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A double decoupling postponement approach for integrated mixed flow production systems

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Abstract

Purpose – In a mixed flow production environment, interactions between production planning and scheduling are critical for mixed flow distributed manufacturing management. The purpose of this paper is to assist manufacturers in achieving real-time ordering and obtaining integrated optimization of shop floor production planning and scheduling for mixed flow production systems.
Design/methodology/approach – A double decoupling postponement (DDP) approach is presented for production dispatch control, and an integrated model is designed under an assemble to order (ATO) environment. To generate "optimal" lots to fulfil real-time customer requests, constant work in progress (CONWIP) and days of inventory dispatching algorithms are embedded into the proposed DDP model, which can deal with real-time ordering and dynamic scheduling simultaneously. Subsequently, a case study is conducted, and experiments are carried out to verify the presented method.
Findings – The proposed DDP model is designed to upgrade a previous CONWIP method in the case study company, and the proposed model demonstrates better performance for the integration of production planning and scheduling in mixed flow manufacturing. As a result, the presented operation mechanism can reflect real-time ordering information to shop floor scheduling and obtain performance metrics in terms of reliability, availability and maintainability.
Research limitations/implications – The presented model can be further proliferated to generic factory manufacturing with the proposed logic and architecture.
Originality/value – The DDP model can integrate real-time customer orders and work in process information, upon which manufacturers can make correct decisions for dispatch strategies and order selection within an integrated system.

Keywords Operational research, Simulation

Paper type Research paper

1. Introduction

The requirements of product diversity and variability have substantially increased with recent rapid developments of economies and technologies. For example, in the electronics and automatic product industries, products can have a variety of different specifications, technical parameters, shapes, colours and sizes. These products are updated frequently. Automobile manufacturers usually create a new brand every five years, and also make small improvements every year. The update frequency of electronic products is greater; consequently, manufacturers have to shorten the

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manufacturing cycle time (CT) and on-time delivery rate (ODR), improve product categories and organize production according to customer requirements and market orders. Therefore, manufacturers need to adopt a production line that can tailor many different types of products at the same time with high flexibility (Vrabic and Butala, 2011). This type of production line can flexibly meet the requirements of production planning with different types of product families, is defined as a "mixed flow" production line, and has been the focus of many researchers in recent years (He *et al.*, 2011). Based on the considerations of customer requirements or reasonable usage of manufacturing resources, the mixed flow production line is an important development of the manufacturing industry.

In the past few decades, researchers have investigated four production scheduling models: single model, parallel model, flow shop and job shop. The mixed flow-shop model is different from these four production scheduling models. It is a model that includes parallel models and flow-shop models, but it does not consist of two overlapping models. In recent years, studies of mixed flow production line scheduling have focused on simple models that have a few steps and a few machines. To deal with the significant complexities of mixed flow manufacturing, numerical techniques have been applied for production planning and scheduling problems in many factories. Numerous models have been developed using optimum scheduling strategies searching with mathematical or intelligent methods (Elmaraghy *et al.*, 2009; Colledani *et al.*, 2010; Min and Yih, 2010; Sun *et al.*, 2011). Compared with traditional job-shop and flow-shop production lines, mixed flow manufacturing demonstrates much higher flexibility for manufacturing management. It takes several weeks to run the manufacturing cycle from production planning to scheduling. After a demand forecast has been set in the production planning period, the actual orders may change frequently during the factory scheduling stage. Therefore, manufacturers should demonstrate faster order acknowledgement cycles. The avoidance of an excess of finished goods and the simultaneous adaption of the variability of customer orders require a much more flexible and collaborative mechanism compared with conventional manufacturing processes, where the production planning and scheduling are carried out separately. After static planning, scheduling is conducted sequentially. Currently, in mixed flow production research, many studies have focused on the demand forecast, inventory management, production planning or production scheduling. To correctly respond to external real-time customer order variations, a collaborative or integrated approach can perform better than conventional methods in order to facilitate manufacturing flexibility and adaptability (Phanden *et al.*, 2011). Hence, it is necessary to develop a collaborative model to integrate the production planning and scheduling from the external real-time order perspective, to investigate the fundamental elements necessary for integrating planning and scheduling activities, and for running a quantitative algorithm accordingly.

This study proposes a practical method that integrates production planning and scheduling in mixed flow manufacturing. To correctly respond to external real-time order variations, a double decoupling postponement (DDP) model is presented. Subsequently, an operation mechanism is proposed to discuss the interaction process of the DDP model. Both a constant work in progress (CONWIP) algorithm and a days of inventory (DOI) algorithm are embedded into the integration to reflect the inventory vs orders status. To testify the effectiveness of the presented method, a case study is conducted to simulate a factory mixed flow environment.

This paper is arranged as follows: in Section 2, previously published work related to the current research is reviewed. A DDP model is introduced in Section 3. In Section 4, the operation mechanism of the DDP model is discussed. In Section 5, a case study is presented, and experiments are carried out to verify the proposed method. Conclusions and future work are given in Section 6.

