of the initial conditions of a production process affects task allocations and may alter the effectiveness of the control.

Thus, it is important to validate each allocation and to detect whether a specific allocation is harmful or not. That leads to the notion of robustness. It is also very important to test the task allocation and to check if the choice of the allocation is pertinent or not by allowing tolerance calculations or extrapolation of the next allocations to come.

- Decidability: Because of the complexity of the production structure, it is difficult to analyse the behaviour of an enterprise. The question is: are the shopfloors too complex to allow their behaviour to be foreseen? This question is meaningful in a centralised structure but not in a distributed one. In the first case, the key to a satisfying DM is the realism of the production model. In a distributed environment, the key is not to model correctly the structure but to integrate the dynamic aspects of the structure.

The logical model to be used in the metal forming processes is the one introduced by Tchako and Tahon (1994) for a packaging line and further used by Trentesaux et al (1998) for an intelligent manufacturing system. It is the holder of the command-control system, which is associated to one or more workstations, a metal forming line or machine. Its functions are:

- Local management of one or more workstations, while integrating control, real time management and man-machine communications;
- Communication support between stations and databases, relating to tasks and process planning. Management of the information relating to: task flows, data loading and unloading, direct control of the process, direct exchange of the information between sub-systems.

And it includes:

- *A decision system*: Based on a representation of the different agents, it holds the algorithms for the decision support system. It detects the nature of the messages received by the communication system and choose the best suited strategies to be adopted by the sub-systems. In cooperation between different agents, the decision system makes or refuses a task announcement.
- *A control system*: It manages the command orders for the automation, which controls the conveyor such as the one used sheet metal forming process, a control signal to motors used in any processes.

Three systems are required to support the decision and control systems. The decision support system is part of these three systems, which are:

- *A Communication system* responsible for the information exchanges through a local area network. The messages can be either internal ie between each of the sub-systems of the metal forming system or external eg questions (request, reservation) and answers (acceptance, discharge, release)
- *An information system* to support the required information for the sub-systems; and
- *An interface system* to ensure the dialogue with the human operator and the interactions between the different sub-systems.

INTELLIGENT DECISION SUPPORT SYSTEM

The intelligent decision support system to be used for the metal forming industry is at the operation level. It deals with three different issues: task allocation or reallocation processing, local queue management, and production resource management. It is able to structure and present relevant data to the user (the relevance of the data depends on decision typology), to assist the user during his decision making if required, to make up decisions, and to inform the user if required.

The intelligent decision support system is different from the traditional decision support system. In addition to the functions provided by decision support system, it also includes a function to optimise the process with previous information from the process and the knowledge acquired and accumulated by the operators, engineers and managers. As illustrated in Figure 2, the shopfloor conditions are monitored with a monitoring system. A database is generated from the monitoring system. The intelligent decision support system makes decisions starting from analysing the information, then control of the shopfloor and logical control of the system.

Decision centre

As shown in Figure 2, the decision centre consists of a knowledge base and a heuristic inference/search. The knowledge base and the heuristic inference are interactive. However, the information in the knowledge base is not just coming from the heuristic inference/search, which is based on the information obtained from the monitoring system. The knowledge base also has inputs from the shopfloor personnel (operators, engineers and managers), research scientists who have developed constitutive and empirical models for the process. Furthermore, as the information technology advances rapidly, the knowledge base gets information from simulations with various models including the one used in the decision support system. The hybrid knowledge base, which is composed of the information from the shopfloor data base, simulation models, constitutive and empirical models, and the expertise from the operators, engineers and managers, provides significantly more information than the shopfloor data base. Consequently, this improves the accuracy of decisions to be made based on the information provided from the hybrid knowledge base.

