Real-time Design Control of Manufacturing Operations

By A.B. Gembeh, Dr K.V Pandya, and Dr S.K. Banerjee.

Department of Design, Manufacture and Engineering Management

University of Strathclyde, Glasgow G1 1XJ.

Tel: 0141 552 4400 Fax: 0141 552 0557 E-mail:- cler18@strath.ac.uk.

Abstract

This paper provides the use of real-time structured methodology which is strategically applied with a production control tool that is responsive to dynamic shop events using a heuristic search method. This is implemented in a rule-based system and tests have shown to provide improvements in performance.

Keywords: Real-time design, P-I-C, production control, Simulation, CIM.

1 INTRODUCTION

The design of manufacturing systems have several effects on their operation and performance. Several methods have been applied to manufacturing design in order to cope more effectively with real-time requirements such as being able to meet task deadlines, high reliability, adaptability and responsiveness to change. Design control is concerned with providing adequate tooling, structural and operational modes in maintaining high performance. The main aim of this paper is to provide a production control tool that is responsive to changes in a dynamic shop in order to meet the effects of random disturbances such as in demand orders, interarrival times, machine breakdown, and material shortages. These have been developed through the modelling of Computer Integrated Manufacturing(CIM) operations using Process-Information-Control(P-I-C) methodology (Gembeh, 1996), and then simulated to evaluate their performance measurements.

2 MANUFACTURING SHOP ENVIRONMENT

The manufacturing shop environment includes five machines with several buffers which produce 9 part varieties and a stock pool where products are being stored before their release to the customer. Jobs and orders arrive at random and some fail

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to meet their due dates. Machine breakdown is also frequent as well as blockages at the bottleneck centre. These incur large Work-In-Progress(WIP) and long waiting times. Incidentally some machines undergo starving which results in poor utilisation. In order to solve these impending problems a flexible strategy is implemented based on heuristic search of alternative job routings in which parts are being processed according to machine availability. If the machines are busy, blocked, or in a breakdown state alternative machines are being allocated for processing. Flexibility is also attained through multiple process plans where parts are prioritised and these compete for resource and timing constraints.

In order to provide for effective control and management of shop, their activities are strategically applied in design life cycle phases for the purpose of manufacturing integration in an effort to gaining several benefits such as reducing response times, standardisation of processes, creating the right culture, performance monitoring and improvement.

3 STRATEGIC PHASES FOR DEVELOPMENT

The key aspects of development are synchronised in design life cycle phases which include the following:-

Requirements Definition: The requirements definitions for the manufacturing operations are kept in a common database. This performs several functions which specify system boundaries and component tasks, store program files, and keeps available real-time user access information. A pilot and feasibility study helps evaluate the requirements of the system. Suitable vendors are chosen based on the target definitions for meeting due dates, leadtimes, attaining the right product mix, and in minimising costs. These requirements are customised to meet variations of demand and shop activity. The design problem is specified by a set of functions and parameters which describe the activity scope and database domains. All requirements are implemented through a suitable culture which thrives on flexibility, continuous improvement, and monitoring. The specifications at this level are used for conceptual development.

Conceptual Modelling: The conceptual model provides the modular framework of operations for the intended features required to meet the functionality of system and the proposed target measurements. It is being developed so that it reflects system goals, management vision, meet production requirements and constraints. These represent the main knowledge domain upon which control is being based. The use of closed loop Material Requirements Planning(MRP) reduces the system's responses and improves error corrections. The physical features evaluated in the conceptual model are used for development in the design phase.

Design and Detailed Design: The architectural frameworks provide the basis for model building and forms the backbone for all existing and future processes. A

detailed design is obtained by modular top-down decomposition of the structural units which retain the relationship between tasks and their sub-components. In order to check the effectiveness of design the model is further subjected to several tests such as design modification, verification, and validation. Design modification is the means of accomodating change to enhance model properties and functions. Verification involves checking the accuracy of model against the specifications, and require approval at a senior management level or by authorised personnel. Design validation invloves comparison of performance model against standard methods and results. The validated model is assessed by quality assurance.

Quality Assurance: The quality assurance phase provides useful functions which include maintaining data integrity in order to drive operations correctly, minimise errors, and provide appropriate responses to change. It involves interface and feedback links with the database and user. Methods which are being applied include removal of data and file redundancies, error checking, maintaining data consistencies, proper and accurate documentation. Also used are software improvement techniques that enhance software quality such as through metamodel development. The resulting structures are more responsive to change, with easy data access facilities. Viable design models are used for implementation.

Implementation: The implementation phase performs several services that include data exchange links, interface for application tools, and programming facilities. The applications of models are tested through simulation to evaluate performances such as: utilisation which determine resource effectiveness; tardiness which determine order lateness; and makespan which determine the completion time of all jobs. What-if capability is being used to demonstrate response to change, and for optimisation of performance.

