Journal of the Society of Korea Industrial and Systems Engineering
Vol, 29, No. 2, pp.43－50, June 2006.

철강 제조 공정의 주요 생산 계획 이슈를 고려한 생산 계획 시스템의 적용

박경종* · 오형술**

*광주대학교 경영학과
**강원대학교 산업공학과

The Application of Planning System Considering Main Planning Issues of Steel Manufacturing Process

Kyoung-Jong Park* · Hyung-Sool Oh**

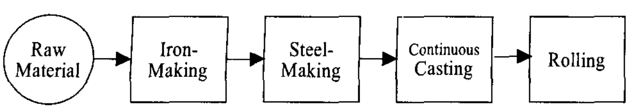
*Dept. of Business Administration, Gwangju University
**Dept. of Industrial Engineering, Kangwon National University

본 연구에서는 철강 제조 공정에서 발생하는 생산 계획 문제를 설명하고 해결 방법을 제시한다. 철강 제품 중에서도 판재류(냉연, 아연도, 석도, 칼라 제품)를 생산하는 공정으로 연구 범위를 제한하고 적용하는 부분은 철강 공정의 스케줄링 분야를 배제한 생산 계획 분야만을 대상으로 한다. 특히, 철강 제조 공정의 생산 계획 문제들 중에서 가장 중요하게 고려되는 원료 충당 문제, 용량 할당 문제, Batched Annealing Furnace(BAF) 설비 운영 문제를 중심으로 설명하고, 이 문제점들을 해결하기 위한 방안을 제시한다. 또한, 제시된 방법을 특정의 툴에 적용하여 생산 계획 시스템을 구축하고 효과를 설명한다.

Keywords : material allocation, capacity allocation, Batched Annealing Furnace resource operation

1. Introduction

We use many steel products among artificial materials and the steel industry is a base industry that supplies materials to all industries. The steel is used as the raw materials for cutting products, industrial products, and construction products, because the steel is superior to strength, hardness, and toughness than other materials. We simply explain the steel manufacturing process shown on the <Figure 1>.



<Figure 1> Steel manufacturing process

The iron-making process is a base process to make a metallic stain. The steel-making process makes a pure steel after eliminating impurities from a metallic stain. The continuous casting process makes a solid metal from the steel of liquid status. The rolling process converts a steel into steel plates or wire rods. The rolling means the process to make the wide or thin plate after inserting a slab or a billet produced from the continuous casting process. This rolling process is divided into the hot rolling process and the cold rolling process (POSCO 2003).

We can't easily make a planning of a steel process because the manufacturing process of steel products has the properties of discrete process among processes but the process has the properties of continuous process within a process.

To solve the planning problems of a steel manufacturing process has the discrete properties and the continuous properties, many researchers have been studied about it. The Sa (1997)'s theoretical study related to a planning of steel process explained that job sequences are decided with product width, material status, package weight, welding condition, and plating quantity and also the paper mentioned the WIP (work-in-process) aspects to increase manufacturing productivity. Park and Lee (1997) studied a heuristic method to allocate manufacturing quantity considering production capacities per factory and facility characteristics. But these studies didn't consider various constraints but only considered special constraints to make a planning. So, these studies have limitations when we apply to various environments. Kim (2000) developed a planning system of cold rolling mills and applied it to a field. But the applicable area of the system is very limited and we can only use the system at a short term planning horizon.

If factories are locally separated, at a headquarter we make a planning considering constraints and send planning results to factories. If a factory to make a planning and a factory to manufacture products using the planning result are locally separated, we send a factory data to a headquarter's planning system and make a planning considering each factory's characteristics. In these planning process, we make a planning system considering associated systems to treat basic data and planning results because we need the synchronization and the speediness of a planning process. Therefore, we should make a tool-based planning system to gain effective results whenever we make a planning in order to reflect adequately related systems and environments.

Smitomo metal company developed a plate management information system called as FRIENDS to control all operations of an order process, a manufacturing process, and a shipping process. This system contributes to quality, due date, and cost competitiveness through facility automation and simplification (AnySteel.com 2003). But, the FRIENDS system can't immediately consider urgent orders or exception status occurred when we make a planning. Lee and Whang (2000) designed a management system for materials of steels and irons and developed it. But the system don't cover all scopes of a steel process and only consider the control aspect of materials. Kim and Park (2003) developed a scheduling system for CAL (Continuous Annealing Line) process in a cold rolling mill. But the system only consider a scheduling level. Also the considered constraints are very limited.

