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Production Scheduling Model in Aluminium Foundry

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There are numerous methods and strategies for production management which are successfully implemented in the metal industry and in the automobile and machine tools industry in particular. However, little research has been published regarding scheduling foundry operations. Therefore, the main goal of this paper is to develop a new mathematical model for scheduling foundry operations based on the MRP II (Manufacturing Resource Planning), JIT (Just in Time) and OPT (Optimized Production Technology) concepts. The research strategy includes a review of available literature and integration of the developed mathematical model into a foundry for testing the model with real data. The proposed model is successfully implemented into the ERP (Enterprise Resource Planning) system of Aluminium Ltd. in Mostar. The conclusions offered in this paper are based on the results of the tests carried out in that single foundry so that further work is required to validate the findings at other foundries and other manufacturing areas.

Keywords: aluminium production, scheduling, mathematical models, tardiness minimization

0 INTRODUCTION

In today's competitive industrial environments the main goal of a company is to earn profit. Meeting customer demands completely and in time and offering them high-quality products is a must if the goal is to be reached. Among other factors the existence of a good and effective planning and scheduling system is a major precondition to achieve the necessary competitiveness and fulfil the given task. But the planning and scheduling issues are very complex because of the ever changing needs of customers and the existing constrains in different manufacturing fields, including the metal industry. Therefore, researches have been conducted aimed at finding the solution to the problem.

The research carried out by Van Voorhis and Peters [1] about production system practices of steel foundries in the USA has pointed out that there is no widely accepted software system that has essentially solved the problem of generating pouring schedules for steel foundries. According to the research, only a few foundries used software to assist in scheduling, while most of them schedule operations manually [1] to [3]. Therefore, there is a need to address this problem by developing a new mathematical model and software for pouring scheduling. The paper proposes a mathematical model to find a feasible pouring schedule based on the MRP II (Manufacturing Resources Planning), JIT (Just in Time) and OPT (Optimized Production Technology) concepts. The proposed model was implemented into the ERP (Enterprise Resource Planning) system of Aluminium Ltd. in Mostar and successfully applied for the furnace and pouring scheduling. Section 1 of the paper gives a review of literature, section 2 describes the problem and the mathematical model of pouring scheduling. Section 3 deals with the results of the model implementation into the ERP system by the system screenshots. Section 4 gives the conclusions and ends the paper.

1 LITERATURE REVIEW

1.1 General Production Scheduling Problem

Special attention has been given to scheduling problems ever since the fifties of the last century. Following the appearance of Gantt chart a number of papers has been published that discuss the models and methods for solving scheduling problems. In the literature on production planning and scheduling various models and methods are used: mathematical programming, e.g. [4] to [8], and artificial intelligence, e.g. [9] to [11], [49] and [50]. The models mentioned in literature can be classified as deterministic and stochastic, and as static and dynamic.

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The published papers treating the production scheduling problem deal with different types of production. In their paper [12] the authors treat a single-machine batch scheduling problem, and the objective of established model is to minimize the maximum lateness. In the paper [13] the authors compare various methods for the flow-shop scheduling problem with late work objective function. The problem of scheduling a multiprocessor task model with parallel work on several processors that is often used in modern manufacturing systems is discussed in [14]. The paper applies scheduling in time windows for the objective function of maximum lateness and schedule length. An overview of development and approaches to solving the flow-shop problem is given in the paper [15]. A concise review of the techniques developed up to that time for solving the job shop scheduling problem is presented in the paper [16]. The authors of the paper [17] deal with the job shop scheduling problem for flexible manufacturing system. To solve the job-shop scheduling problem a new time and memory efficient representation of the disjunctive graph is given in the paper [18]. In the papers [19] and [20] the authors discuss the optimization of multiple conflictuous criteria for flowshop scheduling problem. The authors of the paper [21] treat the resource-constrained project scheduling problem. The review of the fundamental approaches for project scheduling under uncertainty is given in the paper [22]. The authors of the paper [23] elaborate the activities scheduling problem aiming at minimizing the project duration with the possibility to perform the activities in several variants. The project scheduling problem classification is also given. The authors of the papers [24] and [25] the scheduling problem with the setup time included, in contrast to most models that disregard the machine setup time or consider it as part of the processing time. The authors of the paper [26] deal with the family scheduling model which includes the setup times when there are family setup times aimed at minimizing total earliness and total tardiness. In their paper [27] the authors treat the problem of scheduling orders with various priority rules.