2. Literature review

In recent years, integration production planning or scheduling approaches have attracted investigations on optimal demand control policies or production scheduling problems. For real-time scheduling problems, Wang *et al.* (2008) proposed a real-time distributed shop floor scheduling framework using an agent-based service-oriented architecture. The distributed scheduling was conducted through integration with Web services in a service-oriented shop floor. A case study was conducted to validate the presented dynamic distributed scheduling mechanisms. Ham *et al.* (2010) studied a real-time scheduling problem of a multi-stage flexible job-shop floor, and a binary integer programming model was formulated with an integrated scheduling decision for the flexible job-shop scheduling problem. A real-time scheduling procedure was presented to generate a schedule with competitive quality using IP. Min and Yih (2010) developed a real-time multi-objective scheduler for the selection of decision rules for decision variables in order to obtain the desired performance measures at a certain production interval. Accordingly, a system control strategy based on a simulation technique and a competitive neural network was suggested. Zhu *et al.* (2011) setup a two-stage stochastic integer programming model for the multi-period scheduling of multi-product batch plants under demand uncertainty involving the constraints of material balances and inventory. Useful advice was provided for the multi-period scheduling of multi-product batch plants under demand uncertainty. In addition, to incorporat customer orders into shop floor real-time scheduling, Jia and Mason (2009) integrated job scheduling problems with multiple orders in identical parallel machines to minimize the total weighted order completion time in a 300 mm semiconductor manufacturing operation. A number of polynomial-time heuristic approaches have been proposed to solve NP-hard problems, and experimental results have identified appropriate heuristic techniques for analysing the scheduling problem. Sun *et al.* (2011) developed a composite allocation rule-based decision policy to allocate product lots by integrating customer orders in semiconductor supply chains. Different lot allocation decision policies were evaluated and compared using representative data sets. Computational test results indicated that the presented policies could improve the quality of the solution and reduce the cost of the solution significantly. From these studies, it can be observed that customer orders have attracted researcher attention and have been embedded into real-time scheduling and search optimal solutions within shop floor internal dispatching processes.

Furthermore, progressive research studies have focused on integration problems between planning and scheduling (IPPS). To model the integrated architectures, Nejad *et al.* (2011) presented a multi-agent architecture of an integrated and dynamic system for process planning and scheduling of multiple jobs. A negotiation protocol was discussed to generate process plans and schedules of manufacturing resources and individual jobs. To verify the effectiveness of the proposal, a case study was conducted to validate the performance of the integrated architecture. To identify the integrated approaches, Phanden *et al.* (2011) reviewed current IPPS research papers and divided the IPPS methods into non-linear approaches, closed loop approaches and distributed approaches. The relative advantages and disadvantages were reported and classified accordingly. Phanden *et al.* (2013) introduced an approach to integrate process planning and scheduling. Their approach could quickly integrate these two functions with a process plan selection module, a scheduling module, a schedule analysis module and a process plan modification module. The experiments showed that this could be easily implemented in a company with existing process planning and scheduling, and that it displayed better performance than a hierarchical approach. Mohapatra *et al.* (2013) considered integration of process planning and scheduling as a multi-objective optimization problem in reconfigurable manufacturing settings. In their research, machining features were grouped according to tools, considering criteria such as makespan, machining cost and machine utilization. To search multi-objective optimal results, various types of artificial intelligence techniques have been employed. Cai *et al.* (2009) introduced a GA-based adaptive setup planning approach to solve integration problems with minimization of makespan and machining costs and maximization of machine utilization as the objectives. Zhang and Fujimura (2012) presented a particle swarm optimization approach to handle a multi-objective integrated process planning and scheduling problem. The approach aimed to obtain a set of high-quality trade-off solutions. Mohammadi *et al.* (2012) developed a mixed integer programming scheduling model, and a hybrid multi-objective simulated algorithm was proposed to obtain the optimal solution. To solve a multi-objective problem, Mohapatra *et al.* (2013) developed a meta-heuristic, non-dominated sorting genetic algorithm, which was applied to take into account the computational intractability of the problem. A hybridized simulated annealing algorithm was introduced by Kumar and Venkumar (2014) for flow-shop scheduling under a dynamic environment.

From the above studies, it is apparent that various approaches of integrated planning or scheduling have been investigated, and that the developed methods were mostly focused on the job sequence problem, or the orders fulfilment problem at single or several stations. Hence, the discussions were mostly focused on internal factory integration or work cell lot dispatch optimization. However, it is necessary to incorporate external disturbances into the integration discussion, such as order cancellations, rush orders or increases in orders. In addition, practical approaches need to be generated to assist manufacturers in demonstrating effective collaboration. Especially for mixed flow manufacturing areas, the elaborated models need to be further developed by taking the complexity of mixed flow manufacturing into account. In order to achieve this, it is necessary to establish an integration mechanism of production planning and scheduling from the external customer order perspective, to develop practical methods that reflect the orders into real-time scheduling activities and achieve finite customer order fulfilment. In particular, to facilitate industrial applications, a practical dispatching method should be introduced to solve real production flow issues. Consequently, the presented DDP method is generated from an S company project to optimize the case factory manufacturing process, and the case study is discussed in detail.

3. Model development

3.1 Assumptions

The following three assumptions have been considered in the model:

- Assumption 1: the model is specifically designed for an ATO manufacturing environment, and the decoupling point is well-defined after the constraint station.

- Assumption 2: to digest the flushing materials from the decoupling point quickly, the capacities of the back area are set to triple those of the constraint station.
- Assumption 3: the order changes are aligned with the feasible raw material (RM) quantity. Then, there are unlimited RMs to feed to the production floor.

3.2 DDP model development

As the manufacturing process for a mixed flow production system is extremely complex, it requires a very flexible mechanism to reflect the variability and uncertainty of customer orders. As shown in Figure 1, the workflow is modelled to integrate the production planning and the scheduling from a customer order perspective. The external customer orders change frequently and quickly, and then customers expect companies to tailor products and solutions uniquely to match their requirements. To respond to real-time order requests, the DDP method has been introduced to model mixed flow production lines. The whole shop floor is separated two areas: the front area and the back area. Two decoupling points are set at the beginning and the middle of the shop floor. The front area mainly focuses on WIP control, and the control method is CONWIP. The RMs are pulled based on the kitting signal from the RM point direction. In the back area, the semi-finished goods (SFG) are stored in a semi-finished goods inventory (SFGI) store, and the SFGs are pulled based on real-time order requests. Two decoupling points – RM and SFGI – also interact with each other. If the quantity of SFGs is marginal, the SFGI point will send a kitting request to RMs for SFG replenishment.

