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IMPROVEMENT OF MANUFACTURING PRODUCTIVITY AND RESPONSIVENESS THROUGH INTEGRATED PROCESS PLANNING AND AUTHORIZING

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Original scientific paper

Authorizing can be described as an endogenous system signal that determines whether a job release is allowed or not. Whereas job releases are *scheduled* in *push systems,* they are *authorized* in *pull systems* since pull-type manufacturing systems are controlled by downstream information. Traditionally, *process planning* and *authorizing* are regarded as separate tasks performed sequentially, where authorizing is implemented after process plans have been generated. In view of the fact that their functions are usually complementary, higher productivity and responsiveness can be achieved when they are integrated. Although the studies related with *integrated process planning & scheduling (IPPS)* are increasingly popular, according to our best knowledge, there is no study researching the integration of *process planning* and *authorizing*. This study aims to call attention to the integration of process planning and authorizing through presenting a novel model that is called *integrated process planning & authorizing (IPPA)*. Primary implementation results of IPPA demonstrate that making the integration and hence gaining advantage through integration are pertinent. SMEs can especially get in favour of IPPA because of its slight dependence on (professional) software support.

Keywords: *authorizing, process planning, responsiveness, scheduling*

Poboljšanje proizvodnosti i reaktivnosti kroz integrirani proces planiranja i autoriziranja

Izvorni znanstveni članak

Autoriziranje se može opisati kao signal u okviru sustava koji određuje može li neki posao započeti ili ne. Dok se u *push sustavima* započimanje poslova *programira,* u *pull sustavima* oni se *autoriziraju* budući da se proizvodni sustavi pull tipa upravljaju downstream informacijama. Tradicionalno se *procesi planiranja* i *autoriziranja* smatraju odvojenim zadacima koji se izvršavaju u slijedu te se autoriziranje izvršava nakon što su napravljeni planovi za odvijanje procesa. Imajući u vidu činjenicu da su njihove funkcije obično komplementarne, veća se proizvodnost i reaktivnost mogu postići kad se one integriraju. Iako radovi koji se bave *planiranjem i programiranjem integriranih procesa (IPPS)* postaju sve popularniji, koliko mi znamo, nema rada koji razmatra integraciju *planiranja i autoriziranja procesa.* Cilj je ovoga rada upozoriti na integraciju planiranja i autoriziranja procesa predstavljanjem novog modela nazvanog *planiranje i autoriziranje integriranih procesa (IPPA).* Prvi rezultati primjene IPPA pokazuju da je primjereno vršiti takvo integriranje te onda i stjecati prednosti kroz tu integraciju. Mala poduzeća (SMEs) naročito mogu imati koristi od IPPA zbog toga što on slabo ovisi od (profesionalne) softverske podrške.

Ključne riječi: *autoriziranje, planiranje procesa, reaktivnost, programiranje*

1 Introduction

Small & medium sized enterprises (SMEs) have become a central part of manufacturing industry, especially in developing countries, owing to their large share in total number of enterprises and in total employment [1]. *Productivity* and *responsiveness* of SMEs are the two fundamental issues to be improved in order to provide qualitative success as well as quantitative success and competitiveness. Responsive manufacturing enables SMEs to operate in a flexible batch-production environment and to respond to changes and disturbances imposed by customers or the production system itself [2].

Integration of process planning & scheduling (IPPS) has been intensively worked as a research subject in the last two decades to improve the manufacturing productivity and responsiveness. IPPS has influenced considerable improvements to the productivity and responsiveness where process plans are flexible [3, 4]. Reductions on flow-time and WIP, increased use of production resources and adaptation to irregular shop floor disturbances can be realized through the integration of process planning and scheduling because their functions are usually complementary.

However, this integration causes to have to handle more complexity than carrying out these tasks sequentially. Handling higher complexity also means higher dependence on professional software support while implementing this integration. On the one hand, software packages available in the market are not affordable for most SMEs today because they have generally limited resources and they are not able to pay huge amounts of money for the implementation of such professional software systems [5]. On the other hand, many solutions provided in the packages focus on *Gantt chart*, which is generally doomed to fail in job-shops because of high data maintenance and because of their high sensitivity to uncertainty, resulting in unstable schedules [6].

Whereas job releases are *scheduled* in push systems, they are *authorized* in pull-type manufacturing systems. *Authorizing* can be described as an endogenous system signal that determines whether a job release is allowed or not. It is based on downstream information related with system status. Implementation of authorizing can provide handling lower complexity to its implementers when compared job-shop scheduling that is an NP-hard problem. Handling lower complexity means a slight dependence on professional software support.

Although pull systems are generally associated with good perceptions on performance of flow-lines, they are also now for job-shops as discussed in the third section of this paper in detail. When existing pull systems are reviewed, it is observed that authorizing is carried out after developing process plans despite the fact that their functions are complementary as well. Implementation of an integrated approach for process planning and authorizing can also make possible to obtain better results on manufacturing productivity and responsiveness. Furthermore, integration of process planning &

authorizing can be preferred by SMEs instead of IPPS because of its slight dependence on professional software support. According to the authors' best knowledge, integration of process planning and authorizing has not been investigated previously although IPPS has been worked intensively. There is an increasing need for deep research and application of integrated process planning and authorizing to overcome software support problem. This study therefore calls attention to this integration by proposing a disruptive model named as *integrated process planning & authorizing (IPPA)* to meet this requirement.

The remainder of this paper is organized as follows: In the second section, traditional and integrated approaches are discussed and a brief literature review on IPPS is given. In the third section, the most popular pull systems are discussed. Feasibility of achieving the integration of process planning and authorizing are investigated as well. IPPA is introduced in the fourth section. Strategies for implementation of IPPA are given in the fifth section. Contribution & industrial relevance of IPPA are given in the sixth section. Finally, concluding remarks are presented.

2 Theoretical background & literature review on IPPS

Flexibility is a complex, multidimensional, and hard to capture concept [11]. It is a major issue in achieving agility and responsiveness [12]. Flexibility can actually be seen as the available potential of a manufacturing system for handling expected and unexpected events [13]. Sethi & Sethi [11] discussed 11 different flexibilities. These are machine, material handling, operation, process, product, routing, volume, expansion, and program, production, and market flexibilities.

Routing and operation flexibility are the two ones that are faced in general within the IPPS scope. Therefore, these flexibilities are solely discussed in this paper. Detailed information for the rest can be found in Sethi & Sethi [11], and Koste & Malhotra [14].

Fig. 1 shows two flexible process plan networks. This representation was firstly proposed by Ho & Moodie [15]. Three node types are used in this network representation, namely; *starting*, *intermediate* and *ending nodes*. Starting and ending nodes indicate start and completion of the production process of a certain job, respectively. Operations are represented by using intermediate nodes. Arcs connecting the nodes represent precedence relations between operations. Producing the same product with alternative operations routes is a type of the flexibility provided in such a network. For instance, job *J*1 (Fig. 1a) can be processed with any one of 1-2-3-4-9, 1-5-6-7-9, and 1-5-8-9 operation routes. This kind of flexibility is called as *routing flexibility* [14]. An operation can be processed on alternative work stations in different ways with distinct processing time. This is the second type of flexibility provided in such a network. The first operation of job *J*1 can be performed on any member of set of feasible workstations {1, 2} with processing time 18 and 22, respectively. This kind of flexibility is called as *operation flexibility* [2, 11].