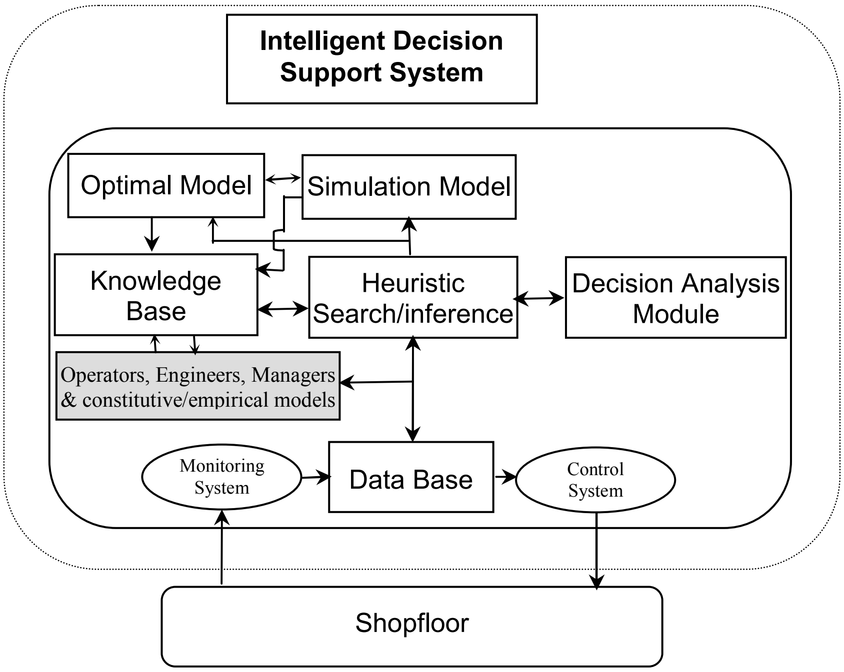

Figure 2. Intelligent decision support system for metal forming process

Decision centre actively interacts with the lower and upper levels. It actively requests information from the knowledge base and data base, simulates using the models in the decision support system, and selects the most appropriate solutions based on the various evaluation models of the decision analysis module. Therefore, decision centre is responsible for the qualitative presumption to have the problem structured. It then makes suitable decisions and ensures the quality of such decisions with mathematical and simulation models (Wang et al. 1993).

Decision support system

There are two parts in the decision support system: an optimal model and a simulation model. They support the decision centre, quantitatively evaluate the knowledge, and make prediction during decision making. They are fulfilled by two models:

- *Optimal model*: The optimal model quantitatively provides information on the system performance through different models such as machine speed-up model or overtime model developed by Wang et al (1992) based on optimum theory. In metal forming processes, there are many processes involved with high temperature (for hot forming) and friction (for cold forming). The models need to be developed for these processes to consider their different requirements.

  The optimal model has to be coordinated with the simulation model based on specific conditions to call the optimal model. During the prediction, the decision centre first calls the optimal centre and then, the simulation centre or *vice versa*.

- *Simulation model*: There are two functions in the simulation model: simulation and scheduling, although both of them are doing the same job to make a schedule for the management of a metal forming process. The scheduler generally makes a schedule for the machine tools (such as furnace, drawing or extrusion machines etc); while the simulator makes a more detailed schedule for the operations such as loading/unloading, part transportation, etc.

The regular scheduling and rescheduling are two major activities to be carried out in the simulation model. Regular scheduling focuses on the problems like loading check, sequencing and routing. The simulator, however, is more difficult and the selection of an appropriate model has to take the material flow and plant layout etc into account. In addition, the simulator takes a longer time to achieve a prediction than the scheduler, and can only be used in a situation where an auxiliary facility is breakdown or there is enough time for the decision making with a simulator.

- *Decision analysis module*: Generally, there should have more than one model for the decision centre to choose from to get an optimised model. The decision analysis module is used for the decision centre to choose a suitable alternative. It evaluates short term performance ie total tardiness, throughput and machine utilization to handle abnormalities of machine breakdown, operation errors etc.

Algorithm of the decision making in decision centre

The intelligent decision making simulates the manner what human being thinks. When an operator in a shopfloor observes any abnormalities, a decision is made depending on whether the situation is under the range acceptable for the process or any adjustment needs to be made. If the immediate action is required, the operator will need to stop the machine to make changes on the set-up. Therefore, for the decision support system, a similar decision has to be made to cope with the abnormal situations occurred.