System Change and Maintenance: This is the final phase of development and include model management, maintenace, model updating, and tool re-development. The Information Technology enabling system is being re-developed through application of process re-engineering concepts such as improving the adaptive features by re-structuring the information system, process innovation, and the integration of new units and processes. Much of the design and maintenances are attained in EXCELERATOR/RTS using P-I-C modelling.

4 P-I-C INTEGRATOR FOR A PRODUCTION CONTROL TOOL

The P-I-C integrator consists of three design engines: the processor; information and data accessor; and controller. These are event-triggered and interact with one another through unified Structured Analysis Design Technique(SADT).

The Processor: The processor performs the work done on the material control system and is modelled primarily with Transformation Graphs(TRG) which provides useful outputs from data that are coordinated to the preceeding jobs of the

routing. As well as sending signals to the controller on the production status they also receive feedbacks which instructs them of what actions to take and when. Demand orders are prioritised as they enter the shop and these initiate release of material from stock. Parts are directed with optimum routing based on the availability of machines which are selected with global rules which determine job selection and sequencing, and at a local level based on machine status. If there is breakdown, blockage or starving at machine centres alternative routes are selected in order to meet the required due dates and performance levels. Excess parts are stored in buffers and if machines are idle they await until being processed. Deficient parts are also identified and kept in the shortlist whilst performance evaluations are kept in the simulation report. These files and data requirements are manipulated by the data accessor.

Fig 1 The Processor for the Material Control System

The Data Accessor: The data accessor contains input files which specify production requirements such as: the Master Production Schedule(MPS), inventory and routing files; provides user access facilities and data updating through the data dictionary. A centralised database model is created with entity relationship diagram which specifies the inter-relationships between internal and external data components and their dependencies. Structure charts depict inter-communication links and data transfers among the various hierarchic levels which constitute the three-layered control model. These include the strategic layer which provides planning and user

interfacing, the adaptive layer which is the site for functional and data integration, and the execution layer where machine sensors detect disturbances. Signals from the data accessor initiates control.

The Controller: The controller consists of several tools such as matrix graphs, control TRG, primitive process specifications and State Transition Diagrams(STD) which depict the status of events and their logic. These control shop activities through MRP and resource requirements planning at the strategic level; WIP levelling, queue control, and process-control activities at the adaptive level; Stock control and input/output control at the execution level. Providing the central means for integration is the data dictionary where manufacturing records are kept. This is used to generate electronic algorithms into program constructs which are expressed in C or cobol. The data dictionary is also the site for metamodelling where common meta data structure is used for unification of object components, class types, and attributes. The rules and heuristics which are being developed are applied in the batch mode to meet the production targets .

5 BATCH PRODUCTION APPROACH FOR FLEXIBLE MANUFACTURING

Batch production is attained in the fixed mode rather than variable as it provides greater stability, is practically easy to implement and analyse. Small batch sizes are being used since they are flexible and can therefore readily meet production changes. Supervision is attained through effective personnel management. This occurs at the shop level where tasks and resources are being allocated, at the cell control level which provides strategic control, and at the bottom facilities level which manages and maintains equipments. The batch jobs form multiple identical components which are simultaneously moved between machine centres at strategic locations in order to minimise material movement from stock and between centres, while increasing the processing capability of high priority parts. Through job formation and splitting subsequent loads are periodically released and these reduce the randomness at which jobs arrive and compete for resource before and after processing. Batching also minimises the effects of tool changing and set-ups. Their prioritisation are synchronised with the global selection rules which execute real-time activity. Suitable batch sizes ranging from 3 to 10 are tested by simulation.

6 EXPERIMENTAL DESIGN AND SIMULATION

The part types are produced according to MPS requirements and a production smooth parameter is used as a cumulative percentage which determines the difference between production values and requirements as a ratio of their production targets. Disturbances in the shop are caused by random exponential variations of demand orders, interarrival times, breakdowns and repairs. As a result high dynamic activity is being attained and the results are presented with consistency of 30 runs minimum. Their activities are controlled by 9 process plans which execute each part

and these determine the allocation of resources when required. The job shop specifications are shown below.

Number of Machines(M/c)= 5 Average Machine Processing time= 50.68 Secs
 Exponential(exp) demand range= $\exp(0.2553)$ to $\exp(1.467)$ Stock=1
 Average time between Machine movement= 90 Secs Number of part types=9
 Due date = 48 hrs No. of Process plans= 9 No. of Job types= 39 Batch size=10
 Total Number of Products required= 1620 Set-up time= 60 Secs

The performance of operations are dependent on several factors which include machine availability, demand distribution, buffer space, and resource capabilities which is single for each machine. Tests are performed in order to determine the optimum system using production rules and to show how they respond to changes such as machine breakdown, and material shortages. The starving at machine centre is measured by its intensity(I) given as $\text{arrival rate of part}(\frac{A_rate}{Service\ rate(S_rate)})$. The results and analysis of tests are shown in the next section.

7 RESULTS AND ANALYSIS

The shop operations are simulated using FACTOR/AIM subject to the following production rules and heuristics.