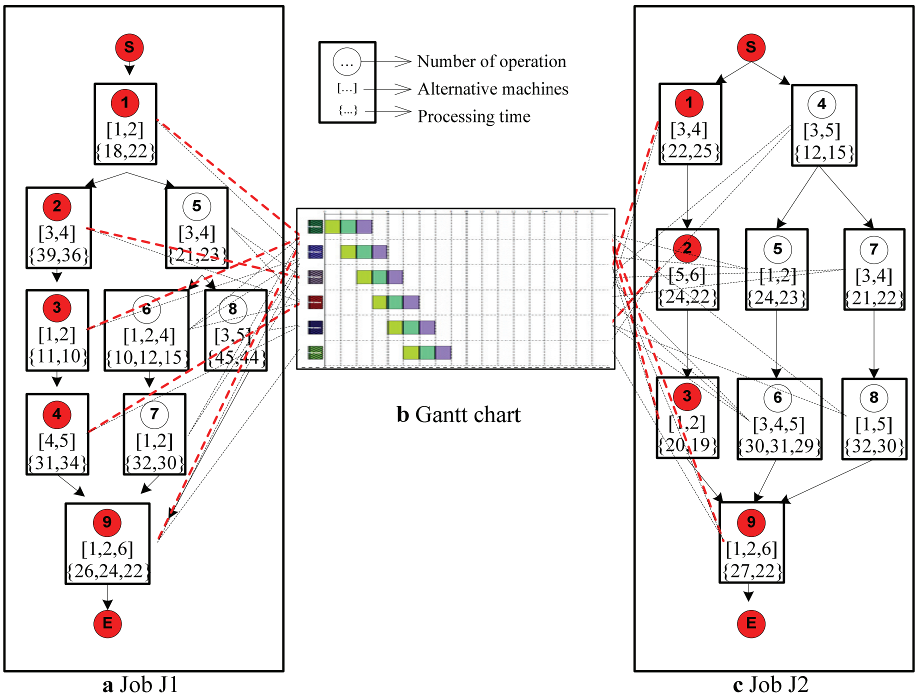


Figure 1 Integrated process planning & scheduling (IPPS)

Most jobs may typically have a large number of alternative process plans [7÷10]. Where process plans are flexible, integration of process planning with scheduling should be performed for an efficient use of limited production resources and eventually to achieve superior overall system performance [16÷20].

In the literature many integration models for IPPS have been reported in different implementation approaches [21]. Mostly known proposed models are as follows: *nonlinear process planning (NLPP)*, *closed loop process planning (CLPP)* and *distributed process planning (DPP)*.

NLPP uses alternative process plans to enhance the flexibility of manufacturing systems [21]. The model works as the following: Alternative process plans are ranked with respect to pre-defined process-planning optimization issues. According to the ranking list, alternatives in the list are tried to be submitted from top to down order when the job is required. The first one which is suitable for the current status of the shop floor is provided to scheduling system.

The methodology of CLPP uses a dynamic process planning system with a feedback mechanism [8]. In this model, process plans are dynamically generated in accordance with feedback of available resource information which is provided by production scheduling. This dynamic simulation system can enhance real-time, intuition and manipulability of process planning system and also enhance utilization of alternative process plans.

DPP performs both process planning and production scheduling simultaneously with a hierarchical approach [8]. Process planning and production scheduling are divided into two phases in this model. In the first phase, initial planning is performed through analysing the characteristics of jobs and the relationships between jobs. Moreover, primary process plans are determined and process resources are evaluated simultaneously. In the second phase, detailed planning is performed by adjusting process plans to the current status of corresponding shop floor. Detailed process plans and production schedules are obtained.

Li et al. [9], Shao et al. [8], Li & McMahon [17] and Jain et al. [22] can be given as examples for NLPP. Wang et al. [23], Kumar & Rajotia [24] are examples for CLPP. Li et al. [25], Sugimura et al. [26] and Wang et al. [27] are examples for DPP. Other than these approaches, their combination is examined as well in the literature. Shao et al. [8] proposed NLPP and DPP integrated model. Based on this model, a simulation approach based modified GA has been developed. Additionally, Li et al. [10] developed a new hybrid-algorithm approach to facilitate the integration and optimization of the IPPS problem. Comprehensive reviews can be found in Li et al. [21], Wang & Shen [28], Tan & Khoshnevis [18], and Chen & Khoshnevis [29].

3 Pull systems & feasibility of IPPA

Hopp & Spearman [30] describe pull systems as the production control systems which limit the WIP levels. Pull systems have become popular with just-in-time manufacturing (JIT) that is the production control system of lean manufacturing philosophy [31÷32]. Although there are many pull systems in the literature only well-known ones are briefly explained in the following. A *KANBAN* system uses a number of cards to limit WIP on each station [33÷36]. A job can be processed in one station only if there are available cards in this station to be attached to it [37]. After processing this job, the card can be attached to a new job. *CONstant-Work-In-Process (CONWIP)* system is introduced by Spearman et al. [38] as an alternative to KANBAN. CONWIP limits the total WIP of system. A card is attached to a job when it enters system and it is withdrawn when the job is processed [37, 39÷40]. *Drum-Buffer-Rope (DBR)* is the production control system of theory of constraint (TOC) which is a methodology that helps the manager to concentrate on the most critical issues [41÷43]. Since the WIP is limited in upstream workstations of bottleneck workstation, it can be said that DBR is a pull system according to definition of Hopp & Spearman [30].

For pulling flows in a *job-shop*, it is not possible to use the same techniques as for mass production lines in which WIP levels are used as control instructions [44]. In pull systems developed for job-shop environments, kanbans represents the capacity rather than WIP. Therefore, in such systems, available capacity triggers job releases rather than replenishing WIP gaps in the systems. *Paired-cell Overlapping Loops of Cards with Authorization (POLCA)* is a material control system developed for companies which have to supply high-variety or custom engineered products [45]. It is a hybrid push-pull system that combines the best features of card-based pull systems and push systems [45]. *COntrol of BAlance by CArd BAsed NAvigation (COBACABANA)* system finds its roots in *Work Load Control (WLC)* concept [6]. WLC concept is designed to meet the need of make-to-order industry [46÷50]. The basic philosophy of WLC concept fits the versatile environment of job-shops by providing a controlled predictable shop floor situation, without planning too much in detail [51]. COBACABANA is a card-based form of WLC concept. The cards loop between planner and all critical workstations [6].

In pull systems explained briefly in this section, authorizing is carried out after making process plans. As discussed in the first section of this paper, implementation of an integrated approach for process planning and authorizing may also make it possible to obtain better results where the process plans are flexible as well as IPPS. However, is it possible that process planning and authorizing can be integrated? The following question firstly needs to be answered to accomplish this integration. What are the requirements expected from a typical pull system to integrate process planning and authorizing? If we want to benefit from the process plan flexibility, we are about a pull system which is developed for job-shop manufacturing environments. Moreover, authorizing should be performed by a central unit. It is needed to accomplish efficient use of limited production resources by properly assigning tasks of process plans. After reviewing the structures of the well-known pull systems, it is observed that COBACABANA can meet these requirements since it is developed for job-shop environments and authorizing is performed by a central unit, namely; *display of available release cards*.

Land [6] recently developed a COBACABANA system to control job-shop manufacturing environments. In this system, cards, which authorize the releases of jobs in the job-pool, are called as *release cards*. In order to balance the workload of each workstation specific numbers of release cards are allowed. Each release card represents a specific part of the workload of corresponding workstation. Total release card of a workstation is equal to the maximum workload that can be in the workstation. Thus, workloads of the stations are kept under balance and WIP level is limited. As a result, the amount of flow time stabilization is provided. Fig. 2 shows the card loops between release and workstations in COBACABANA. Types of required card are determined according to routes of corresponding jobs. Additionally, the amounts of these cards are determined by taking processing times of the jobs on each workstation into account. A job can be authorized if the required cards are available. The COBACANA system meets the expectations above-mentioned.