4. DDP operation mechanism

4.1 Notation

The following notation is used in this paper:

$i = 1,2, \ldots, n$ product kind
$j = 1,2, \ldots, m$ time period
$P_t =$ product name
$\beta_i =$ coefficient of product P_i priority
$Q_{ij} =$ order quantity for P_i in period j
$CW_{ij} =$ quantity of P_i in warehouse in period j
$S_{ij} =$ inventory quantity of SFGI store for P_i in period j
$B_{ij} =$ back area WIP quantity of P_i in period j
$G_{ij} =$ overall inventory target of P_i in period j
$W_{ij}^{f} =$ front area WIP quantity of P_i in period j
$W_{ij}^{b} =$ back area WIP quantity of P_i in period j
$W_{ij} =$ overall WIP quantity of P_i in period j

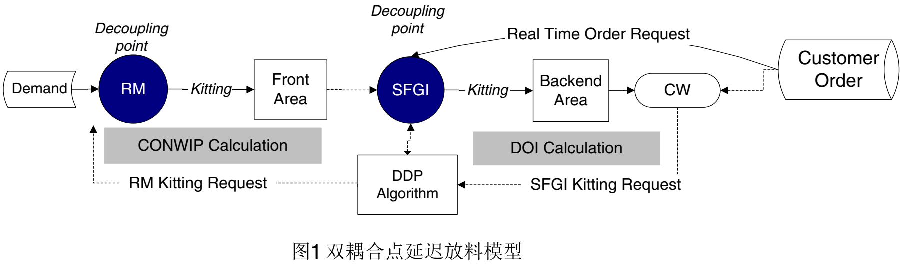

Figure 1.
DDP model

G_{ij}^{f*} = front area WIP target of P_i in period j
G_{ij}^{b*} = back area WIP target of P_i in period j
G_j^{f*} = overall WIP target in period j
C_j^b = capacity of bottleneck in period j
CT_j^a = average CT in period j
$Maxcap_{SFGI}$ = maximum capacity of SFGI
μ_{ij} = days of inventory (DOI)
μ_{ij}^* = target of DOI

4.2 Operation mechanisms and interaction processes

In the presented DDP model, the DOI μ_{ij} level is the key parameter to differentiate the different inventory scenarios. The DDP operation mechanism is described as shown in Figure 2. At the beginning of each factory floor production, the DOI μ_{ij} will be initiated, and different μ_{ij} levels compared to the μ_{ij}^* (healthy DOI target that considers the CT perspective) levels will shift to different decoupling point scenarios: RM or SFGI. The detailed operation mechanisms for RM and SFGI are discussed in the following.

4.2.1 RM decoupling point operation mechanism. If $\mu_{ij} \geqslant \mu_{ij}^*$, then the inventories of the production line are healthy. In this scenario, to avoid overflow of WIP before the constraint station, the kitting out strategies of RM should be based on the CONWIP

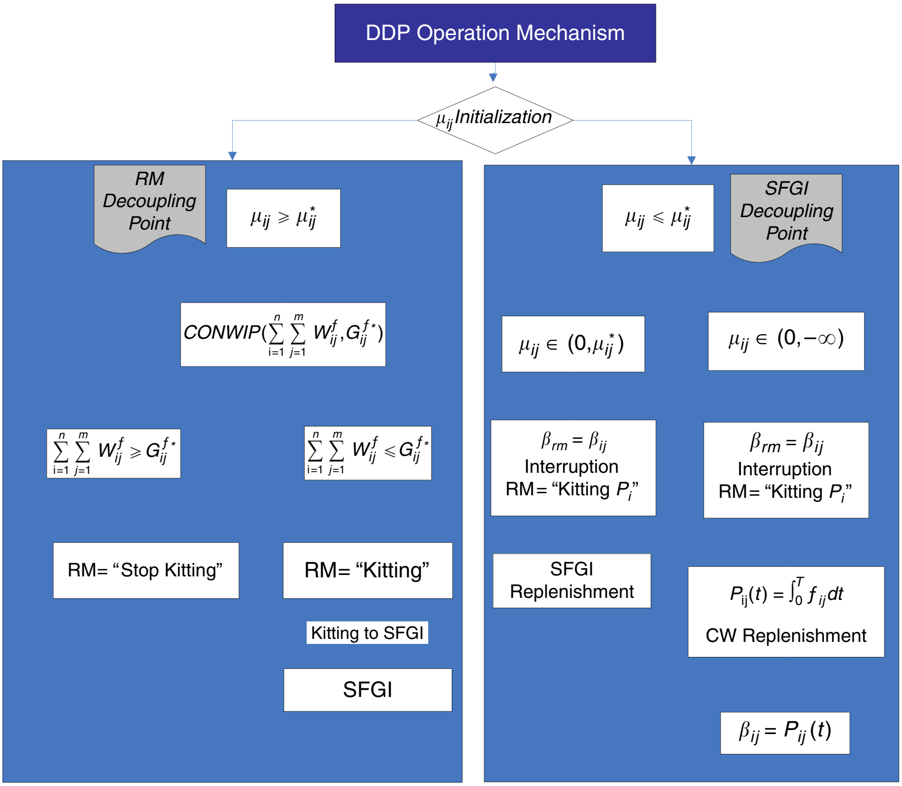

Figure 2.
DDP operation mechanism

strategy to release a great deal of RMs onto the production floor. If $\sum_{i=1}^{n}\sum j = 1mW_{ij}^{f} < \sum_{i=1}^{n}\sum_{j=1}^{m} G_{ij}^{f*}$, then the front area WIP is below the CONWIP healthy WIP target, and RM should release materials based on the manufacturing production scheduling strategies. If $\sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}^{f} \geqslant \sum_{i=1}^{n}\sum_{j=1}^{m} G_{ij}^{f*}$, then some redundant WIPs are stacked on the production floor. The kitting activities should be stopped, and the constraint station needs to digest the WIPs as soon as possible. The kitting strategies can be summarized as function (1a):