- *Immediate response*: The immediate reaction is to stop any process with abnormal situation or/and find a way to temporally stabilise the conditions on the shopfloor. Under situations such as machine break down, unacceptable quality and operational errors, an immediate reaction is required. In addition to the immediate reaction on the shopfloor to isolate the facilities, stop processing and stop feeding materials, the relevant departments to the process also needs to be notified for them to make corresponsive and appropriate reaction. Normally these departments include engineering and maintenance department, the departments for the processes before and after the current process.
- *Reasoning*: As there are too many operational parameters in the metal forming processes, it is not an easy task to find the right causes for the failures. Generally, the reasons for failures either can be checked out with the monitoring system or cannot. For the later situation such as die breaking or die wear, it may need to be identified by the engineers from other departments. With the decision support system, all areas, such as human errors, event failures, equipment failures, tool and fixture failures, and production prediction errors, should be checked.
- *Evaluation and judgement*: The impact of the occurrence of an abnormality has to be evaluated and following action to be justified. These include, for example, how long the problem will be resolved and how the problem occurred, what immediate action to be taken to deal with the load increase or capacity loss, what preliminary decision to be made, what the net loss of the process is, and whether the prediction can be finished within a certain time limit. Direct reaction, urgent decision and net impact assessment are the major items developed from this model.
- *Alternatives*: The alternatives will be selected based on the information obtained from the evaluation and judgement. There are many alternatives for direct action, pre-action, and general alternatives. Some of them are discussed by Wang et al (1993) for the manufacturing system.
- *Self learning and solution*: Finally, the best alternative has to be selected. It needs to decide:

  If the results of the alternative have different value of total tardiness, choose the alternative that has the minium value of tardiness;

  If the results of the alternatives have the same value of total tardiness, choose the alternative that has the maximum value of weighted throughout and machine utilisation.

To improve the efficiency of intelligent decision support system with the self-learning, the experience of decision making strengthens the rules of impact judgement and alternative selection. There are many different self learning modules according to the abnormal situations, ie rush order and order change, job delay or advance and facility breakdown etc. In the self learning, production conditions such as batch size and routine, job allowance, and machine utilisation are used as inputs while the impact assessment, alternatives, and time period are the outputs. There are two stages in the self learning and decision making process. With the use of the format of rules, “if premise then conclusion”, and during the generation of the rules, the conclusion is generalised first and then the premise is generalised. Through the use of the self learning processing, the efficiency of the intelligent decision support system will be improved.

APPLICATION OF THE INTELLIGENT DECISION SUPPORT SYSTEM INTO FORGING

Forging process is one of the popular processes in metal forming. There are several kinds of forging process, such as compressive, bending, shear, sectioning, and joining forging. However, the forging process is normally divided into two main groups, open-die and closed-die forgings.

There are many parameters involved in the forging process, ranging from materials properties (hardness, alloy, forgeability, etc), temperature (cold/hot forging, stability of temperature, conductivity), die material and condition (hardness, wear, dimension etc), lubricant (type, friction coefficient etc), to equipment and part geometry. For a forging processing, there are a number of steps in order to achieve the deformation required.

The forging is an automatic production system. If the process in very stage is computer controlled, it can be easily central monitored and controlled with intelligent decision support system as its loading and unloading are also automatic. Suppose there are totally N stages in the forging process and the machine *i* (less than N) is breaking down. Then the intelligent decision support system starts to work on the situation and make following decisions:

- *Immediate action*: Stop and isolate machine *i* and retrieve relevant data; remain normal conditions for other machines, as they are functional.
- *Reasoning*: Decide what type of the failure is for machine *i,* find the reason from maintenance department (M.D.) for the failure.
- *Impact judgement*: Require report from M.D. for the recovery period; estimate the impact; judge whether direct action, urgent decision, pre-action need to be taken.
- *Alternatives*: Whether other parts can be made; have more shifts next day or weekend.
- *Solution*: Based on the alternatives selected, reschedule the process to decide which one has the minimal tardiness and find the better reschedule.

CONCLUSIONS

An intelligent decision support system integrated with expert knowledge of shopfloor personnel is developed generally for metal forming process and discussed in particular for forging process. There are three main modules in the intelligent decision support system, decision centre, decision support, system and decision analysis. The system integrates the expertise of shopfloor personnel (operators, engineers, and managers), constitutive and empirical models, artificial neural networks predictions, and quantitative models with the information acquired with monitoring system. Together with the traditional intelligent decision support system developed for automated manufacturing, the system developed in the work takes expert knowledge into account rather than personal intervention for more accurate system control. It is able to handle the abrupt and unexpected situation occurred in the metal forming plants. Although only the forging process is briefly analysed, any other processes such as rolling, drawing and upsetting can also be simulated.

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