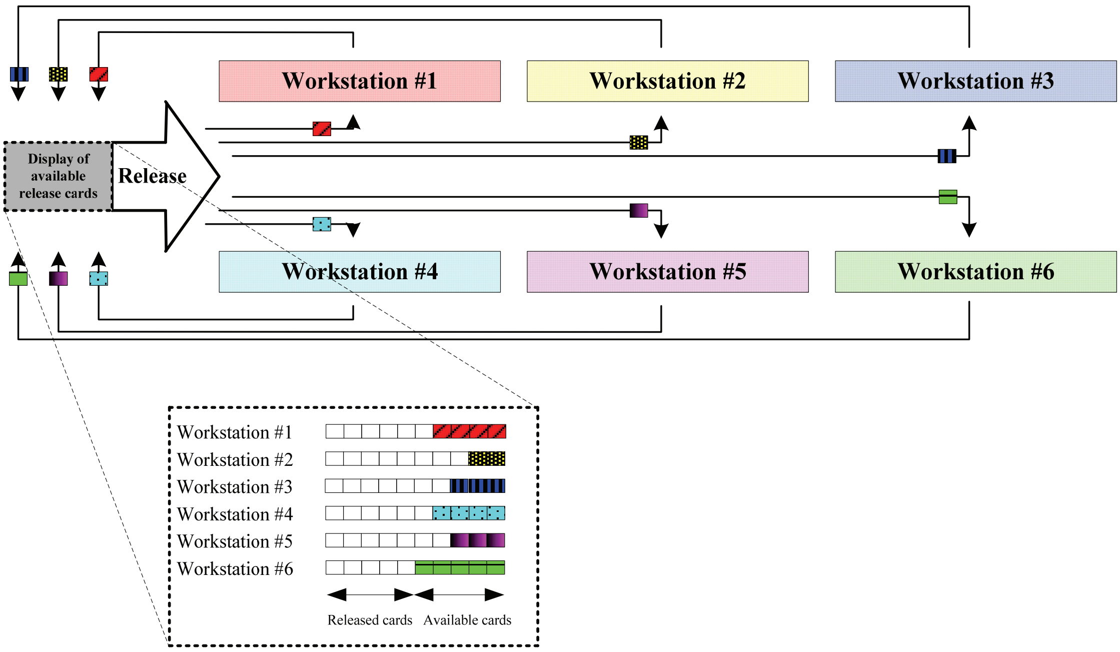


Figure 2 Card loops in the COBACABANA system

4 Proposed model

This study proposes a model, namely; integrated process planning & authorizing (IPPA), which integrates process planning and authorizing. Fig. 3 shows the IPPA model. Available release cards are monitored with the help of *display of available release cards* in the model (see Fig. 2). These cards are used for authorizing the jobs in the job-pool. Display of available release cards of the IPPA takes the same role with Gantt chart of the IPPS. Flexibilities in process plans (such as Fig. 3a and Fig. 3c) are taken into account while job release authorizing with the proposed IPPA model.

Optimization of the network shown in Figure 3 according to the amounts of the available release cards integrates the process planning and authorizing. As a result of the integration, more feasible solutions can be obtained when comparing the traditional approach. Therefore, finding better solutions can be possible.

5 Strategies for the implementation

Two strategies are proposed for implementation of the IPPA model in the following.

5.1 Implementation of the IPPA model: Strategy 1

Traditional approach, i.e., the COBACABANA, and the integrated approach, i.e., the IPPA model, have been implemented on a hypothetic scenario for comparison. In the scenario, the data from Sundaram & Fu [52] is used to generate orders (see Tab. 1). According to this data, there are 5 workstations ($WS1$, $WS2$, $WS3$, $WS4$, and $WS5$) in the shop floor. There are 4 jobs in the job-pool ($J1$, $J2$, $J3$, and $J4$), and each job undergoes 4 different operations in a specified order. Moreover, these jobs have only operation flexibility in their process plan networks. Besides, it is assumed that the initial quantities of available release cards of the workstations are 11, 16, 17, 15, and 23, respectively.

When flexibilities are taken into account, a greater number of jobs may be authorized by using available cards with the IPPA model. An IPPA model which aims to reach solution with maximizing the numbers of authorized jobs uses the following mathematical model. The mathematical model given below is used to optimize the network shown in Fig. 4.

Indices

j Jobs
o Operations routes
w Workstations routes
i Workstations

Parameters

R_{jowi} Quantities of required release cards
C_i Quantities of available release cards
k Quantity of jobs in job-pool
n Quantity of workstations
m_j Quantities of alternative operations routes of jobs

Decision variables

X_{jow} 1, if w workstation route on o operation route is selected for job j; 0, otherwise

Y_{jo} 1, if o operation route is selected for job j; 0, otherwise

Objective function

$$\max z = \sum_w \sum_o \sum_j X_{jow} Y_{jo}$$

Constraints

$$\sum_w \sum_o \sum_j R_{jowi} X_{jow} Y_{jo} \le C_i, \ (\forall i = 1,\ldots,n) \quad (1)$$

$$\sum_w X_{jow} \le 1, \ (\forall o = 1,\ldots,m_j), (\forall j = 1,\ldots,k) \quad (2)$$

$$\sum_o Y_{jo} \le 1, \ (\forall j = 1,\ldots,k) \quad (3)$$

$$X_{jow} = \{0,1\} \quad (4)$$

$$Y_{jo} = \{0,1\}, \quad (5)$$

Constraint 1 is needed to limit the amounts of required release cards with the amounts of available release cards. Constraint 2 makes sure that one workstation is selected for each operation route at most. Constraint 3 ensures that one operation route is selected for each job at most. If an operation route is selected for a job, this job is authorized. Objective of the proposed model is to maximize amounts of the jobs authorized.

While implementing traditional approach, process plans are carried out by considering the minimization of total processing time. The process plans determined for each job were X_{113}, X_{211}, X_{312} and X_{412}, respectively. Values of these variables are assigned as 1 in the mathematical model of the traditional approach.

After optimization of the release authorizing, the jobs authorized release to the shop floor. Fig. 5 shows information flow in the IPPA model. The mathematical model is used to elaborate the optimal release authorizing of the jobs. In the example, simulation model of the shop floor is developed by using *ARENA* simulation software. In the simulation model, *create* module generates entities according to the solutions of the mathematical model. The simulation model is used to evaluate this authorizing plan under realistic conditions.