$$\mathrm{CONWIP}\left(G_j^{f*}, \sum_{i=1}^{n}\sum_{j=1}^{m} W_{ij}^{f}\right) = \begin{cases} \sum\limits_{i=1}^{n}\sum\limits_{j=1}^{m} W_{ij}^{f} \geqslant G_j^{f*}, \mathrm{RM} = \text{“holding”} \\ \sum\limits_{i=1}^{n}\sum\limits_{j=1}^{m} W_{ij}^{f} < G_j^{f*}, \mathrm{RM} = \text{“releasing”} \end{cases} \tag{1a}$$

4.2.2 SFGI decoupling point operation mechanism. When $\mu_{ij} < \mu_{ij}^{*}$, then the inventories to support the order requirements are tending to marginal or shortage. The SFGI decoupling point will be triggered to respond to real-time orders. SFGI will be a pulled inventory to fulfil the central warehouse (CW).

When $\mu_{ij} \in \left(0, \mu_{ij}^{*}\right], \beta_{rm} = \beta_{ij}$ and RM = "KittingP_i", then the SFGIs of P_i are tending to shortage to fulfil real-time orders, and the RM decoupling point will be triggered, RMs will be triggered from the shop floor and the SFGI will be replenished to ensure healthy inventory levels of the SFGI point.

When $\mu_{ij} \in (0, -\infty)$, $\beta_{rm} = \beta_{ij}$ and RM = "KittingP_i", then the inventories are already in the negative, and backorders exist. Hence, the releasing priority of RM β_{rm} should be assigned β_{ij}, and a penalty will be added accordingly. The penalty parameter is f_{ij}. If $\mu_{ij} < 0$, the penalty is triggered, and f_{ij} will be set to "1". In function (1b), if $\mu_{ij} \geqslant 0$, there is no penalty, and f_{ij} will be set to "0". In function (1c), the accumulator $P_{ij}(t)$ integrates f_{ij}, and the maximum of $P_{ij}(t)$ means that P_{ij} is the most urgent product and needs to be kitted immediately. Accordingly, the kitting lot list should be arranged according to the order of $P_{ij}(t)$:

$$f_{ij}\begin{cases} 1 & \mu_{ij} < 0 \\ 0 & \mu_{ij} \geqslant 0 \end{cases} \forall i \in \{1, 2, \ \ldots \ , n\}, \ \forall j \in \{j = 1, 2, \ \ldots \ , m\}, \tag{1b}$$

$$P_{ij}(t) = \int_{0}^{T} f_{ij} dt \ \forall i \in \{1, 2, \ \ldots \ , n\}, \ \forall j \in \{j = 1, 2, \ \ldots \ , m\}, \tag{1c}$$

In addition, the SFGI point also calculates the inventories of SFGs vs the capacity utilization. If the inventories of SFGI $S_{ij} \geqslant 90$ per cent S_{max}, then the SFG stock is becoming full, and the SFGs need to be flushed into the CW immediately to avoid SFGI overflow.

The interaction processes between RM and SFGI are shown in Figure 3.

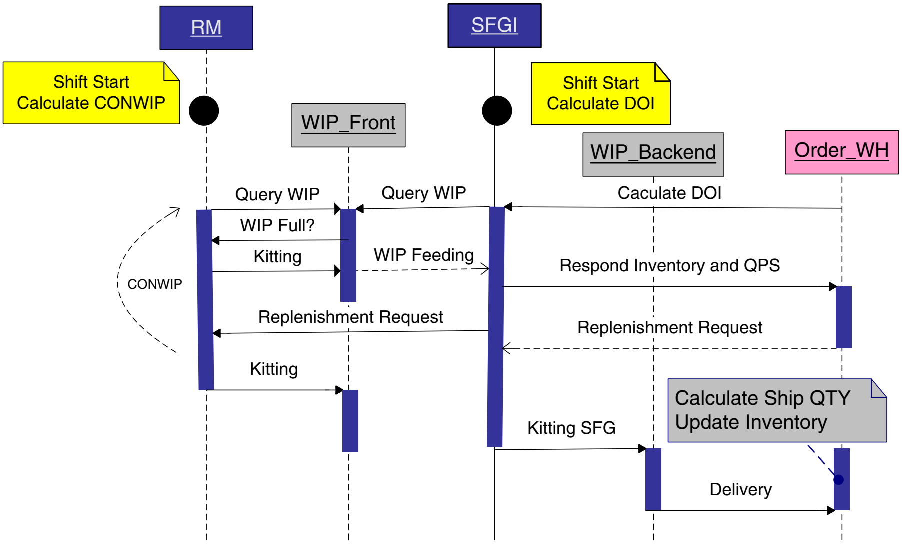

Figure 3.
Interaction processes of RM and SFGI

5. Case study

5.1 *Production line analysis*

A case study is conducted on S company mixed flow production management. The detailed manufacturing process flow is shown in Figure 4. Based on S company mixed flow factory current scheduling strategies, the finished goods product matrix is directed by the demand forecast, and the factory builds inventories to master the production planning requests. RM will be kitted out into the shop floor based on the demand forecast. After test machine (constraint station) fusing, the finished products will be moved to the CW without any reconfiguration opportunities. However, in real-life manufacturing, customer demands fluctuate significantly. This causes two major issues to the scheduling strategies. First, there is a potential risk that customer orders may be easily missed. Actual customer backlogs fluctuate and have much higher variability, which results in a potential order shortage in the warehouse. Customer requests are therefore rejected without an opportunity to swap within the product family, because the final units have already been fused. Second, the excess inventories are held on the shop floor or in the warehouse. As orders are changed randomly, excess inventories easily build up on the shop floor or in the warehouse without digestion. Therefore, the holding costs are increased.