1.2 Foundry Operations Scheduling

Most papers about scheduling problems in the metal industry deal with various planning and scheduling models for steel production. In the paper [28] a mixed integer linear programming model is given. The objective function is to minimize the total completion time. In the paper [29] a mathematical model for steel billets production scheduling is presented. Linear programming method is used and the objective function is to make a maximum profit on selling the billets. The mathematical model for steelmaking-continuous casting production scheduling based on the just-in-time (JIT) concept is given in the paper [30]. The linear programming method is applied and the objective function is to minimize the cost function. According to [30] no systematic research has been realized so far on the general structure, model and algorithm which can be applied to steelmaking plants. In the paper [31] authors reviewed the planning and scheduling systems developed for steel production. However, little research has been published regarding scheduling foundry operations. An example of Gantt chart (from 1903) for foundry operations scheduling is shown in the paper [32]. A recent survey on this topic may be found in the papers [1], [2] and [33] to [37]. Mathematical model for pouring scheduling, formulated by integer programming, is given in the paper [1]. The authors of the paper [33] suggest mixed integer linear programming formulation for the scheduling problem. The objective function is to minimize total tardiness. In the paper [34] the authors apply a mixed integer linear programming method to model the production planning and scheduling in small foundries. The authors [35] use ant colony optimization metaheuristic to solve the aluminium casting scheduling problem by computerized scheduling application. The paper [36] presents a software solution for aluminium production complex process management. The authors of the paper [37] describe a lot-sizing model for foundry. Objective function is to minimize the total production costs. The paper [2] describes the application of multiobjective evolution algorithms in multicriteria optimization of operational production plans in foundry.

1.3 ERP System

The papers [38] and [39] compare several ERP systems (recognized global solutions and local solutions) used in Croatia. There is an ample supply of the software for financial operations, management of human resources and payroll accounts while the supply of the software for commodity and material transactions is less adequate. However, the supply of production software and that for production management in particular is completely inadequate. The mentioned research has shown that compared to imported commercial packages the Croatian solutions are better, cheaper and easier to implement. The most important parts of the ERP system are planning and scheduling [40]. However the researchers think that the applied methods of planning built in the computer systems are too simple. Not even the linear programming methods are in most cases included into the standard program packages for planning and scheduling [41]. The ERP system manufacturers are beginning to include the operation research optimisation methods (e.g. mixed-integer programming) to upgrade the quality of operations planning and scheduling [42]. Most software manufacturers avoid getting involved in solving this problem. Further research is necessary in order to find an efficient and user friendly computer-aided tool for scheduling. The ERP system practical application advantages and disadvantages are often discussed in professional journals, but the research on ERP and applied planning and scheduling methods are under-represented in literature, except for the researches on reasons for implementation or the ERP system implementation itself, e.g. [43] to [46].

According to the AMR Research[1] the world five largest ERP system manufacturers: SAP, Oracle, Sage Group, Microsoft, SSA Global, control nearly 80% of the ERP system market. Most of the ERP systems available are modular. Typical modules are accounting, human resources, production and logistics. Each module contains specific business processes, access to common data base and ability to operate as independent application. Thus the system structure can be quickly changed and upgraded. The software of the above mentioned software manufacturers is used in some foundries. However, the expensive, large and computer equipment demanding ERP systems are not available to small and medium companies especially when they have particularities the ERP system has to be adjusted to [40]. It is also highly complicating to modify the commercial software so as to adjust it to the requirements of the foundry operational processes.

2 PROBLEM DEFINITION

This paper deals with scheduling issues in foundries. The production of aluminium casting products (blocks, ingots, wire) is a combined continuous discrete production with processes: electrolysis in electrolytic cells, pouring into transfer crucibles, transfer and pouring of alloy to the furnace, molten metal control and purification by adding the required ingredients according to the customer's alloy specification, pouring into moulds, control, product cutting and delivering. Figure 1 gives a scheme of production lines in the foundry Aluminium Ltd. in Mostar. The production process encompasses five production lines with ten furnaces and a finishing workshop for production of aluminium cast items:

- line CC3 for producing billets with furnaces P10 and P9,
- line CC2 for producing T-ingots with furnaces P8 and P7,
- line CC1 for producing blocks with furnaces P6 and P5,
- line BROCHOT for producing alloyed ingots with furnaces P3 and P2,
- line - wire rolling mill CLESIM with furnace P1.

Tasks set to the production of aluminium casting products scheduling system are:

- to calculate the available furnace capacity for the total of 24 hours,
- to group products according to alloy specification,
- to group products according to dimensions of moulds,
- to open production order with the products grouped as mentioned above,
- to create daily plan for production based on work shifts,
- to schedule daily production for the lines and available capacities of furnaces.

Furnaces cause bottlenecks. Based on the OPT concept, bottlenecks are identified as critical manufacturing resources and scheduled first. Also, furnaces and moulds must be coordinated. The mathematical model and algorithm for pouring scheduling is developed based on algorithm [47] with adjustment to the specific problem of scheduling foundry operations. The objective is to find feasible production schedule. Let $S_a = \{i_a | i \in a\}$ be a set of items which can be produced by the

[1] http://www.simplysap.com/sap-news/sap-articles/erp-software-will-grow-to-$29-billion-in-2006.htm (20.1.2007)

same alloy and $\mu_o = \{m_i | i \subset S\}$ a set of moulds for items with similar dimensions. Thus the items are grouped to production order o.

