MODERN METHODS FOR MANUFACTURING PLANNING AND SCHEDULING

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The paper deals with modern methods which can be used for planning and scheduling of manufacturing systems. Creating of production plans, using different software products is discussed. Advanced planning and scheduling methods are used for planning and scheduling. The outputs as Gantt charts are presented. Different optimization methods are applied for schedule optimization. Production plan, for every machine is created, after applying the optimization. Scheduling by using Lekin, 'Spreadsheets' and Asprova is described and compared.

1. INTRODUCTION

Manufacturing facilities are complex, dynamic and stochastic systems. From the beginning of organized manufacturing, workers, supervisors, engineers, and managers have developed many clever and practical methods for controlling production activities. Many manufacturing organizations generate and update production schedules, which are plans that state when certain controllable activities (e.g., processing of jobs by resources) should take place. Production schedules coordinate activities to increase productivity and minimize operating costs. A production schedule can identify resource conflicts, control the release of jobs to the shop, ensure that required raw materials are ordered in time, determine whether delivery promises can be met, and identify time periods available for preventive maintenance [Herrmann 2007].

Given the limitations of applying information technology or analyzing problems mathematically, let to the conclusion that a comprehensive approach is needed to improve production scheduling. As modern manufacturing moves towards manufacture-to-order and virtual environments that both increase the complexity of the operation and demand an increasing rapid response time, it becomes more important than ever that manufacturing enterprises have 'Advanced Planning and Scheduling' (APS) systems that can reliably schedule complicated operations quickly. At the same time, scheduling plays an increasing role in many service industries, such as the transportation, computer, and communication industries [Pinedo 2012].

The iterative use of simulation and scheduling is presented as a powerful technique for making all-round productivity improvement recommendations. Using a Scheduling tool also allows the plant to use both proactive and reactive methods to respond to sequence and priority changes while maintaining productivity levels. The schedule so generated is then used as an input into the simulation [Vasudevan 2008].

[Angelidis 2013] presents a specific custom-built simulator designed to support solution approaches for scheduling problems in complex assembly lines found in industrial environments, which is often mentioned in the literature as a Multi-Mode Resource-Constrained Multi-Project Scheduling Problem (MMRCMPSP) with activity splitting [Buddhakulsomsiri 2006]. The scheduling of this type of assembly production lines is a very complex task. It is defined as a large combinatorial order problem.

Unfortunately, many manufacturers have ineffective production scheduling systems. They produce goods and ship them to their customers, but they use a broken collection of independent plans that are frequently ignored, periodic meetings where unreliable information is shared, expediters who run from one crisis to another, and ad-hoc decisions made by persons [McKay 2004].

In this publication is presented the implementation of various optimization methods for planning and management of manufacturing company.

2. MANUFACTURING MODEL CONFIGURATION

Scheduling is an important tool for manufacturing and engineering, where it can have a major impact on the productivity of a process. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility when to make, with which staff, and on which equipment. Production scheduling aims to maximize the efficiency of the operation and reduce costs [Magalhaes 2003].

Manufacturing model configurations (models) are presented using different software products. Models include all processes from receiving of raw materials, manufacturing to purchasing. The purchases raw materials are 'Steel-M1' and 'Gear-X' and the produces products are AX100 AX200 BX100 BX200 CX100 and CX200. They are produced through cutting, additional processing, assembly, and in the end they are packed and sold.

The flow of processes for producing each product is shown below:

- Steel-M1 – Cutting – Processing – Inspection1 – Shaft-A;
- Steel-M1 – Cutting – Processing – Inspection1 – Shaft-B;
- Steel-M1 – Cutting – Processing – Inspection1 – Shaft-C;
- A, Gear-X – Assembly – Inspection3 – AX;
- B, Gear-X – Assembly – Inspection3 – BX;
- C, Gear-X – Assembly – Inspection3 – CX;
- AX – Packing – AX100;
- AX – Packing – AX200;
- BX – Packing – BX100;
- BX – Packing – BX200;
- CX – Packing – CX100;
- CX – Packing – CX200;

2.1 Production scheduling using 'Lekin'

LEKIN® [Pinedo 2012] is a scheduling system developed at the Stern School of Business, NYU. LEKIN® was designed as an educational tool with the main purpose of introducing the students to scheduling theory and its applications. Besides that, the system's extensibility allows (and encourages) to use it in algorithm development. The project has been directed by Professor Michael L. Pinedo and Associate Professor Xiuli Chao.