5.2 *Simulation implementation*

To solve the above problems in the case company, the proposed DDP model is employed to integrate dynamic scheduling and real-time ordering problems. To verify the effectiveness of the proposed DDP approach for the manufacturer, a simulation is developed.

5.2.1 Simulation model. The proposed DDP model is built upon Flexsim5.0 software, which provides a user-friendly interface and debugging environment. The simulation model is shown in Figure 5. The development of simulation experiments is applied using the common object request broker architecture (CORBA) for developing

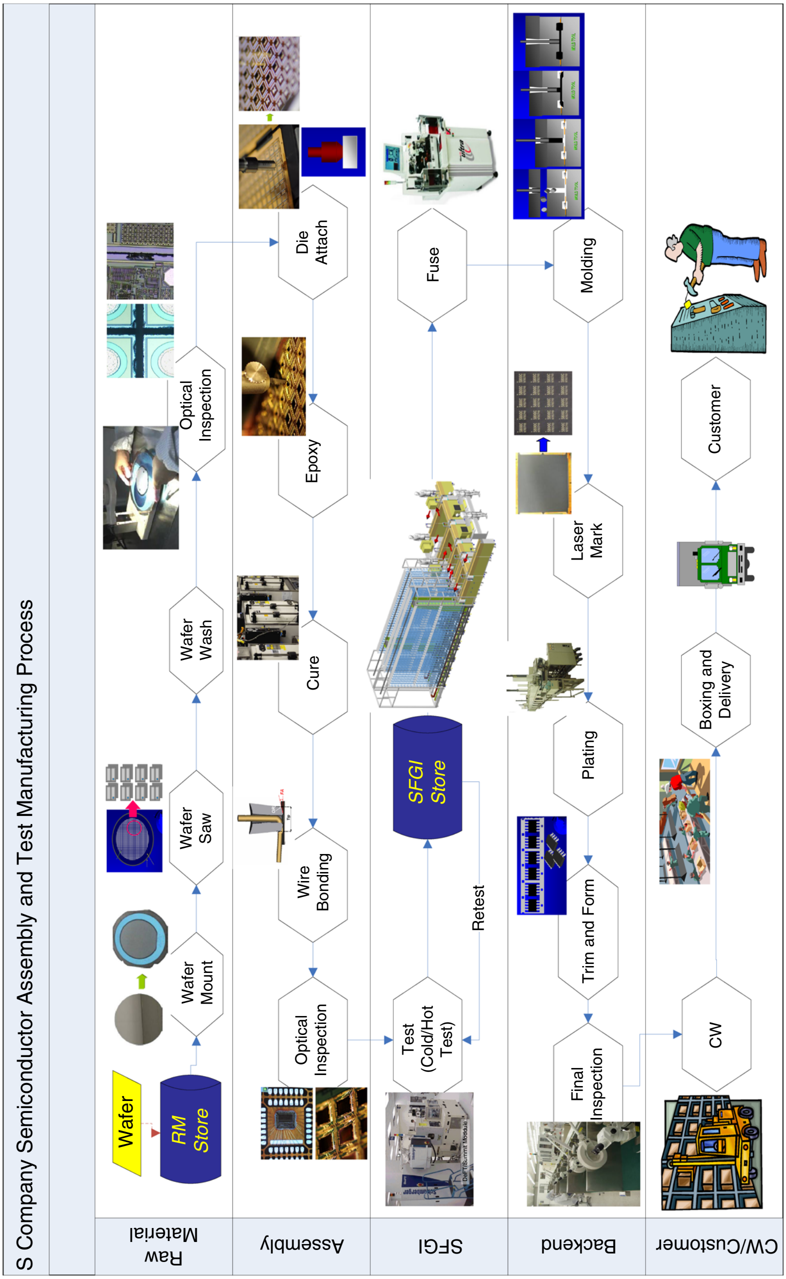

Figure 4. Overview of the manufacturing process of the case company

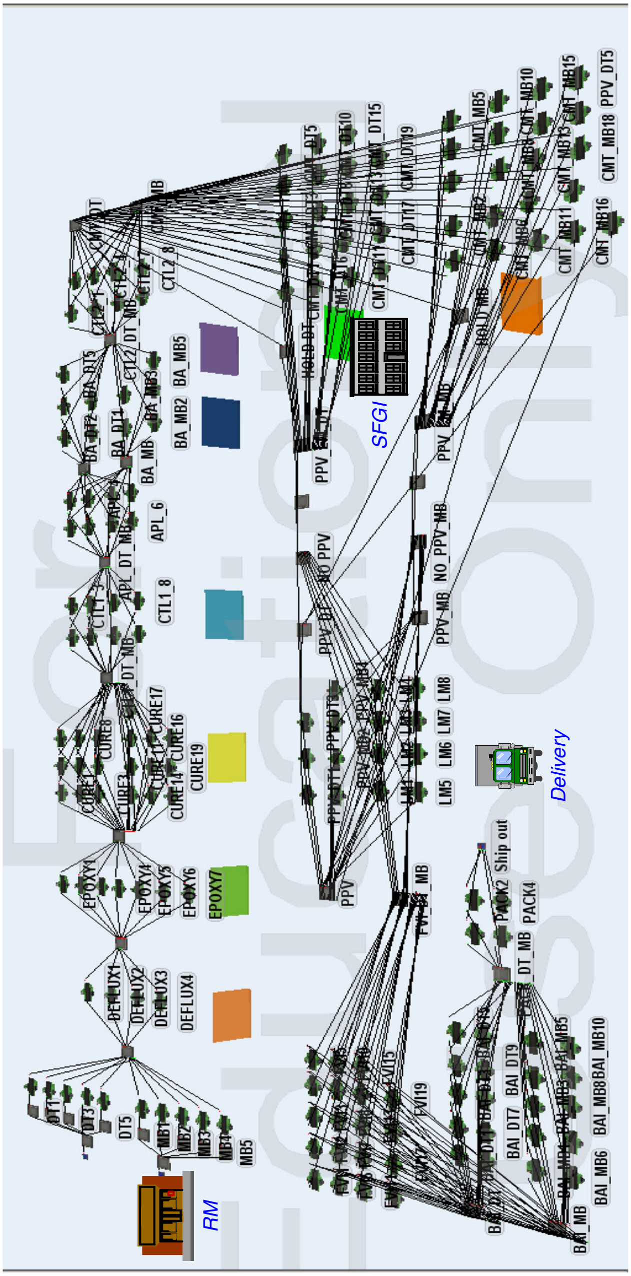

Figure 5.
Simulation model
in flexsim

the simulation. CORBA is an open standard that provides comparable services for building distributed client/server infrastructures. Numerous implementations of CORBA have been programmed by Java. It is widely available across many platforms, such as Microsoft-based systems and UNIX environments.

5.2.2 Experimental design. In order to prove the feasibility of the proposed DDP approach, a series of simulation experiments have been conducted to analyze the DDP performance in the S company manufacturing environment. A simulation model including 172 machines in 14 stations with two products has been constructed using Flexsim5.0. The model makes use of features such as products, product routes and preventive maintenance (PM). Although their processing times follow different distributions, many products have an identical processing route. Machine unavailability has been defined by the consideration of PM and breakdown. All machines have fixed PM schedules in the model. Breakdown is modelled using the mean time between failure and the mean time to repair using appropriate distribution arguments. The CONWIP algorithm is embedded in the front area, and the DOI algorithm is embedded as the material kitting strategy in the back area. Certain unessential details are not included in the model; for example, operators are not modelled in our study. Some machines are capable of being converted to produce different products, but our model does not include such machine reconfigurations. The machine allocations for different product families are fixed in the simulation model. The simulation framework is shown in Figure 6, and the simulation scenarios are listed below:

- product: CPT – DT and MB;
- lot size: 2,625 units;
- dispatching rules: first in, first out;
- simulation time: 13 weeks; and
- ignore: operator, environment, rework conversion, change consumables, lot to lot setup time, machine setup time.

5.3 Simulation results analysis – As-is/To-be

To verify the effectiveness of the proposed DDP model, the simulation is conducted within 13 work weeks in S company. Several parameters of the manufacturing

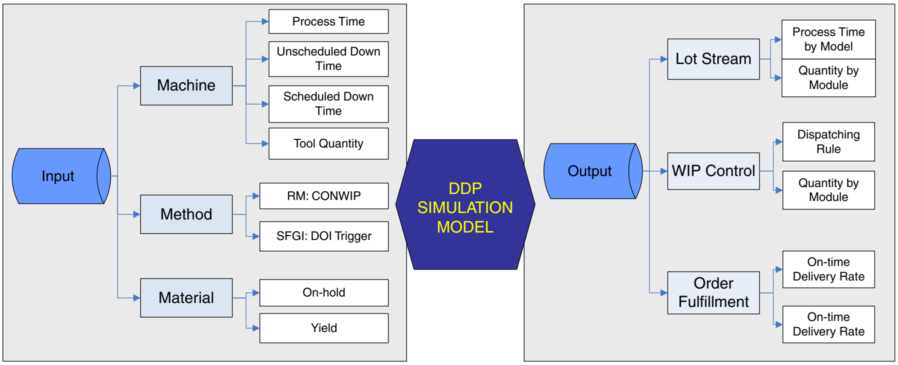

Figure 6.
Simulation framework

operation are compared to analyse the simulation results. Before simulation, three assumptions are established in the simulation manufacturing environment:

(1) The capacities of the back area are always supportable.

(2) The orders fluctuate in accordance with the feasible RM quantity. Then, there are unlimited RMs (wafers) to feed the production floor.

(3) The simulation model is specifically designed in the ATO manufacturing environment.

The performances of 13-week production are compared between the As-is production model (CONWIP) and the To-be model (DDP). The comparison results of three indicators are listed in Figures 7 and 8. In Figure 7, it can be observed that the order fulfilment tendency is to increase after DDP (To-be) implementation. Figure 8 shows several indicators: ODR, product CT and production inventory. It can be observed that the DDP (To-be) model shows relatively stable performance enhancement in ODR and CT in Figures 8(a) and (c). For the inventory, the DDP displays a decreasing trend, owing to order fluctuation and then the redundant WIPs are reduced accordingly. The statistical results of these three indicators are analysed in Table I. Under the DDP model, the ODR shows a 15.39 per cent enhancement as the "right" product segments are fused in accordance with the true order requirements. The CT is reduced by 3.79 days as the redundancy inventories are cleared out, and then the WIP moves faster. The mean value of the inventory is reduced by 6.6 per cent as the kitting quantity is aligned with the demands of the true orders. From the results of the standard deviation (SD) and coefficient of variation (CoV), the variability of the DDP (To-be) model is higher than the CONWIP (As-is) model because the DDP model aligns with the variation of real-time orders. From the simulation results, the proposed DDP model shows a more robust performance compared to the previous CONWIP model in S company.