The following notation is used:

Indices:

$a = 1,\ldots, A$	alloys
$c = 1,\ldots, C$	charges
$f = 1,\ldots, F$	furnaces
$i = 1,\ldots, I$	items
$j = 1,\ldots, J$	operations
$l = 1,\ldots, L$	production lines
$m = 1,\ldots, M$	moulds
$o = 1,\ldots, O$	production orders
$t = 1,\ldots, T$	periods

Parameters:

b_i	weight of item i [kg]
$dd_{i,o}$	delivery date for item i and order o
K_i	tardiness of item i [day]
$k_{l,f}$	utilization factor of furnace f on production line l
$K^R_{l,f,t}$	available capacity of furnace f in a day t [hours]
$K^{cap}_{l,f}$	capacity of furnace on production line per hour [kg/hour]
$n_{a,t}$	number of charges for alloy a
N^R_m	available quantity of moulds type m [pieces]
n^h_s	number of hours in shift s
$\delta_{s,t}$	number of shifts in a day
o^h	number of overtime hours
$\Pr(i)$	priority of item i
$q_{i,c}$	quantity of items i from one charge [pieces]
$q_{i,o}$	quantity of items i per production order o [pieces]
$q_{i,t}$	quantity of produced items i in period t [pieces]
$q^n_{i,t}$	ordered quantity of item i [pieces]
$q^z_{i,t}$	inventory of item i in period t [pieces]
Q_{raw}	total quantity of melted aluminium [kg]
Q_l	quantity of melted aluminium for line l [kg]
$Q_{l,f,c}$	quantity of melted aluminium for charge in furnace f on line l [kg]
$t_{i,j}$	processing time of operation j of item i [hours]
$t_{l,f,c}$	processing time of charge c in furnace f on production line l [hours]
$t^{pour}_{l,f,c,i}$	duration of pouring of item i from furnace f on production line l [hours]
tm_m	time of assuring necessary quantity of mould type m
$tp^{pour}_{l,f,c,i}$	start time of pouring operation of item i
$tp_{l,f,c}$	start time of processing charge c in furnace f on production line l
$tz_{i,o}$	finish time of item i on production order o
$tz^{pour}_{l,f,c,g}$	finish time of pouring
$\delta_{s,t}$	number of shifts s in a day t
ε	transportation time between pouring and succeeding operations
$\tau_{l,f,c,c+1}$	time between charges

Decision variables:

$x_{i,m}$	binary variable, $x_{i,m} = 1$ if item i is produced in mould type m, otherwise $x_{i,m} = 0$
$y_{a,c}$	binary variable, $y_{a,c} = 1$ if alloy a is produced in charge c, otherwise $y_{a,c} = 0$
$y_{i,c}$	binary variable, $y_{i,c} = 1$ if item i is produced from charge c, otherwise $y_{i,c} = 0$
$\zeta_{g,c}$	binary variable, $\zeta_{g,c} = 1$ if item g is produced from same charge c as item i

Mathematical model is formulated as follows:

Minimize

$$H = \sum_i K_i \tag{1}$$

subject to:

$$K_i = \begin{cases} 0 & if \quad dd_{i,o} \geq tz_{i,o} \\ tz_{i,o} - dd_{i,o} & otherwise \end{cases} \tag{2}$$

$$q_{i,o} \geq \max\left(0, q^n_{i,t} - q^z_{i,t}\right) \tag{3}$$

$$\sum_t q_{i,t} \geq q^n_{i,t} \qquad \forall i \tag{4}$$

$$\sum_c q_{i,c} = q_{i,o} \qquad \forall o \tag{5}$$

$$q_{i,c} \leq \min\left\{ q_{i,o}, \frac{Q_{l,f,c}}{b_i} - q_{g,o} \cdot b_g \cdot \zeta_{g,c} \right\} \tag{6}$$

$$\sum_a n_{a,t} \cdot Q_{l,f,c} \leq K^R_{l,f,t} \cdot K^{cap}_{l,f} \tag{7}$$

$$b_i \cdot N^R_m \leq Q_{l,f,c} \tag{8}$$

$$K^R_{l,f,t} = \left[\sum_s \delta_{s,t} \cdot n^h_s + o^h \right] \cdot k_{l,f} \tag{9}$$

$$\sum_l Q_l \leq Q_{raw} \tag{10}$$

$$\sum_i x_{i,m} \cdot q_{i,o} \leq N^R_{m,t} \tag{11}$$

$$tp^{pour}_{l,f,c,i} \geq \max\left(y_{a,c} \cdot \left(tp_{l,f,c} + t_{l,f,c}\right), \sum_i x_{i,m} \cdot tm_m, \psi_{i,g} \cdot tz^{pour}_{l,f,c,g} \right)$$
$$g \neq i,\ \Pr(g) \geq \Pr(i) \tag{12}$$

$$t_{i,j=1} \geq tp^{pour}_{l,f,c,i} + t^{pour}_{l,f,c,i} + \varepsilon \tag{13}$$