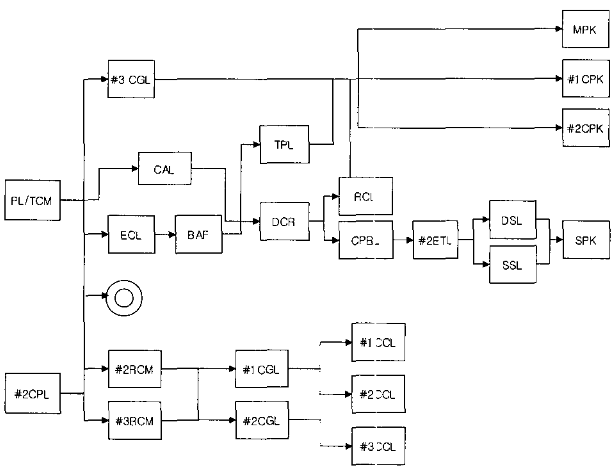
Also some companies developed an in-house system to solve planning problems. But, the planning accuracy is poor because these systems can't control various constraints. Therefore, in this study we propose a method using a tool-based system to solve exception status, connection problems of related systems, and various constraints when we make a planning. Also we propose a method to solve main planning issues occurred at a planning level of a steel process. In other words, we don't consider technical problems to construct a system but consider planning issues to apply a planning system included in an APS system.

In chapter 1, we explained general steel process and current application status, and in chapter 2, we will explain a steel process included in study scope. In chapter 3, we will explain the main issues of a steel process and will propose a solving method of proposed problems. Also we will apply the method to a system. Finally, in chapter 4, we will propose conclusions and future researches.

2. Process Explanation

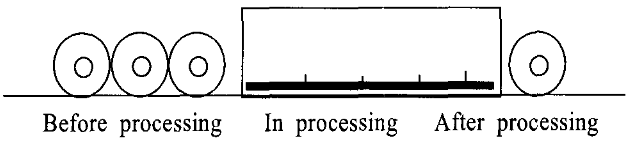
In this paper, we consider only the planning issues of a steel manufacturing company. A company buys a rolled steel of coil status and makes end products using it. Also, we restrict manufacturing products of the company to the cold-rolled product, the pre-painted product, the galvanized product, and the tinplated product. The manufacturing factory is divided into F-1 and F-2. The two factories are separated with local area but can't make independently products. The input of a raw material starts from F-1 factory and the end product is made by F-2 factory or vice versa. That is, to make a product we use two factories, F-1 and F2, or we use only one factory according to the characteristics of a product.

We explain a steel process that is study scope of this paper at the <Figure 2>. If we observe a process flow of a steel manufacturing process shown on the <Figure 2>, we know the first process is PL/TCM operation but the flow of processes is divided into separate flows according to end products. The process, PL/TCM, eliminates surface scales of hot coils and makes products with adequate width. Also all products must pass the process, PL/TCM to be end products. The cold-rolled products pass the process, PL/TCM-CAL-TPL-RCL or PL/TCM-ECL-BAF-TPL-RCL. The pre-painted products pass the process, CPL-#3RCM-#2CGL-#2CCL, and the galvanized products pass the process, CPL-#3RCM-#2CGL or PL/TCM-#3CGL. The tinplated products pass the process, #2ETL-SSL. The initial input process is the process, PL/TCM, regardless of characteristics and types of a product. But, we should control a planning process through characteristics and types of product requested by a client because the pass routing is differentiated with the client requests (Dongbu Steels 2003).



<Figure 2> Process flow of steel products

The raw materials of a steel process start from the status of a unit coil. Because a steel manufacturing process has properties of continuous process within a process, the second coil is fed into a process, which is welding with the first coil. Therefore, we consider input constraints like coil characteristics, weights, allowed order tolerances, and welding allowances whenever we input a coil to a process. If a connected coil are finished at a process we cut the coils and move to next operation with status of a unit coil. That is, like the <Figure 3> if the raw material of a unit coil is in processing status the coils are manufactured with connected status. But, if a process is finished we cut a connected coil to the separate unit coils and move to next operation.



<Figure 3> The coil status in processing

If a welded coil passes a process, the weight of a welded coil is changed and new welding marks are appeared on a unit coil because a manufacturing process of steel products has simultaneously the continuous manufacturing status and the discrete moving status. And then we cut a connected coil to the separate unit coils. These characteristics much effect on a steel manufacturing process. So, we consider many constraints more than general industries.