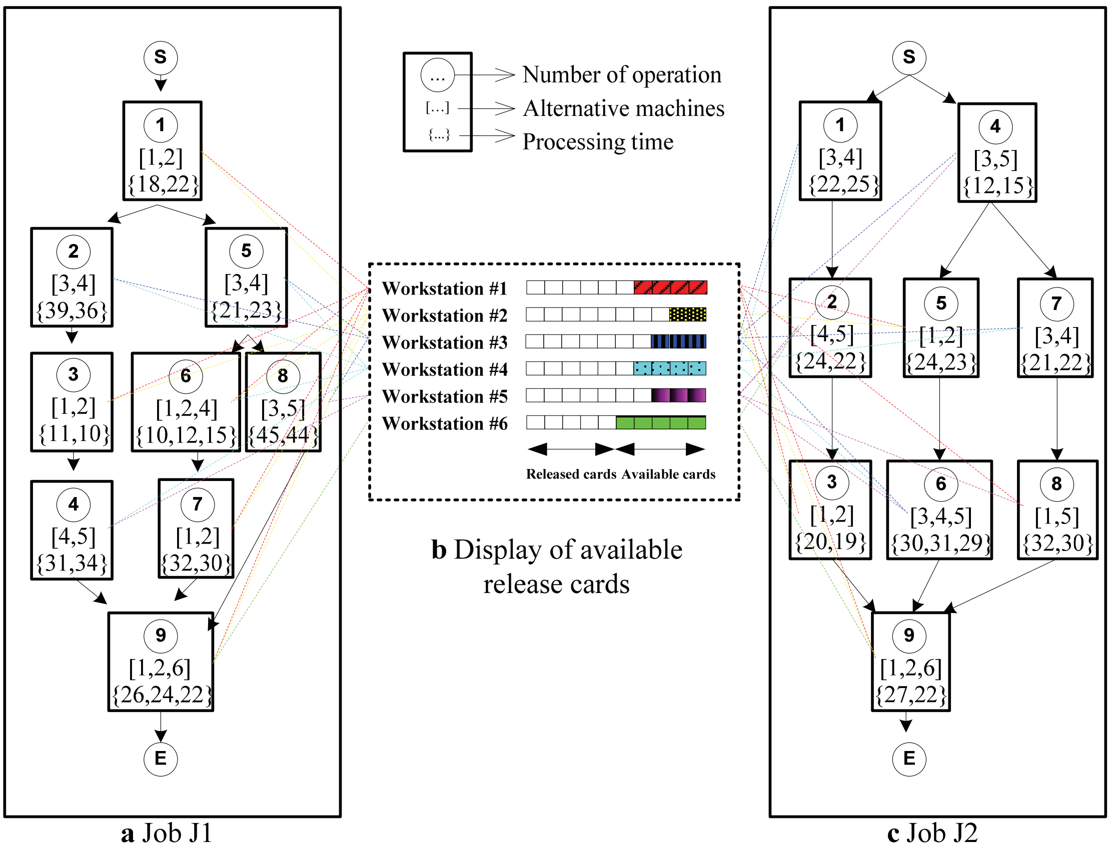


Figure 3 Integrated process planning & authorizing (IPPA) model

Table 1 The data used in the illustrative example

Job	Operation 1	Operation 2	Operation 3	Operation 4
J1	5 (*WS1*), 3 (*WS2*)	7 (*WS2*)	6 (*WS3*)	3 (*WS4*), 4 (*WS5*)
J2	7 (*WS1*)	4 (*WS2*), 6 (*WS3*)	7 (*WS3*), 7 (*WS4*)	10 (*WS5*)
J3	4 (*WS1*), 5 (*WS2*), 8 (*WS3*)	5 (*WS4*)	6 (*WS4*), 5 (*WS5*)	4 (*WS5*)
J4	2 (*WS2*), 6 (*WS3*)	8 (*WS3*)	3 (*WS3*), 8 (*WS4*)	7 (*WS4*), 4 (*WS5*)

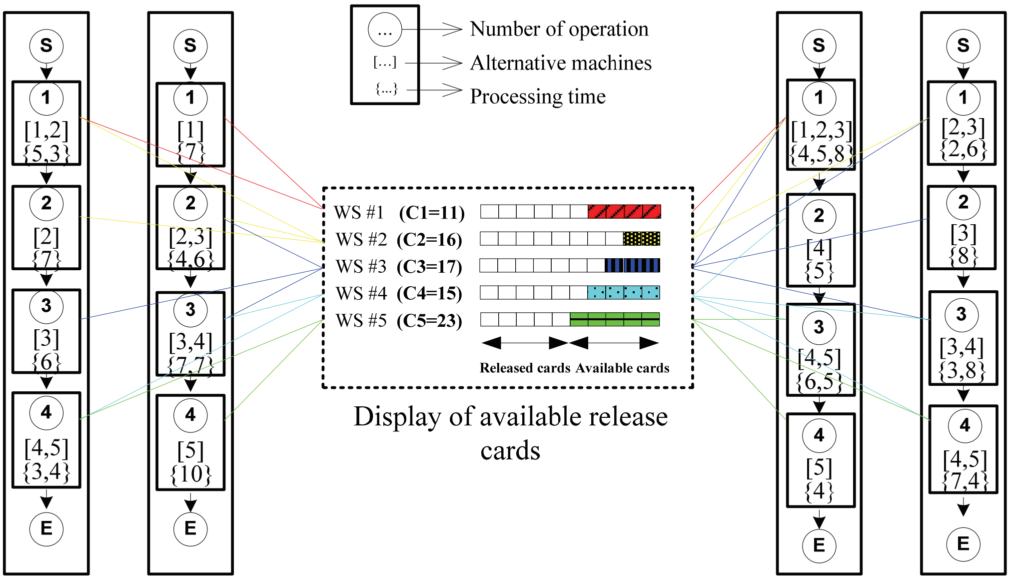


Figure 4 Network representation of the problem

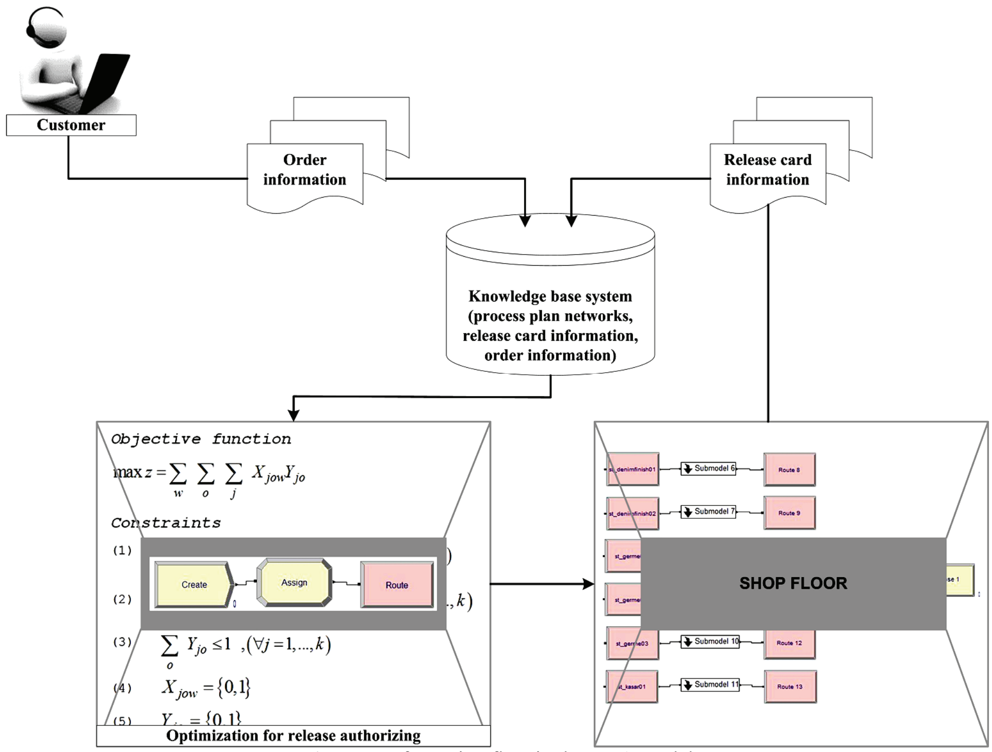


Figure 5 Information flow in the IPPA model

Table 2 Results obtained by traditional approach vs. integrated approach (IPPA)

		Traditional approach				Integrated approach			
Jobs	j	1	2	3	4	1	2	3	4
Authorized operation routes	Y_{jo}	Y_{11} 1	Y_{21} 1	Y_{31} 1	Y_{41} 0	Y_{11} 1	Y_{21} 1	Y_{31} 1	Y_{41} 1
Authorized workstation routes	X_{jow}	X_{113} 1	X_{211} 1	X_{312} 1	X_{412} 1	X_{113} 1	X_{212} 1	X_{312} 1	X_{412} 1
Authorized jobs	$X_{jow}Y_{jo}$	1	1	1	0	1	1	1	1
Optimal solutions	$\sum\sum\sum X_{jow}Y_{jo}$	3				4			

5.1.1 Results of the implementation of Strategy 1

Tab. 2 shows the results obtained after implementing these two approaches. The optimal value that represents number of the jobs authorized is found as 3 for traditional approach. One of the jobs in the job-pool is not authorized when the traditional approach is executed. When looked at the Y_{jo} values, it is observed that Y_{41} value is 0 (Tab. 2). *Job #4* is not authorized when traditional approach is executed. However, the optimal solution is found as 4 for the integrated approach. All of the jobs in the job-pool are authorized although the quantities of available release cards are equal for both traditional and integrated approach. The traditional approach is underperformed since it assumes that all of the resources are available while developing process plans.