$$\sum_j t_{i,j} + t_{l,f,c,i} \leq dd_{i,o} - tp_{l,f,c,i} \tag{14}$$

$$tp_{l,f,c+1} \geq tp_{l,f,c} + t_{l,f,c} + 1 + \tau_{l,f,c,c+1} \tag{15}$$

$$\sum_a y_{a,c} = 1 \qquad \forall c \tag{16}$$

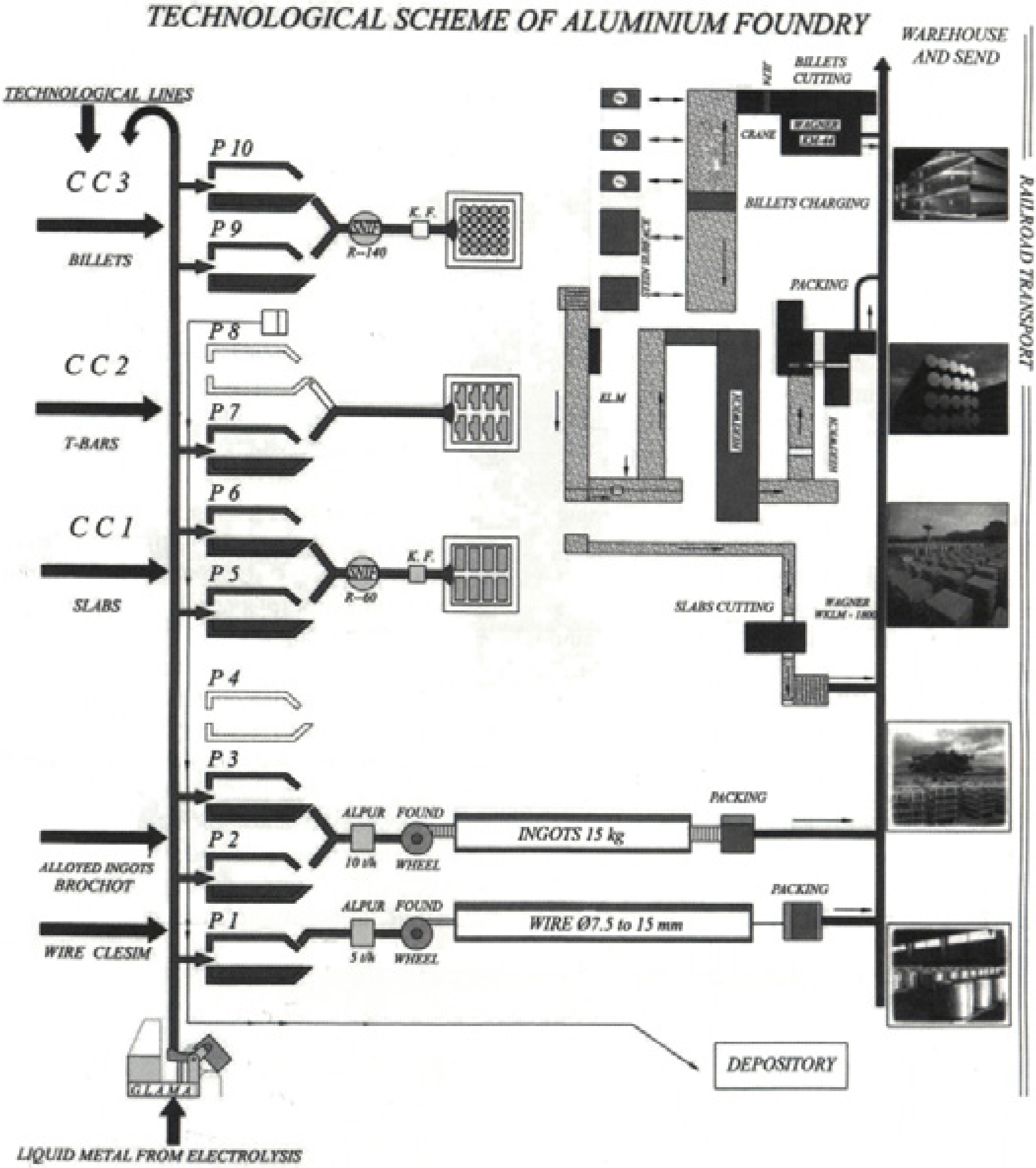


Fig.1 *Technological scheme of aluminium foundry*[2]

$$\sum_{a} y_{i,a} = 1 \quad \forall i \tag{17}$$

The objective function is to minimize tardiness of production order (1). Tardiness can be expressed by the term (2). Constraint (3) determines the order quantity for item i of production order o. Constraint (4) ensures that the quantity of produced items in the planning horizon is equal to the ordered quantity. Constraint (5) ensures that the total quantity of items i from all charges is equal to the production order quantity. Constraint (6) determines the quantity of item i for producing from charge c according to the available quantity of alloy in the charge. Constraint (7) determines that the total quantity of different alloy for period t is equal to or less than the available furnace capacity. Constraint (8) ensures enough mould capacity. The mathematical term (9) determines the available capacity of furnace f on production line l for day t. Constraint (10) guarantees that the consumption of the total required quantity of melted aluminium for all production lines does not exceed the