As mentioned above section, we make a planning system using a special tool to solve issues and propose a solving method within the tool's functionalities. The used tool is i2 company's FP and the tool is very popular at planning fields. The tool makes optimal planning results per factory considering master data and constraints if manufacturing quantity of a factory is fixed according to factory conditions.

We configure pre defined functions called "record" and "server flag" to apply FP tool for planning issues. We configure the record and the server flag to make a planning and then we save the conditions to the text file (called flag file) and we execute FP engine. Using FP engine, at first we make an initial planning called ICP (infinite capacity planning) considering constraints. The ICP stage supposes that the resource capacities are unlimited and the constraints of raw materials are considered. At second, using the result, we solve constraints considering the resource capacity, the priority, the due date, and etc. we called this stage as FCP (finite capacity planning). Finally we act scheduling process if we need it. Or we change the result of a planning using a manual planning job and then send the result to fields (i2 technologies 2002, 2003). Also, we develop an in-house system that is interfaced with the tool.

3. The Planning Issues of Steel Process

In a steel manufacturing process, the main problems occurred at a planning are classified into the problem of material allocation, the problem of capacity allocation, and the problem of BAF resource allocation.

3.1 the problem of material allocation

3.1.1 problem explanation

If a customer orders some products we peg raw materials to customer's orders considering product characteristics to make order products. The considering constraints are the percentage of order allowance, the standard material, the standard width, the used factory of raw material, the R/S selection, the product maker, the priority, the unit weight of product (including or excluding welding line), the allowance range of welding line, the surface status of raw material, the maker of raw material, the tolerance, and etc. The difficult point is that we should simultaneously consider "the percentage of order allowance + the unit weight of product + the allowance range of welding line" and we should optimally allocate raw materials to the orders.

The percentage of order allowance is also called the percentage of delivery allowance. The coverage of the percentage of order allowance is explained using [$-\alpha$, $+\alpha$]. If the percentage of order allowance is $\pm\alpha$ and if a customer orders A ton, we allocate the satisfied raw materials to the order quantity in [$-\alpha+A$, $\alpha+A$]. We suppose the raw material, B ton, is pegged to the order, A ton, and the C ton is used to make products and the D ton remains to WIP. Then the remaining order quantity is B-C ton and the remaining input quantity is B-C-D ton. So the actually remaining input quantity, E ton, is calculated using (equation 1).

$$-\alpha+A <= C+(D-f)+E <= \alpha+A \quad (1)$$

f : the decreased quantity of WIP when D ton is used to make end products.

If we suppose that the coverage of order allowance is [$-\alpha+A$, $\alpha+A$] and that the matching quantity between raw materials and orders consists of $-\alpha+A$, $-\alpha+A+\beta$, $-\alpha+A+\beta+\gamma$, and $\alpha+A$, we decide the selected final quantity of raw material as $\alpha+A$. When we allocate raw materials to an order, the coils of raw materials are orderly selected into i ton, i+j ton, i+j+k ton and etc. If i+j is less than $\alpha+A$ and i+j+k is larger than $\alpha+A$, we select only i ton and j ton. Also if we can't select the combination of raw materials to satisfy the coverage of minimum allowance of orders we select the combination of raw materials that is near to the coverage of minimum allowance of orders.

<Table 1> The solution of material allocation considering constraints

Constraints	The usable material coil	25 ton, 30 ton, 15 ton, 18 ton, 10 ton
	The requested unit weight of product	8-10 ton
	The actual product weight to consider the loss rate of product	9-11 ton
	The allowance range of welding line	0
	The order quantity	55 ton
	The percentage of order allowance	±10%
Solution	10 ton, 18 ton, 30 ton	

If a client requests the unit weight of a product as [m, n] ton, we decide the unit weight of a final product as [$m+\delta$, $n+\delta$] ton that is more heavy than the client's request weight because we consider a loss rate through manufacturing process. So, the weight of selected coils to make a final product is combined by [$m+\delta$, $n+\delta$], [$2(m+\delta)$, $2(n+\delta)$], [$3(m+\delta)$, $3(n+\delta)$], and etc.

Also when we consider the product weight we include a constraint, either including of welding line or not. If we suppose the allowance range of welding line is zero then the manufactured final products should not select the unit coils that have welding line.