Fig. 6 shows the shop-floor status after the implementation of the traditional approach (Fig. 6a) and the integrated approach (Fig. 6b). When the traditional approach is executed, 3 jobs are released to the shop-floor. However when the integrated approach is executed, 4 jobs are released to the shop-floor with same initial quantities of available release cards.

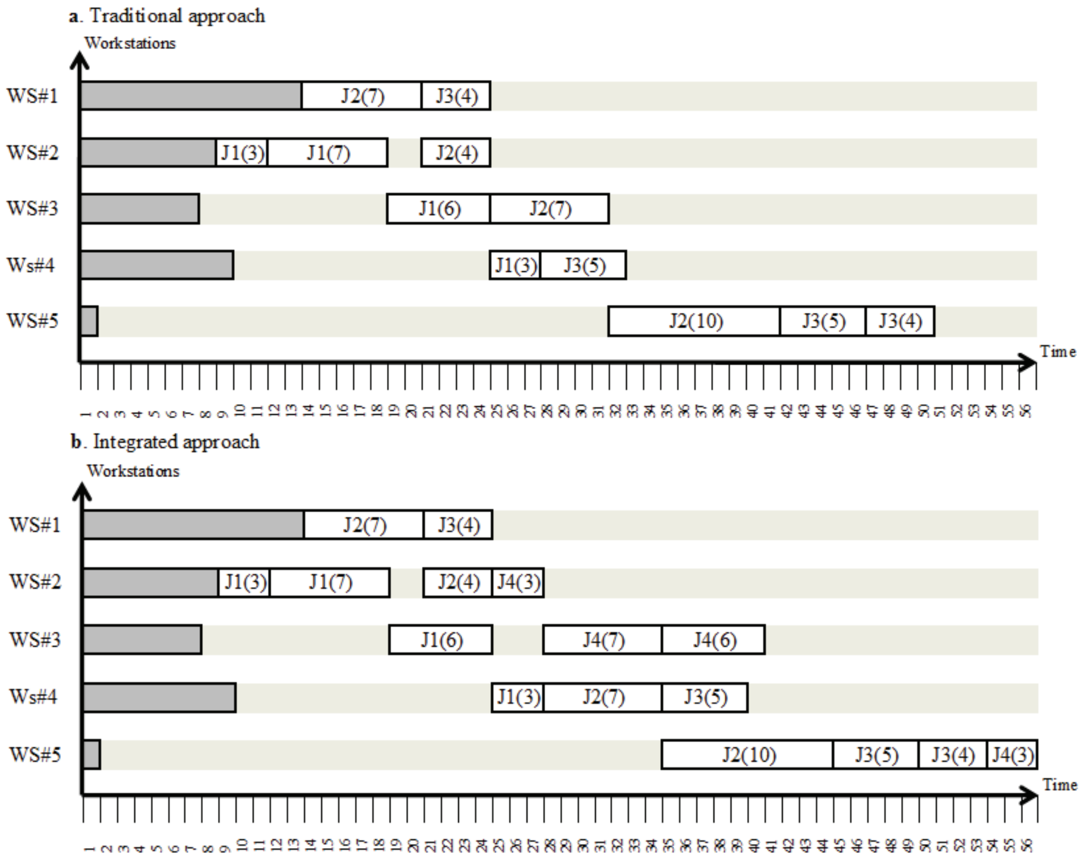


Figure 6 Shop-floor status after the implementation of traditional (a) and integrated (b) approaches

By implementing the IPPA model, throughput rate is increased from 0,06 to 0,0714 product/unit time. Obtained results show that the IPPA model outperforms the traditional approach because it takes balance of workloads of the workstations into account while developing process plans. It is noteworthy to indicate that, since network of IPPA also comprises the network of the traditional approach, the best solution of the integrated approach will always be better than or at least will be equal to the best solution of traditional approach.

5.2 Implementation of the IPPA model: Strategy 2

In *Strategy 1* discussed in the previous section, arriving and ready orders are not sent to the shop floor immediately. Instead, they are kept in a pre-shop pool before release. In a specified frequency, the mathematical formulation which has the objective of maximizing the numbers of authorized jobs is solved. As discussed in the previous section in detail, *Strategy 1* does not consider completion time and due-date related performance measures. Therefore, another strategy is proposed in this section.

Our second strategy (*Strategy 2*) works dynamically by sending one by one of arriving and ready orders to the shop floor as soon as the release cards are available for the jobs. While sending jobs to the shop floor, process plan networks of the jobs are taken into account and the most suitable alternative process plan according to the available release cards is used during authorizing of the jobs. If the release cards for the first process plan route of a job are not available, the other process plan route is controlled for availability. If there is one available route, this route is selected. In case more than one alternative route is available, the route which has the maximum value in the minimum remaining release cards level for workstations is selected. The strategy prevents loading to the bottleneck workstations thanks to flexibilities of process plans of the jobs. The second strategy can be a member of the NLPP class from the classification perspective of integrated approaches mentioned in the second section of this paper.

In the following example, *Strategy 2* is used for implementation of the IPPA model. The data used in this example are obtained from a textile mill in Turkey. The problem appears in the finishing operations after weaving of clothes. There is a flexible job-shop environment in the finishing department of the mill. There are 8 workstations.

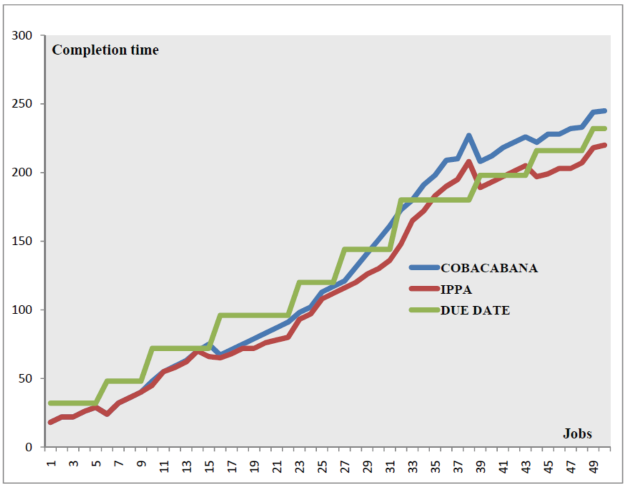
The amounts of machines of the workstations are 2, 4, 3, 1, 1, 1, 4, and 1, respectively. The machines are identical. There are 50 jobs in the job pool. The operations routes, processing time and due dates for each job are given in Tab. 3. The jobs are ranked according to the earliest-due-date (EDD) dispatching rule.