[2] http://www.aluminij.ba/About_us-Technological%20scheme%20of%20the%20foundry.htm (18.8.2006)

available melted aluminium. Constraint (11) ensures that the consumption of moulds does not exceed the available quantity of moulds. Constraint (12) determines the starting time of pouring items i from charge c in furnace f on production line l. The operation of pouring item i is assigned to the furnace according to the defined priority of items. Also, according to the MRP II concept all needed resources (e.g. moulds) must be provided for the start of operation. Constraint (13) ensures the starting time of subsequent operations on item i (after pouring into moulds). Constraint (14) enforces that the sum of the charge processing time in the furnace and subsequent operations times is less than or equal to the difference between due date and starting time of the charge c processing in the furnace f. That enforces production according to the JIT concept. Constraint (15) ensures that the succeeding charge is started only when the preceding charge is finished and poured. The time between charges is taken into account. Constraint (16) ensures that there is only a single alloy in each charge. Constraint (17) ensures that each product is made from just one alloy.

3 IMPLEMENTATION OF MATHEMATICAL MODEL

The model, Croatian solution of the ERP system [40], has been used in the Aluminium Ltd. foundry in Mostar since March 2006. Some screenshots of the developed planning and scheduling system are given and discussed below.

The ERP system contains information about the capacities that will be monitored during the foundry operations process. Bottlenecks as critical capacities are defined. Furthermore, the definition of technological operations is given. Each operation is defined in view of its duration and capacity. Figure 2 shows the technological operations for production of aluminium casting products. After creating orders the next task is to determine the production order (production line and quantity from one charge are automatically offered) and the basic plan. By the selection of the number of charges the basic plan for that day is determined. Figure 3 shows the procedure for determining the basic production plan. Figure 4 shows the basic plan that defines the deadlines and also shows the realisation of contracted times (planned finishing time with regard to the deadline).

Detailed scheduling with the dates, shifts and hours of the pouring operations start times for every production order is determined after the basic plan has been generated. After the selection of the date and production line, the system offers all production orders planned for that day. Afterwards, the selection of production order is performed and the process of scheduling starts. Figure 5 shows the start-up for the generation of the detailed plan.