We explain a sample solution to satisfy the constraints, the percentage of order allowance, the unit weight of product, and the allowance range of welding line at below the <Table 1>.

3.1.2 solution approach

We consider simultaneously the priority of orders, the usage interval of orders, the priority of usable raw materials, the interval of usable raw materials, and the 3 constraints explained at above section 3.1 to solve the problem of material allocation. We must proceed with the next steps to obtain optimal planning results considering all constraints.

Step 1 : we calculate the production quantity using equation, $-\delta+A <= C+(D-f)+e <= \delta+A$. And also we consider the coverage of order allowance, [$-\delta+A$, $\delta+A$].

Step 2 : We construct BOM (bill-of-materials) of raw materials using "the priority of raw materials and the usage interval of raw materials" considering the priority of orders and the usage interval of orders. When we make the BOM we follow next priorities because we provide the various combination of a unit weight and consider the allowance range of welding line per each order.
- Priority 1 : standard raw material + the allowance range of welding line : 0
- Priority 2 : standard raw material + the allowance range of welding line : 1
- Priority 3 : alternative raw material + the allowance range of welding line : 0
- Priority 4 : alternative raw material + the allowance range of welding line : 1

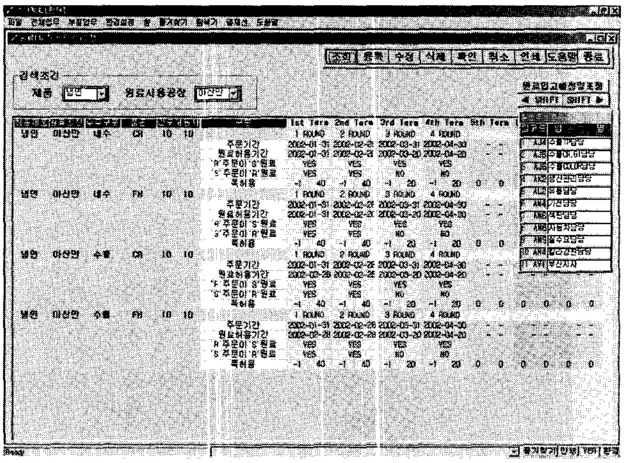
Step 3 : We proceed the material allocation process using the priority of orders and the constructed BOM.

Step 4 : We investigate the allocated sets of raw materials and orders after finishing the material allocation. If the allocated raw materials are the greater than or equal to the number of the allowance range of welding line, then we cancel the combination of the allocated raw materials and go to the Step 2.

At the Step 2, the reason to construct the BOM considering the allowance range of welding line and the unit weight of products is as following : The characteristics of steel products can be differentiated from orders. Also, if the allowance range of welding line is zero, we can only construct the BOM in case the weight of a unit coil of raw materials is included in $[m+\delta, n+\delta]$, $[2(m+\delta), 2(n+\delta)]$, $[3(m+\delta), 3(n+\delta)]$, and etc.

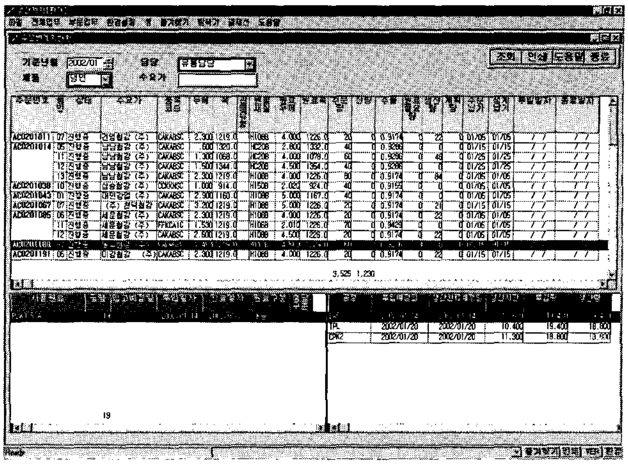
At the Step 3, when we allocate orders to raw materials we consider an important characteristic that we can't allocate a unit coil to 2 orders in a steel process at the same time. So, it is essential to search an order capable of covering a unit coil because it is impossible to split a unit coil to the greater than or equal to the 2 unit coils.

In order to solve the problem of material allocation using the proposed procedures, at first we set the usable raw materials and the allowed interval of the raw materials. The developed screen of the <Figure 4> shows the process. That is, we configure the basic constraints, the order interval for material allocation, and the allowed interval of usable raw materials.