Table 3 The data used in the illustrative example

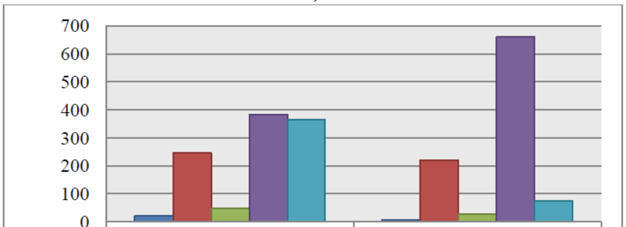
Job	Opr. 1	Opr. 2	Opr. 3	Opr. 4	Opr. 5	Due
*J*1	7 (*WS*2), 7 (*WS*1)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)			32
*J*2	4 (*WS*1)	7 (*WS*2)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)		32
*J*3	4 (*WS*1)	7 (*WS*2)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)		32
*J*4	4 (*WS*1)	7 (*WS*2)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)		32
*J*5	4 (*WS*1)	7 (*WS*2)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)		32
*J*6	6 (*WS*7)					48
*J*7	4 (*WS*8)	6 (*WS*7)				48
*J*8	4 (*WS*8)	6 (*WS*7)				48
*J*9	4 (*WS*8)	6 (*WS*7)				48
*J*10	4 (*WS*4)	7 (*WS*2), 7 (*WS*5)	5 (*WS*3)	6 (*WS*7)		72
*J*11	4 (*WS*1)	4 (*WS*4), 4 (*WS*5)	7 (*WS*2)	5 (*WS*3), 5 (*WS*6)	6 (*WS*7)	72
*J*12	4 (*WS*1)	4 (*WS*4), 4 (*WS*5)	7 (*WS*2)	5 (*WS*3), 5 (*WS*6)	6 (*WS*7)	72
*J*13	4 (*WS*1)	4 (*WS*4), 4 (*WS*5)	7 (*WS*2)	5 (*WS*3), 5 (*WS*6)	6 (*WS*7)	72
*J*14	4 (*WS*1)	4 (*WS*4), 4 (*WS*5)	7 (*WS*2)	5 (*WS*3), 5 (*WS*6)	6 (*WS*7)	72
*J*15	4 (*WS*1)	4 (*WS*4), 4 (*WS*5)	7 (*WS*2)	6 (*WS*7)		72
*J*16	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*17	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*18	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*19	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*20	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*21	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*22	4 (*WS*4), 4 (*WS*5)	6 (*WS*7)				96
*J*23	4 (*WS*1), 4 (*WS*3)	7 (*WS*2), 7 (*WS*5)	4 (*WS*8)	6 (*WS*7)		120
*J*24	4 (*WS*1), 4 (*WS*3)	7 (*WS*2), 7 (*WS*5)	4 (*WS*8)	6 (*WS*7)		120
*J*25	4 (*WS*1), 4 (*WS*3)	7 (*WS*2), 7 (*WS*5)	4 (*WS*8)	6 (*WS*7)		120
*J*26	4 (*WS*1), 4 (*WS*3)	7 (*WS*2), 7 (*WS*5)	4 (*WS*8)	6 (*WS*7)		120
*J*27	4 (*WS*8)	6 (*WS*4), 6 (*WS*5)				144
*J*28	4 (*WS*8)	6 (*WS*4), 6 (*WS*5)				144
*J*29	4 (*WS*8)	6 (*WS*4), 6 (*WS*5)				144
*J*30	4 (*WS*8)	6 (*WS*4), 6 (*WS*5)				144
*J*31	4 (*WS*8)	6 (*WS*4), 6 (*WS*5)				144
*J*32	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)		180
*J*33	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)	180
*J*34	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)	180
*J*35	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)	180
*J*36	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)	180
*J*37	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)		180
*J*38	7 (*WS*5)	7 (*WS*2), 7 (*WS*1)	4 (*WS*6)	5 (*WS*3), 5 (*WS*4)	6 (*WS*7)	180
*J*39	4 (*WS*8)	6 (*WS*7), 6 (*WS*5)				198
*J*40	4 (*WS*8)	6 (*WS*7), 6 (*WS*5)				198
*J*41	4 (*WS*8)	6 (*WS*7), 6 (*WS*5)				198
*J*42	4 (*WS*8)	6 (*WS*7), 6 (*WS*5)				198
*J*43	4 (*WS*8)	6 (*WS*7), 6 (*WS*5)				198
*J*44	6 (*WS*7), 6 (*WS*5)					216
*J*45	6 (*WS*7), 6 (*WS*5)					216
*J*46	6 (*WS*7), 6 (*WS*5)					216
*J*47	6 (*WS*7), 6 (*WS*5)					216
*J*48	6 (*WS*7), 6 (*WS*5)					216
*J*49	4 (*WS*1)	7 (*WS*2)	6 (*WS*7), 6 (*WS*5)			232
*J*50	4 (*WS*1)	7 (*WS*2)	6 (*WS*7), 6 (*WS*5)			232

5.2.1 Results of the implementation of Strategy 2

The jobs are released by implementing the IPPA model with *Strategy 2* in simulation environment of the finishing department of the mill. The results of the IPPA model and traditional approach, i.e., the COBACABANA, are compared (Fig. 7a and Fig. 7b). *Number of tardy jobs* ($\sum U_j$), *makespan* ($C_{\max}$) and *maximum tardiness* ($T_{\max}$) are taken into account in comparison since the planners of the mill noticed that efficiency on customer satisfaction and effectiveness on resource utilization of the mill are considerably related with these measures. Other than these measures, *total earliness* ($\sum E_j$) and *total tardiness* ($\sum T_j$) are also reviewed to show the differences in detail between the COBACABANA and the IPPA.



a)



	COBACABANA	IPPA
∑Uj	20	7
Cmax	245	220
Tmax	47	28
∑Ej	383	660
∑Tj	364	75

b)

Figure 7 Comparison results

As can be seen in Fig. 7a and Fig. 7b, the IPPA outperforms the traditional approach, i.e., COBACABANA, in all of the specified measures other than total earliness. Responsiveness is more related with speed of making effective use of the available potential [13]. The magnitude of total earliness therefore can be used to compare the two systems with respect to their responsiveness. The results show that IPPA is more responsive than COBACABANA. In the IPPA model completion time value of each job is smaller than or equal to the occurred completion time in traditional approach (Fig. 7a). *Strategy 2* shows good performance on due date and completion time related measures since the workload is equal to the workload in implementation of traditional approach. Alternative routes in process plans provide skipping of jobs to lower loaded workstations. For detailed information the exact values obtained while executing the simulation run are given in Tab. 4 in Appendix.

6 Contribution & industrial relevance

As a matter of fact, increasing concentration on *responsiveness in manufacturing* really accelerates the interest in the integrated process planning & scheduling (IPPS). However, software packages available in the market are not affordable and do not support the needs of the manufacturing SMEs, which have limited resources and budgets in manufacturing planning and control. The lack of integration of the process planning with shop floor scheduling is recognized as a vital problematic issue to improve the organizational performance of the SMEs. This shows an obvious need of implementation of the pull systems which are able to consider the process plans of jobs in their authorizing processes since they can be implemented with a slight dependence on professional software support.

Existing pull systems consider process plans as an input datum of the authorizing activities. From a real time authorizing point of view, alternative process plans can enhance capability of the systems to cope with predictable events (e.g. improving responsiveness of the systems by reducing the load of bottleneck workstations) and unpredictable events (e.g. machine failures). Therefore, major contributions of the study are that it calls attention to the advantages of integration of process planning and authorizing, and presents a model to achieve this integration.