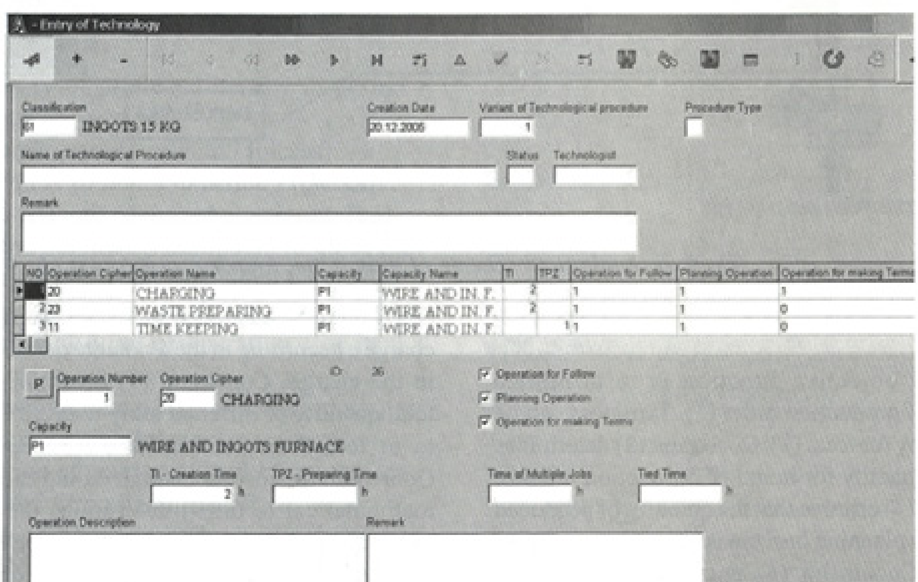


Fig. 2. *Technological operations for production of aluminium casting products*

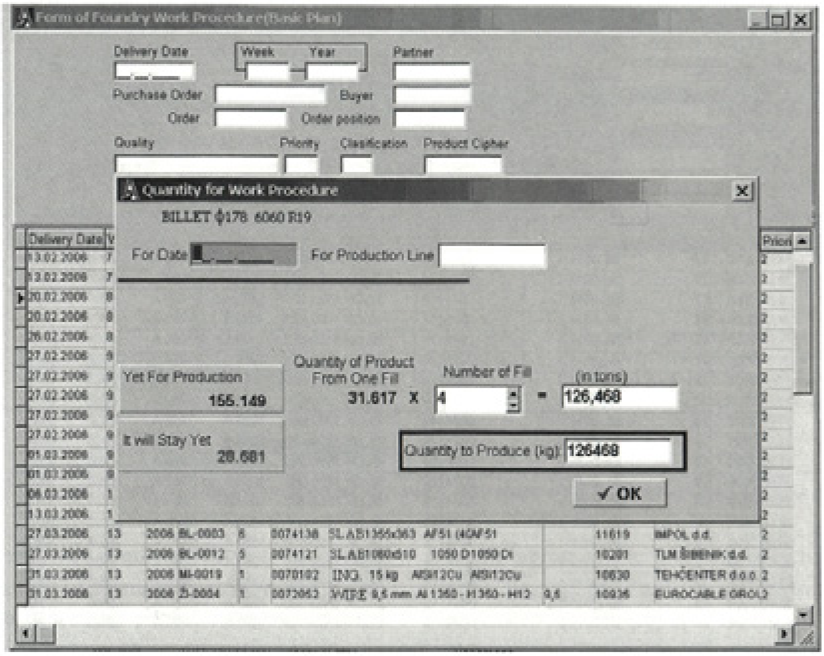


Fig. 3. *Procedure for the generation of basic plan*

ALUMINIJ d.d. Mostar

Basic Plan of Production

FROM 28.09.2006 TILL 03.10.2006

Num1

Date 27.09.2006

Production Line	The	Num. of Fill	Buyer	Order	Purchas Order	Quality	Dimension	Product	Quantity for Production(kg	Produced (kg)	Yet for Production	Date/Week of Delivery	
28.09.2006	7	7											
CC3	7	7											
	1	1	VIBA SrL	TR-0046	390	6060 VIBA	7000; fi 178	0073143	130.	125.145	4.855	25.09.2006	39
	4	4	FEAL d.o.o. za	TR-0086	10/200	6060 FEAL	7000; fi 178	0073048	800.000	122.827	677.173	30.10.2006	44
	2	2	ESTRAL SpA	TR-0083	418	6060 EST	7000; fi 178	0073090	100.000	62.314	37.686	29.09.2006	39
29.09.2006	6	6											
CC3	6	6											
	2	2	ESTRAL SpA	TR-0083	418	6060 EST	7000; fi 178	0073090	100.000	119.036	-19.036	29.09.2006	39
	4	4	ALCOA KOEFEM	TR-0082	417	6060.36	7000; fi 178	0073114	200.000	122.355	77.645	04.10.2006	40
30.09.2006	4	4											
CC3	4	4											
	2	2	ALCOA KOEFEM	TR-0082	417	6060.36	7000; fi 178	0073114	200.000	185.624	14.376	04.10.2006	40
	2	2	ALCOA KOEFEM	TR-0082	417	6060.36	7000; fi 178	0073114	200.000	62.805	137.195	03.10.2006	40
01.10.2006	7	7											
CC3	7	7											
	5	5	ALCOA KOEFEM	TR-0082	417	6060.36	7000; fi 178	0073114	200.000	216.794	-16.794	03.10.2006	40
	1	1	FIN.AL SPA	TR-0084	419	6060 FINAL	7000; fi 178	0073077	100.000	29.766	70.234	09.10.2006	41
	1	1	ANODALL	TR-0090	424	6060 ANOD	7000; fi 178	0073095	300.000		300.000	16.10.2006	42
02.10.2006	6	6											
CC3	6	6											
	3	3	FIN.AL SPA	TR-0084	419	6060 FINAL	7000; fi 178	0073077	100.000	123.268	-23.268	09.10.2006	41
	3	3	FEAL d.o.o. za	TR-0086	10/200	6060 FEAL	7000; fi 178	0073048	800.000	272.634	527.366	30.10.2006	44
03.10.2006	7	7											
CC3	7	7											
	7	7	FEAL d.o.o. za	TR-0086	10/200	6060 FEAL	7000; fi 178	0073048	800.000	493.145	306.855	30.10.2006	44