<Figure 4> The developed screen of the usable raw materials and the allowed periods of raw materials

We follow the material allocation algorithm after we set the usable raw materials and the allowed interval of the raw materials. At the execution screen of the <Figure 5>, we know that the given orders satisfy the constraints and have raw materials greater than or equal to 1 raw material. Then because a unit coil of raw material should not divided into greater than or equal to 2 unit coils, so a unit coil must be matched only an order. Whenever we assign the raw materials to orders we must decrease, as soon as possible, the remnants of a unit coil that is assigned to an order and we should satisfy the constraints at the same time.

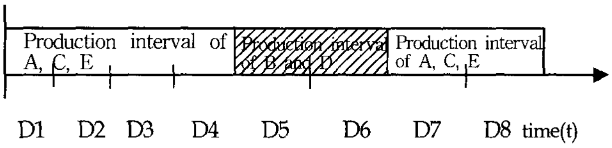


<Figure 5> The results of material allocation process

3.2 the problem of capacity allocation

3.2.1 problem explanation

Another characteristic of a steel manufacturing process is that we should consider the production range (the usable time interval and the quantity) to produce a product through a process operation. That is, we must consider constraints, cycles, and special products can be produced at the given time interval. If we make the products, A, B, C, D, and E, and then the products, B and D, only should be produced at the given time interval. We can't make other products at the given time interval except the products, B and D. If we suppose the intervals, D5 and D6, of the <Figure 6> are reserved to make the products, B and D, the products, A, C, and E, should not be produced at the given time interval regardless of other constraints.



<Figure 6> The production interval of facility considering cycle

Let's suppose we manufacture the products, A, C, and E, at the given time interval, D5, to obtain optimal planning result. Because of the cycle constraints, the products, A, C, and E, only can be manufactured at the time interval, D7. Also, the products, B and D, should be produced at the time interval, [D5, D6], even if we have abundant facilities and time to make products. Eventually, the remaining products after processing at the cycles should be postponed to the next cycle. Therefore the capacity allocation considering the cycle condition of a steel manufacturing process should simultaneously reflect the 2 constraints shown on the <Figure 7>.

Constraint 1 : the special product group should be produced within the fixed time interval called cycle.
Constraint 2 : the assigned products to the cycle only should be produced at the fixed quantity.

<Figure 7> The constraints of capacity allocation

3.2.2 solution approach

To solve cycle constraints, we separate special products from general products. And then we set the starting time and the ending time of special products. We explain it on the <Table 2>.

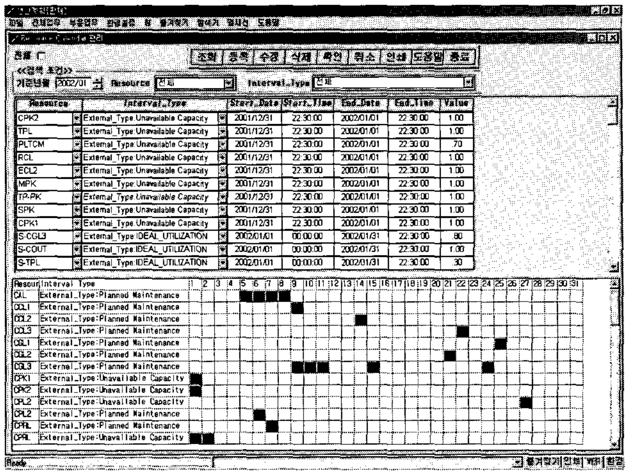
<Table 2> The cycle setting per product of capacity allocation

Product	Producible time	Cycle name	Mfg. quantity	The reconfiguration of producible time considering cycle
A	[D1, Dn]	C1	∞	[D1, D4], [D7, Dn]
B	[D5, D6]	C2	Q	[D5, D6]
C	[D1, Dn]	C1	∞	[D1, D4], [D7, Dn]
D	[D1, Dn]	C1	∞	[D1, D4], [D7, Dn]
E	[D5, D6]	C2	Q	[D5, D6]

At the <Table 2>, the products, A, C, and D, are manufactured using available resources regardless of the available production time. But the available production time of the production items, A, C, and D, should be changed because the production items, B and E, only can be manufactured in the available production time, [D5, D6]. That is, the available production time of the production items, A, C, and D should be changed to the available production time, [D1, D4] and [D7, Dn] because the production items, A, C, and D should not be manufactured at the time interval, [D5, D6].