Rule1: SRLPT :- Search and select the shortest Route with the Least Processing Time

Rule2: PRFCFS :- Search and select according to Planned Routing on First-Come-First-Serve basis

Rule3: SFCFSW :- Search and select the machine available on First-Come-First-Serve basis and if no job exists Wait and allocate to the first job available.

Rule4: SEDDW :- Search and select jobs available to a machine resource with the Earliest Due Date and if no jobs exist Wait until the arrival of selected job.

Rule5: LPLADS/R :- Search and select jobs with the Least Average Dynamic Slack/Remaining jobsteps and if there is none available allocate to the Least Priority resource.

Rule6: LDSMOB :- Search and select jobs with the Least Dynamic Slack for machines which are available with the Minimum Optimum Batchsize and if machines are not available wait until the arrival of selected job.

The rules are implemented with flexibilities ranging from 1 to 2.34 and their performances evaluated. These are being categorised into primary and secondary measurements. Primary measurements such as makespan, utilisation, and tardiness are shown in Fig 2.

The best rule for reducing tardiness is with LDSMOB. SFCFSW and LPLADS/R both produce good results but SFCFSW is preferred since it has lower earliness and

therefore high early factor K, given as arrival rate/earliness. Maximum tardiness is attained with SRLPT and this also provides maximum loads in the system. It is observed that tardiness and loads are better controlled in more flexible systems than in dedicated modes. Their order makespan is reduced as does the waiting times. On average machines with flexibility of 1.5 provide better performance. High flexible machines also provide lower utilisation compared to dedicated modes since their workloads are distributed among greater numbers. Tests with machine breakdown show improved performance with high availability of resources.

Fig 2 Performance Results of Production Rules with some Primary Measurements

Performance tests	Production rules and Heuristics	Order Makespan	Machine Utilisation (%)	Order Tardiness (T)/ Average Lateness (-ve if T=0)	Tardy Orders	Exp. Disturbance= MTBF/ (MTBF + MTTR)
M/c Flexibility						
Dedicated Mode Flexibility=1	SRLPT	4.240	53.8	1.611	190	-
	PRFCFS	2.779	62.0	-30.800	120	-
Flexibility=1.5	SFCFSW	2.11 (1.953)	52.0 (40.8)	-12.715 (-1.247)	92 (92)	-
	SEDDW	2.127 (1.946)	45.2 (41.0)	-12.703 (1.145)	92 (92)	-
Flexibility=(2.34)	LPLADS/R	2.594 (2.023)	44.9 (42.1)	-12.236 (1.042)	82 (92)	-
	LDSMOB	0.917 (1.019)	48.0 (43)	-13.9 (0.630)	26 (26)	-
	LDSMOB	11.486	39.6	16.260	377	0.588
	LDSMOB	1.767	43.4	-13.06	26	0.800
	LDSMOB	1.13	43.8	-13.717	26	0.888

Factors which influence real-time production operations are being classified into controlling and controlled factors. These are expressed in an adaptive mode with a new configuration of matrix as shown in Fig 3.

The symbols in the new matrix are explained as follows: + means increments while ++ much increments; - means decrements, and -- much decrements. The quadrants are divided into upper, lower, and whole regions. In the upper regions increments or

decrements as specified leads to reductions of controlled factors, whereas in the lower region this leads to increase in their values. In the whole regions the effects produce no change. Thus from the study the most contributing factors for control are: batch size variations and machine intensity for control of throughput; due date change for varying machine visits and their utilisation; batch size, machine flexibility, and machine intensity for reduction of waiting times; due date change and machine intensity for increasing production levels; batch size variations for changing product pattern; batch size, machine flexibility and intensities for reduction of loads; and buffer capacities for control of inventory.

Fig 3 Adaptive Control of Production Operations with new matrix

Controlled Factors \ Controlling Factors	Throughput rate	Average visits at M/C centre	Average waiting time	Total products	Average production smooth (+/- %)	Average loads	Average V/P Inventory
	35.33	38	0.636 min.	1630	0.422 min	(32.8) min	9.00
Batch Sizes	$>3K11^+$	+	$>3K11^+$	+/-	$10K7K=4$	$>3K=10^+$	+/-
Machine Flexibility	+/-	+	+	+/-	+/-	$2.34K1.5$ $<=1$	+/-
Buffer Capacity	+/-	+	+/-	+/-	+/-	$>9^+$	$>0K=10^+$
Due Date Change	+/-	48^+	+/-	+	48	+/-	+/-
Machine Intensity ($D=A_{rate}/S_{rate}$)	2.12^+	+	$>2.12K=10$	$x2^+$	2.12	$x2^+$	+/-

8 CONCLUSIONS

The heuristic search method needs to be strategically implemented in order to obtain greater benefits, and it has been shown to be effective in responding to dynamic disturbances in the shop such as machine breakdown. Through the use of high flexible routings a fairly level utilisation is attained, and this is useful since it provides opportunities to increase production and market. This paper also evaluates important factors used for controlling events in an adaptive mode by responding at appropriate times and sufficiently fast enough to minimise the effects of change.

9 REFERENCES

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