7 Concluding remarks

This paper investigates integration of process planning and authorizing as an alternative to integrated process planning & scheduling (IPPS) approach. The primary reason for developing such an approach is the complexity of the IPPS approach and its software support dependence which are not affordable by most of the SMEs. For the integration of these two activities a novel model called integrated process planning & authorizing (IPPA) is presented in this paper. Two strategies are proposed for implementation of the IPPA model as well. Case studies show that the first strategy is effective on throughput rate measure while the second strategy is effective on completion time and due date related measures other than total earliness. In IPPA model, alternative routes in process plans provide skipping of jobs to lower loaded workstations. This is the major reason for having more total earliness value in total earliness performance measure. This can be used as a determinant to demonstrate that the IPPA is more responsive than the COBACABANA.

As a result of the enhancement of responsiveness, IPPA enables its users to release more jobs to the shop floor by using idle capacity. In the future study, developing a hybrid strategy, stemmed from the two strategies, and aims to overcome total earliness issue by releasing more jobs, can be addressed. Moreover, this paper analysis the effects of the integration on pull systems performance rather than comparing with an IPPS approach. Therefore, comparative studies of IPPS and IPPA can also be addressed in the future. This paper has a novel idea according to the research subject. So another way for further studies can be development of an alternative IPPA model by using another pull system or developing pull system which is suitable for integration.

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9 Appendix

Table 4 Exact values obtained while executing the simulation run

		COBACABANA							IPPA						
Job	Due	Opr.	Bgn.	End	Cj	Uj	Ej	Tj	Opr.	Bgn.	End	Cj	Uj	Ej	Tj
*J*1	32				18	0	14	0				18	0	14	0
		7 (*WS*2)	0	7					7 (*WS*2)	0	7				
		5 (*WS*3)	7	12					5 (*WS*3)	7	12				
		6 (*WS*7)	12	18					6 (*WS*7)	12	18				
*J*2	32				22	0	10	0				22	0	10	0
		4 (*WS*1)	0	4					4 (*WS*1)	0	4				
		7 (*WS*2)	4	11					7 (*WS*2)	4	11				
		5 (*WS*3)	11	16					5 (*WS*3)	11	16				
		6 (*WS*7)	16	22					6 (*WS*7)	16	22				
*J*3	32				22	0	10	0				22	0	10	0
		4 (*WS*1)	0	4					4 (*WS*1)	0	4				
		7 (*WS*2)	4	11					7 (*WS*2)	4	11				
		5 (*WS*3)	11	16					5 (*WS*3)	11	16				
		6 (*WS*7)	16	22					6 (*WS*7)	16	22				
*J*4	32				26	0	6	0				26	0	6	0
		4 (*WS*1)	4	8					4 (*WS*1)	4	8				
		7 (*WS*2)	8	15					7 (*WS*2)	8	15				
		5 (*WS*3)	15	20					5 (*WS*3)	15	20				
		6 (*WS*7)	20	26					6 (*WS*7)	20	26				

J5	32				29	0	3	0				29	0	3	0
		4 (*WS*1)	7	11					4 (*WS*1)	7	11				
		7 (*WS*2)	11	18					7 (*WS*2)	11	18				
		5 (*WS*3)	18	23					5 (*WS*4)	18	23				
		6 (*WS*7)	23	29					6 (*WS*7)	23	29				
J6	48				24	0	24	0				24	0	24	0
		6 (*WS*7)	18	24					6 (*WS*7)	18	24				
J7	48				32	0	16	0				32	0	16	0
		4 (*WS*8)	22	26					4 (*WS*8)	22	26				
		6 (*WS*7)	26	32					6 (*WS*7)	26	32				
J8	48				36	0	12	0				36	0	12	0
		4 (*WS*8)	26	30					4 (*WS*8)	26	30				
		6 (*WS*7)	30	36					6 (*WS*7)	30	36				
J9	48				40	0	8	0				40	0	8	0
		4 (*WS*8)	30	34					4 (*WS*8)	30	34				
		6 (*WS*7)	34	40					6 (*WS*7)	34	40				
J10	72				48	0	24	0				45	0	27	0
		4 (*WS*4)	26	30					4 (*WS*4)	23	27				
		7 (*WS*2)	30	37					7 (*WS*2)	27	34				
		5 (*WS*3)	37	42					5 (*WS*3)	34	39				
		6 (*WS*7)	42	48					6 (*WS*7)	39	45				
J11	72				55	0	17	0				55	0	17	0
		4 (*WS*1)	29	33					4 (*WS*1)	29	33				
		4 (*WS*4)	33	37					4 (*WS*5)	33	37				
		7 (*WS*2)	37	44					7 (*WS*2)	37	44				
		5 (*WS*3)	44	49					5 (*WS*3)	44	49				
		6 (*WS*7)	49	55					6 (*WS*7)	49	55				
J12	72				59	0	13	0				58	0	14	0
		4 (*WS*1)	32	36					4 (*WS*1)	32	36				
		4 (*WS*4)	37	41					4 (*WS*4)	36	40				
		7 (*WS*2)	41	48					7 (*WS*2)	40	47				
		5 (*WS*3)	48	53					5 (*WS*3)	47	52				
		6 (*WS*7)	53	59					6 (*WS*7)	52	58				
J13	72				63	0	9	0				62	0	10	0
		4 (*WS*1)	37	41					4 (*WS*1)	36	40				
		4 (*WS*4)	41	45					4 (*WS*5)	40	44				
		7 (*WS*2)	45	52					7 (*WS*2)	44	51				
		5 (*WS*3)	52	57					5 (*WS*3)	51	56				
		6 (*WS*7)	57	63					6 (*WS*7)	56	62				
J14	72				70	0	2	0				70	0	2	0
		4 (*WS*1)	44	48					4 (*WS*1)	44	48				
		4 (*WS*4)	48	52					4 (*WS*5)	48	52				
		7 (*WS*2)	52	59					7 (*WS*2)	52	59				
		5 (*WS*3)	59	64					5 (*WS*3)	59	64				
		6 (*WS*7)	64	70					6 (*WS*7)	64	70				
J15	72				75	1	0	3				66	0	6	0
		4 (*WS*1)	49	53					4 (*WS*1)	45	49				
		4 (*WS*4)	53	57					4 (*WS*4)	49	53				
		7 (*WS*2)	57	64					7 (*WS*2)	53	60				
		6 (*WS*7)	69	75					6 (*WS*7)	60	66				
J16	96				67	0	29	0				65	0	31	0
		4 (*WS*4)	57	61					4 (*WS*5)	55	59				
		6 (*WS*7)	61	67					6 (*WS*7)	59	65				
J17	96				71	0	25	0				68	0	28	0
		4 (*WS*4)	61	65					4 (*WS*4)	58	62				
		6 (*WS*7)	65	71					6 (*WS*7)	62	68				
J18	96				75	0	21	0				72	0	24	0
		4 (*WS*4)	65	69					4 (*WS*5)	62	66				
		6 (*WS*7)	69	75					6 (*WS*7)	66	72				
J19	96				79	0	17	0				72	0	24	0
		4 (*WS*4)	69	73					4 (*WS*4)	64	68				
		6 (*WS*7)	73	79					6 (*WS*7)	68	72				