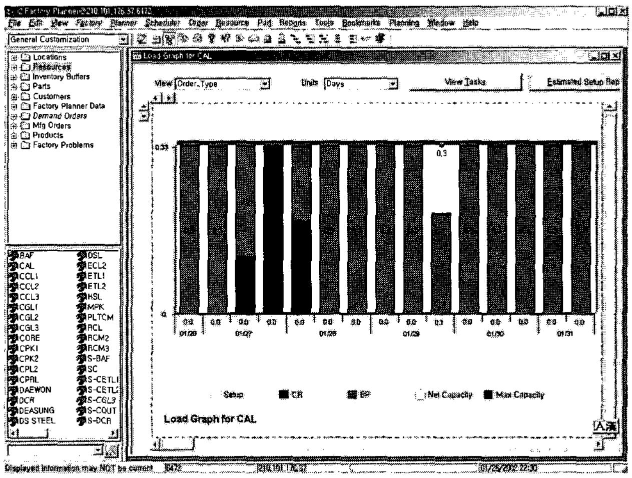
We include additional conditions, the fixed usable manufacturing facilities and the fixed manufacturing quantities, if the manufacturing quantity is fixed regardless of the production capability of manufacturing facilities.

In order to solve the problem of capacity allocation we set the usable date and the usable time of resources shown on the <Figure 8>. And we execute the planning system after we include the constraint that the special product is planned to the special date and the special time. Then we obtain planning results shown on the <Figure 9>.



<Figure 8> The setting of usable time and the usable day of resources

In the <Figure 9>, we know the special product is planned to the special date and the special time because we consider cycle constraints. That is, because cycle constraints are necessary to a process industry like a steel manufacturing process we consider cycle constraints at a planning level.



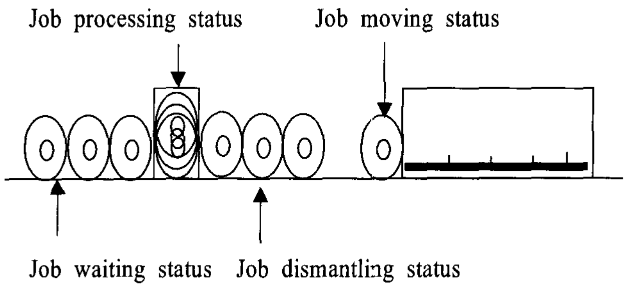
<Figure 9> The results considering cycle constraints

3.3 the problem of BAF resource operation

3.3.1 problem explanation

The BAF resource gathers coil WIPs during a manufacturing process and bakes the coil WIPs. The BAF resource is heat treatment equipment that has box type to heap 3 to 5 levels with coils. Generally speaking, it is very difficult to consider simultaneously multiple BAF resources and to make a planning considering all constraints because general numbers of BAF resource are 20 and each BAF resource selects different unit coil considering coil's characteristics and unit weights.

Also, the BAF resource has coil status of four types. A coil has the job waiting status if a coil doesn't enter a BAF resource, the job processing status if a BAF resource is baking a coil, the job dismantling status to cool down a coil after baking a coil, and the job moving status to move to the next operation after finishing all operations with a BAF resource. We reflect WIP inventory of 4 coil types when we make a planning. The <Figure 10> explains this process. The coils of job waiting status, the coils of job processing status, and the coils of job dismantling status are regarded as WIP of a BAF operation. And the coils of job moving status are regarded as WIP of the next operation.



<Figure 10> The WIP status of coil at BAF resource

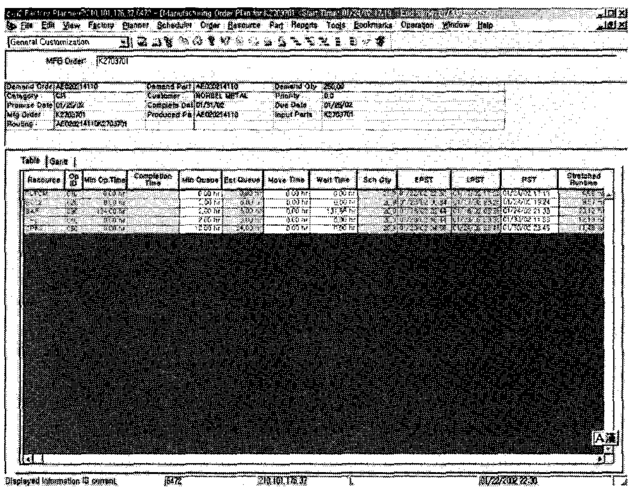
Therefore, we consider 2 constraints to solve the planning problem of BAF resources. At first, we make a planning of each BAF resource in order to obtain real-time planning results considering the weight of a unit coil, the type, and the number of coil. Secondly, we consider the location of WIP to reflect the WIP status because the WIP status of BAF resources is changed by the location of WIP.