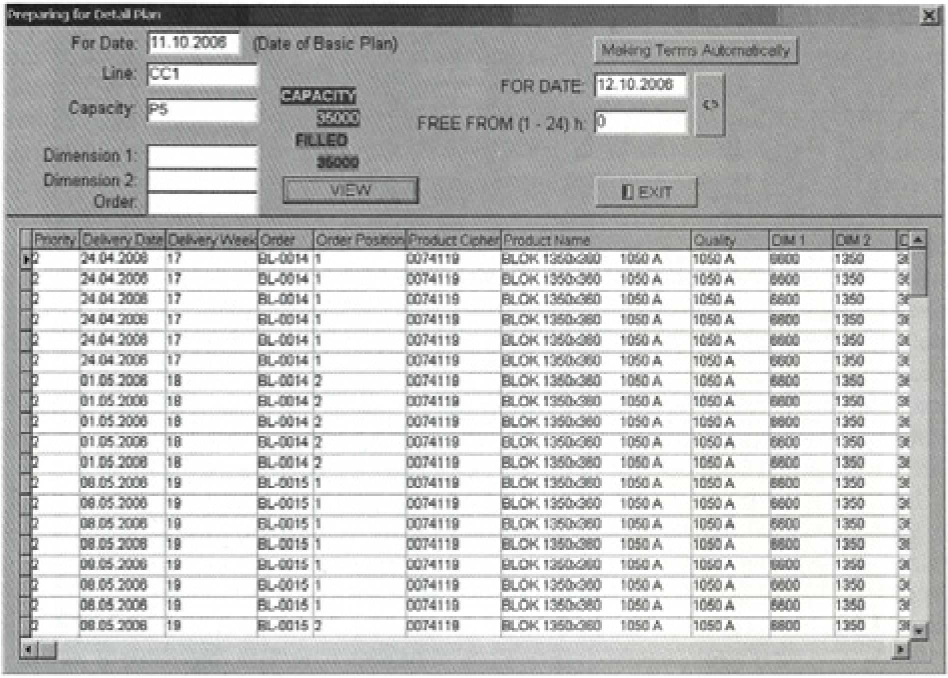
Fig. 4. *Screenshot of the basic plan of production*

Figure 6 shows the screenshot of the detailed plan. A particular task of the system is the rescheduling that solves:

- priority changes for the previously generated plan of pouring,
- changes caused by certain problems in the preparation of pouring.

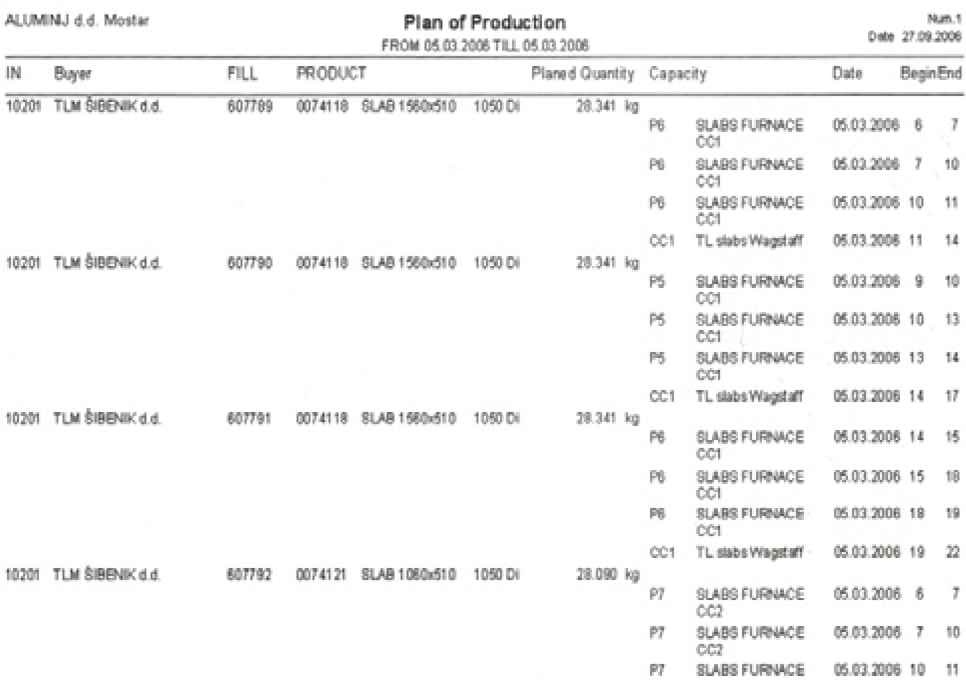
A new production plan is generated whenever a change in production and orders occurs.

According to the previously published research on foundry operations scheduling the authors have concluded that in most cases the foundries schedule operations manually and that only a few of them use software to assist in



Priority	Delivery Date	Delivery Week	Order	Order Position	Product Cipher	Product Name	Quality	DIM 1	DIM 2
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	24.04.2006	17	BL-0014	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	01.05.2006	18	BL-0014	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	01.05.2006	18	BL-0014	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	01.05.2006	18	BL-0014	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	01.05.2006	18	BL-0014	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	01.05.2006	18	BL-0014	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	1	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350
2	08.05.2006	19	BL-0015	2	0074119	BLOK 1350x360 1050 A	1050 A	6600	1350