In Figure 9, the nine months history data of S company are displayed, and the actual orders and demand forecasts are compared. The negative quantities between the actual orders (A) and the demand forecasts (F) are the bars, and the correlation coefficients of A and F are displayed as the line. It can be seen that the actual orders fluctuate significantly in the real-time manufacturing process, and that the demand forecasts are just "forecasts". It is imperative to re-engineer the production model that catches up

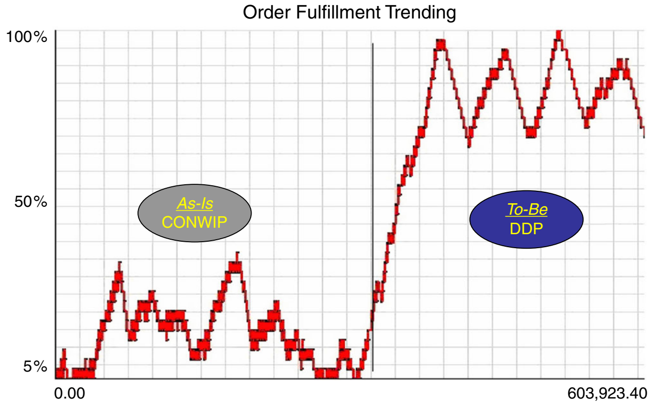

Figure 7.
Order fulfilment trends between As-is and To-be models

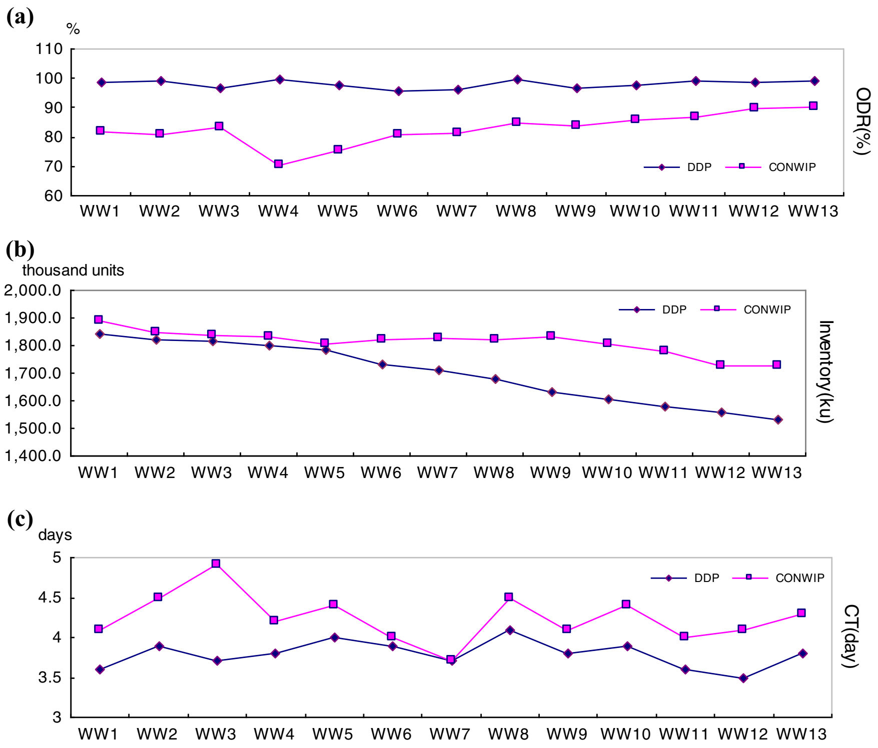

Figure 8.
Various indicator comparison results of DDP and CONWIP models

Table I.
Statistical analysis results of DDP (To-be) and CONWIP (As-is) models

Model	Parameters	ODR (%)	CT (days)	Inventory (ku)
DDP	Mean	*97.97*	*3.79*	*1,699.17*
	SD	*1.44*	*0.17*	109.99
	CoV (%)	*1.47*	*4.50*	6.47
CONWIP	Mean	82.58	4.25	1,811.46
	SD	5.45	0.30	*44.57*
	CoV (%)	6.59	7.11	*2.46*

with customer requirements and to reflect this kind of change into the manufacturing scheduling quickly.

6. Conclusions and future work

In this paper, a DDP approach has been introduced to integrate production planning and scheduling issues. An integrated model has been designed to facilitate mixed flow production processes. From an implementation perspective, the following three conclusions can be drawn:

(1) An integrated DDP model has been designed to modularize the mixed flow production process, and an interaction mechanism has been established to achieve integration of production planning and scheduling.

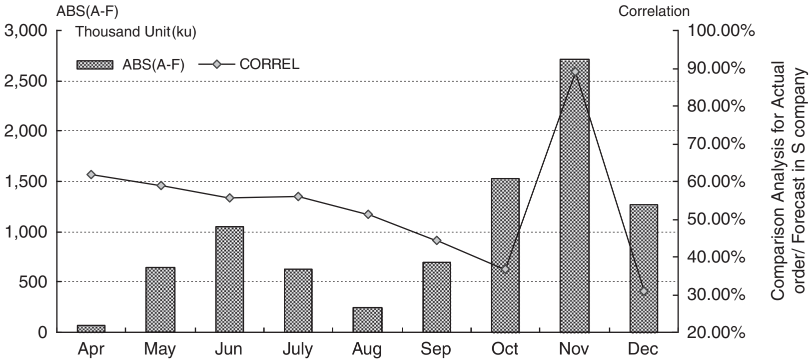

Figure 9.
Comparison analysis for actual orders and forecasts in S company

(2) A practical method has been established to aid real-life mixed flow manufacturers. The DDP model can be easily implemented into real-life manufacturing.