3.3.2 solution approach

When we reflect the problem of BAF resource operation, we make a planning considering the weight of a unit coil, the type, and the number of coil. But, it is very difficult to consider simultaneously all constraints. So we change the condition, x Ton/y Day/z BAF, as w ton/1 Day/1 BAF and reflect and then we solve the problem of BAF resource operation using the daily production quantity and the daily WIP.

When we change the BAF resource condition to w ton/1 Day/1 BAF, the WIP of BAF resources is calculated as WIP of the job dismantling status. The job processing of BAF resources should actually continue during y Day in BAF resources but the processing time is shortly finished than the given processing time because of '1 Day' condition. To solve this problem, we set the staying time of y Day even if the processing time of BAF resource is finished. To control WIP of BAF resources, we regard the waiting WIP ahead of a BAF resource as the WIP of job waiting status.

We obtain the result shown on the <Figure 11> if we reflect the operation process of the BAF resource using the proposed method to a planning process. We can observe the process time of the BAF resource is 134.00 hours shown on the 'Min Op. Time' field. And the real processing time is 20.12 minutes shown on the 'Stretched Runtime' filed and the preliminary setup time is 2 hours shown on the 'Min Queue' field. The remainder time, 131.66 hours, is regarded as wait time shown the 'Wait time' field. We know, therefore, the proposed algorithm satisfies constraints.



<Figure 11> The results considering BAF resource

4. Conclusions and Future Researches

The products in a steel manufacturing process are discretely moved as a unit coil between a process and a process but they are continuously moved as a plate that is connected with each unit coil within a process. Therefore, it is very difficult to make a planning. Especially, the planning including material allocation, capacity allocation, and BAF resource operation is always issued by steel manufacturing planners and has many optional solutions.

In this paper, therefore, we explained the problems occurred when we make a planning of a steel manufacturing process that has the discrete characteristics and the continuous characteristics at the same time, and then we proposed solutions. Also, we proposed a technique to simplify the problems when we use a tool to solve planning issues.

We constructed a planning system using the technique proposed in this paper and connected two factories that are located in another area. And then we gathered data and made a real-time planning. We sent again the results to two factories and reflected the data to the planning system and fields.

Eventually a planning of next operation is affected by the quantity allocation policy of a first operation, PL/TCM, because the most of unit coils are input to a first operation, PL/TCM. In future researches, therefore, we should consider efficient planning policies of the operation, PL/TCM, that is a first operation.

References

[1] AnySteel.Com, "The roles of information technology in steel industry," http://www.anysteel.co.kr/InfoCenter/Resource/basic_info.asp#, 2003.

[2] DongBu Steels, http://www.dbstl.co.kr, 2003.

[3] i2 Technologies, FP User's Manual, 2002.

[4] i2 Technologies, http://www.i2.com, 2003.

[5] Lee S. M. and Whang K. D., "Design and implementation of management systems for the materials of steels and irons," *The Journal Of Industrial Sciences*, 8 : 169-174, 2000.

[6] Kim C. H., "A case study of developing planning system for cold rolling mills," *The Korean Production and Operations Management Society*, 11(2) : 111-131, 2000.

[7] Kim C. H. and Park S. H., "Development and application of scheduling system in cold rolling mills," *IE Interfaces*, 16(2) : 201-210, 2003.

[8] Park C. H. and Lee J. H., "The development of factory allocation logic considering productivity and process," Proceedings of 1997 Spring KORMS/KIIE, pp. 8-10, 1997.

[9] POSCO, http://www.posco.co.kr/docs/kor/steelgallery/steelgallery_product_1.html, 2003.

[10] Sa J. J., "The study on WIP control rules considering EG Job characteristics EG," Proceedings of 1997 Spring KORMS/KIIE, pp. 5-7, 1997.