J20	96				83	0	13	0				76	0	20	0
		4 (*WS*4)	73	77					4 (*WS*5)	66	70				
		6 (*WS*7)	77	83					6 (*WS*7)	70	76				
J21	96				87	0	9	0				78	0	18	0
		4 (*WS*4)	77	81					4 (*WS*4)	68	72				
		6 (*WS*7)	81	87					6 (*WS*7)	72	78				
J22	96				91	0	5	0				80	0	16	0
		4 (*WS*4)	81	85					4 (*WS*5)	70	74				
		6 (*WS*7)	85	91					6 (*WS*7)	74	80				
J23	120				98	0	22	0				93	0	27	0
		4 (*WS*1)	77	81					4 (*WS*3)	72	76				
		7 (*WS*2)	81	88					7 (*WS*2)	76	83				
		4 (*WS*8)	88	92					4 (*WS*8)	83	87				
		6 (*WS*7)	92	98					6 (*WS*7)	87	93				
J24	120				102	0	18	0				97	0	23	0
		4 (*WS*1)	81	85					4 (*WS*3)	74	78				
		7 (*WS*2)	85	92					7 (*WS*2)	78	85				
		4 (*WS*8)	92	96					4 (*WS*8)	87	91				
		6 (*WS*7)	96	102					6 (*WS*7)	91	97				
J25	120				113	0	7	0				108	0	12	0
		4 (*WS*1)	92	96					4 (*WS*3)	87	91				
		7 (*WS*2)	96	103					7 (*WS*2)	91	98				
		4 (*WS*8)	103	107					4 (*WS*8)	98	102				
		6 (*WS*7)	107	113					6 (*WS*7)	102	108				
J26	120				117	0	3	0				112	0	8	0
		4 (*WS*1)	96	100					4 (*WS*3)	91	95				
		7 (*WS*2)	100	107					7 (*WS*2)	95	102				
		4 (*WS*8)	107	111					4 (*WS*8)	102	106				
		6 (*WS*7)	111	117					6 (*WS*7)	106	112				
J27	144				121	0	23	0				116	0	28	0
		4 (*WS*8)	111	115					4 (*WS*8)	106	110				
		6 (*WS*4)	115	121					6 (*WS*5)	110	116				
J28	144				131	0	13	0				120	0	24	0
		4 (*WS*8)	121	125					4 (*WS*8)	110	114				
		6 (*WS*4)	125	131					6 (*WS*4)	114	120				
J29	144				141	0	3	0				126	0	18	0
		4 (*WS*8)	131	135					4 (*WS*8)	116	120				
		6 (*WS*4)	135	141					6 (*WS*5)	120	126				
J30	144				151	1	0	7				130	0	14	0
		4 (*WS*8)	141	145					4 (*WS*8)	120	124				
		6 (*WS*4)	145	151					6 (*WS*4)	124	130				
J31	144				161	1	0	17				136	0	8	0
		4 (*WS*8)	151	155					4 (*WS*8)	126	130				
		6 (*WS*4)	155	161					6 (*WS*5)	130	136				
J32	180				173	0	7	0				148	0	32	0
		7 (*WS*2)	151	158					7 (*WS*2)	126	133				
		4 (*WS*6)	158	162					4 (*WS*6)	133	137				
		5 (*WS*3)	162	167					5 (*WS*3)	137	142				
		6 (*WS*7)	167	173					6 (*WS*7)	142	148				
J33	180				180	0	0	0				165	0	15	0
		7 (*WS*5)	151	158					7 (*WS*5)	136	143				
		7 (*WS*2)	158	165					7 (*WS*2)	143	150				
		4 (*WS*6)	165	169					4 (*WS*6)	150	154				
		5 (*WS*3)	169	174					5 (*WS*3)	154	159				
		6 (*WS*7)	174	180					6 (*WS*7)	159	165				
J34	180				191	1	0	11				172	0	8	0
		7 (*WS*5)	162	169					7 (*WS*5)	143	150				
		7 (*WS*2)	169	176					7 (*WS*2)	150	157				
		4 (*WS*6)	176	180					4 (*WS*6)	157	161				
		5 (*WS*3)	180	185					5 (*WS*3)	161	166				
		6 (*WS*7)	185	191					6 (*WS*7)	166	172				

J35	180				198	1	0	18				183	1	0	3
		7 (*WS*5)	169	176					7 (*WS*5)	154	161				
		7 (*WS*2)	176	183					7 (*WS*2)	161	168				
		4 (*WS*6)	183	187					4 (*WS*6)	168	172				
		5 (*WS*3)	187	192					5 (*WS*3)	172	177				
		6 (*WS*7)	192	198					6 (*WS*7)	177	183				
J36	180				209	1	0	29				190	1	0	10
		7 (*WS*5)	180	187					7 (*WS*5)	161	168				
		7 (*WS*2)	187	194					7 (*WS*2)	168	175				
		4 (*WS*6)	194	198					4 (*WS*6)	175	179				
		5 (*WS*3)	198	203					5 (*WS*3)	179	184				
		6 (*WS*7)	203	209					6 (*WS*7)	184	190				
J37	180				210	1	0	30				195	1	0	15
		7 (*WS*5)	187	194					7 (*WS*5)	172	179				
		7 (*WS*2)	194	201					7 (*WS*2)	179	186				
		4 (*WS*6)	201	205					4 (*WS*6)	186	190				
		5 (*WS*3)	205	210					5 (*WS*3)	190	195				
J38	180				227	1	0	47				208	1	0	28
		7 (*WS*5)	198	205					7 (*WS*5)	179	186				
		7 (*WS*2)	205	212					7 (*WS*2)	186	193				
		4 (*WS*6)	212	216					4 (*WS*6)	193	197				
		5 (*WS*3)	216	221					5 (*WS*3)	197	202				
		6 (*WS*7)	221	227					6 (*WS*7)	202	208				
J39	180				208	1	0	28				189	1	0	9
		4 (*WS*8)	198	202					4 (*WS*8)	179	183				
		6 (*WS*7)	202	208					6 (*WS*7)	183	189				
J40	198				212	1	0	14				193	0	5	0
		4 (*WS*8)	202	206					4 (*WS*8)	183	187				
		6 (*WS*7)	206	212					6 (*WS*7)	187	193				
J41	198				218	1	0	20				197	0	1	0
		4 (*WS*8)	208	212					4 (*WS*8)	187	191				
		6 (*WS*7)	212	218					6 (*WS*7)	191	197				
J42	198				222	1	0	24				201	1	0	3
		4 (*WS*8)	212	216					4 (*WS*8)	191	195				
		6 (*WS*7)	216	222					6 (*WS*7)	195	201				
J43	198				226	1	0	28				205	1	0	7
		4 (*WS*8)	216	220					4 (*WS*8)	195	199				
		6 (*WS*7)	220	226					6 (*WS*7)	199	205				
J44	216				222	1	0	6				197	0	19	0
		6 (*WS*7)	216	222					6 (*WS*5)	191	197				
J45	216				228	1	0	12				199	0	17	0
		6 (*WS*7)	222	228					6 (*WS*7)	193	199				
J46	216				228	1	0	12				203	0	13	0
		6 (*WS*7)	222	228					6 (*WS*5)	197	203				
J47	216				232	1	0	16				203	0	13	0
		6 (*WS*7)	226	232					6 (*WS*7)	197	203				
J48	216				233	1	0	17				207	0	9	0
		6 (*WS*7)	227	233					6 (*WS*7)	201	207				
J49	232				244	1	0	12				218	0	14	0
		4 (*WS*1)	227	231					4 (*WS*1)	201	205				
		7 (*WS*2)	231	238					7 (*WS*2)	205	212				
		6 (*WS*7)	238	244					6 (*WS*7)	212	218				
J50	232				245	1	0	13				220	0	12	0
		4 (*WS*1)	228	232					4 (*WS*1)	203	207				
		7 (*WS*2)	232	239					7 (*WS*2)	207	214				
		6 (*WS*7)	239	245					6 (*WS*7)	214	220				