(3) A new method has been described to optimize integration of planning and scheduling from an external order-driven perspective.

Nevertheless, much work still needs to be developed in the future:

- with the exception of external order impact, other disturbances from internal and external environments should be further investigated and discussed;
- compatibility and expansibility need to be studied further with respect to the complicated interactions within mixed flow systems; debugging work should then be conducted; and
- the integration problems of production planning and scheduling in mixed flow manufacturing still require a great deal of investigation into the detailed technicalities of real-life production processes.

Glossory

ATO	Assemble to order
CONWIP	Constant WIP
CORBA	Common object request broker architecture
CoV	Coefficient of variation
CT	Cycle time
CW	Central warehouse
DDP	Double decoupling postponement
DOI	Days of inventory
FIFO	First in first out
IPPS	Integration problems between planning and scheduling
MPS	Manufacturing production scheduling
MTBF	Mean time between failures
MTTR	Mean time to repair
ODR	On-time delivery rate
OFP	Order fulfilment problem

PM	Preventive maintenance
RM	Raw material
SD	Standard deviation
SFG	Semi-finished good
SFGI	Semi-finished goods inventory
WIP	Work in process

References

Cai, N., Wang, L. and Feng, H.Y. (2009), "GA based adaptive setup planning towards process planning and scheduling integration", *International Journal of Production Research*, Vol. 47 No. 10, pp. 2745-2766.

Colledani, M., Matta, A. and Tolio, T. (2010), "Analysis of the production variability in multi-stage manufacturing systems", *CIRP Annals-Manufacturing Technology*, Vol. 59 No. 1, pp. 449-452.

Elmaraghy, H., Azab, A., Schuh, G. and Pulz, C. (2009), "Managing variations in products, processes and manufacturing systems", *CIRP Annals – Manufacturing Technology*, Vol. 58 No. 1, pp. 441-446.

Ham, M., Lee, Y.H. and Kim, S.H. (2010), "Real-time scheduling of multi-stage flexible job shop floor", *International Journal of Production Research*, Vol. 49 No. 12, pp. 3715-3730.

He, W., Zhu, X.W., Wang, H., Hu, S.J., Lin, Z.Q. and Chen, G.L. (2011), "Multi-objective optimization of product variety and manufacturing complexity in mixed-model assembly systems", *Journal of Manufacturing Systems*, Vol. 30 No. 1, pp. 16-27.

Jia, J. and Mason, S.J. (2009), "Semiconductor manufacturing scheduling of jobs containing multiple orders on identical parallel machines", *International Journal of Production Research*, Vol. 47 No. 10, pp. 2565-2585.

Kumar, S.R. and Venkumar, P. (2014), "Performance evaluation of a hybridized simulated annealing algorithm for flow shop scheduling under a dynamic environment", *Kybernetes*, Vol. 43 No. 7, pp. 1024-1039.

Min, H.S. and Yih, Y. (2010), "Development of a real-time multi-objective scheduler for a semiconductor fabrication system", *International Journal of Production Research*, Vol. 41 No. 10, pp. 2345-2364.

Mohammadi, G., Karampourhaghghi, A. and Samae, F. (2012), "A multi-objective optimization model to integrate flexible process planning and scheduling based on hybrid multi-objective simulated annealing", *International Journal of Production Research*, Vol. 50 No. 18, pp. 5063-5063.

Mohapatra, P., Benyoucef, L. and Tiwari, M.K. (2013), "Integration of process planning and scheduling through adaptive setup planning: a multi-objective approach", *International Journal of Production Research*, Vol. 51 Nos 23-24, pp. 7190-7208.

Nejad, H.T.N., Nobuhiro, S. and Koji, I. (2011), "Agent-based dynamic integrated process planning and scheduling in flexible manufacturing systems", *International Journal of Production Research*, Vol. 49 No. 5, pp. 1373-1389.

Phanden, R.K., Jain, A. and Verma, R. (2011), "Integration of process planning and scheduling: a state-of-the-art review", *Integrated Journal of Computer Integrated Manufacturing*, Vol. 24 No. 6, pp. 517-534.

Phanden, R.K., Jain, A. and Verma, R. (2013), "An approach for integration of process planning and scheduling", *Integrated Journal of Computer Integrated Manufacturing*, Vol. 26 No. 4, pp. 284-302.

Sun, Y., Fowler, J.W. and Shunk, D.L. (2011), "Policies for allocating product lots to customer orders in semiconductor manufacturing supply chains", *Production Planning and Control*, Vol. 22 No. 1, pp. 69-80.

Vrabic, R. and Butala, P. (2011), "Computational mechanics approach to managing complexity in manufacturing systems", *CIRP Annals – Manufacturing Technology*, Vol. 60 No. 1, pp. 503-506.

Wang, C., Ghenniwa, H. and Shen, W. (2008), "Real time distributed shop floor scheduling using an agent-based service-oriented architecture", *International Journal of Production Research*, Vol. 46 No. 9, pp. 2433-2452.

Zhang, W. and Fujimura, S. (2012), "Multiobjective process planning and scheduling using improved vector evaluated genetic algorithm with archive", *IEEE Transactions on Electrical and Electronic Engineering*, Vol. 7 No. 3, pp. 258-267.

Zhu, J., Gu, X.S. and Gu, W. (2011), "Optimal multiperiod scheduling of multiproduct batch plants under demand uncertainty", *Kybernetes*, Vol. 40 No. 5, pp. 871-882.

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