Fig. 5. *Scheduling procedure*



ALUMINIJ d.d. Mostar

Plan of Production

FROM 05.03.2006 TILL 05.03.2006

Num.1
Date 27.09.2006

IN	Buyer	FILL	PRODUCT	Planed Quantity	Capacity		Date	Begin	End
10201	TLM ŠIBENIK d.d.	607789	0074118 SLAB 1560x510 1050 Di	28.341 kg					
					P6	SLABS FURNACE CC1	05.03.2006	6	7
					P6	SLABS FURNACE CC1	05.02.2006	7	10
					P6	SLABS FURNACE CC1	05.03.2006	10	11
					CC1	TL slabs Wagstaff	05.03.2006	11	14
10201	TLM ŠIBENIK d.d.	607790	0074118 SLAB 1560x510 1050 Di	28.341 kg					
					P5	SLABS FURNACE CC1	05.03.2006	9	10
					P5	SLABS FURNACE CC1	05.03.2006	10	13
					P5	SLABS FURNACE CC1	05.03.2006	13	14
					CC1	TL slabs Wagstaff	05.03.2006	14	17
10201	TLM ŠIBENIK d.d.	607791	0074118 SLAB 1560x510 1050 Di	28.341 kg					
					P6	SLABS FURNACE CC1	05.03.2006	14	15
					P6	SLABS FURNACE CC1	05.03.2006	15	18
					P6	SLABS FURNACE CC1	05.03.2006	18	19
					CC1	TL slabs Wagstaff	05.03.2006	19	22
10201	TLM ŠIBENIK d.d.	607792	0074121 SLAB 1060x510 1050 Di	28.090 kg					
					P7	SLABS FURNACE CC2	05.03.2006	6	7
					P7	SLABS FURNACE CC2	05.03.2006	7	10
					P7	SLABS FURNACE	05.03.2006	10	11

Fig. 6. *Production schedule*

scheduling. Thus the development of the operations scheduling model for the manufacture of aluminium casting products renders the present research original and of considerable industrial significance. So the OPT method can be used not only in the production of car parts but also for pouring processes. The mathematical scheduling model has been successfully applied to the foundry,

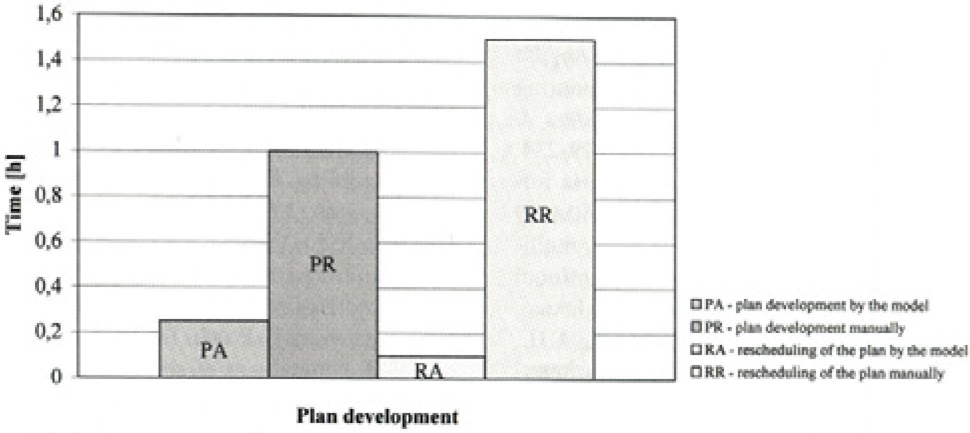


Fig. 7. *Comparison of the time needed for plan development manually and by the model*

and it has significantly improved the set-up process and the scheduling of furnace operations. It is also a precondition for better monitoring of obtained results.

The analysis of the classical and new approach to scheduling is made by comparing the times required for the plan development (shown in Fig. 7). To develop the plan by the model takes 15 min while to do it manually takes 60 min. Rescheduling of the plan by the model takes 6 min while doing it manually takes 90 min.

The other data (monitoring of the quantity produced per day, reduction of production flow, reduction of waiting time in foundry and of consumption of energy required for keeping the foundry temperature constant) will be available only after a year–long monitoring.

4 CONCLUSION

The main goal of this paper was to develop a new mathematical model for scheduling foundry operations based on the MRP II (Manufacturing Resource Planning), JIT (Just in Time) and OPT (Optimized Production Technology) concepts. A considerable effort was made to link academic research with industry requirements in order to achieve this goal. The researches carried out at the Mechanical Engineering Faculty in Slavonski Brod confirmed that the JIT and OPT approach can be applied to solve the foundry operations scheduling problems. The researches also showed that the JIT and OPT concepts, originally developed for discrete production, can be applied for the combination of the process - discrete production, such as the production of aluminium casting products. In this paper a mathematical model is proposed to find a feasible pouring schedule. The use of this mathematical model for scheduling the operations of a foundry reduces the time needed for generating pouring schedules and enables the control of tardiness and adherence to the contracted due dates. The advantage of the proposed model and algorithm in comparison with other algorithms is in its multi-stage approach to planning and scheduling.

The model put forward in this paper is the Croatian solution of the ERP system. It is implemented into the ERP system of the firm Informatics Engineering ININ Ltd. in Slavonski Brod. The mathematical model, an integral part of the ERP system, is successfully applied and tested in the foundry Aluminium Ltd. in Mostar. This practical aspect makes the paper original and of importance to both academic researchers and actual practitioners in the metal industry. With minimum modifications, other foundries and other industries (e.g. food and paper industries) can also integrate this model into their systems.

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