The framework defines the type of scheduling problem that is to be entered. For scheduling the simulation model of the order is picked a "Flexible Job Shop" environment. Once the framework has been selected, the number of the machines and jobs is to be specified. In the current project 6 workcenters are needed. Different jobs are added to the workcenters and their machines. After adding the jobs other settings like processing time, release date, repeatability of the work and the job route, in the machine environment, are also specified.

Full list of every jobs and the total amount of time needed for manufacturing is shown in the Fig.1. The total production time is 131 hours.

Once the relevant data of the problem has been entered, the scheduling process is started. The 'Early Due Date(EDD)' dispatching rule is set in order to generate a schedule. The generated gantt chart of the jobs is show in Fig.2.

Figure 1. Full list of the jobs for producing the simulation model in 'Lekin'
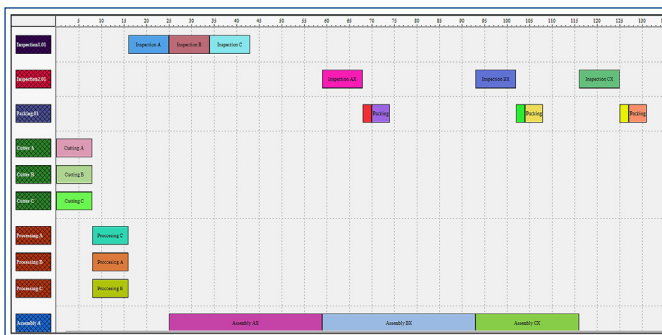

Figure 2. Gantt chart of the jobs in the environment of 'Lekin'

The schedule can be examined in the 'Sequence Window', where several relevant data of the schedule are shown. Once one or more schedules are generated their performance are specified including the scheduling criteria and the running time to obtain different sequences.

2.2 Production planning and scheduling using 'Spreadsheets'

Scheduling production order using spreadsheets can be done by using the software product 'Excel' or similar. Spreadsheets have earned themselves a bad reputation amongst software purists, because they can, and often are, used in an unstructured way. Building a scheduling system requires a structured and disciplined approach. The approach used here is to create lists in the form of databases, with a heading at the top of each column, and with universal formulas that can be copied and pasted down a column, and work on every row. If all the calculations are done in a structured database, then reports, with sub-totals and charts, can easily be created with a 'PivotTable' [Rice 2014].

The beginning of the developing the spreadsheets should start, with creating the columns for the workcenters or machines and the jobs that are going to be done in every center. Knowing the time set for the jobs to be done and using 'Excel' a true and false column is created, showing which job will be done on time and which will not. The final date added to the spreadsheets is shown in 'tab. 1'.

Work Centers	Jobs	Hours	Start	Stop	Quantity	Due	On Time
Cutter 1	Cutting A	8	0	8	5000	120	TRUE
Cutter 1	Cutting B	8	0	8	5000	120	TRUE
Cutter 1	Cutting C	8	0	8	5000	120	TRUE
Processing 1	Processing A	8	8	16	5000	120	TRUE
Processing 1	Processing B	8	8	16	5000	120	TRUE
Processing 1	Processing C	8	8	16	5000	120	TRUE
Inspection 1	Inspection A	9	16	25	5000	120	TRUE
	Inspection B	9	25	34	5000	120	TRUE
	Inspection C	9	34	43	5000	120	TRUE
Assembly	Assembly AX	34	25	59	2500	120	TRUE
	Assembly BX	34	59	93	2500	120	TRUE
	Assembly CX	23	93	116	1692	120	TRUE
Inspection 2	Inspection AX	9	59	68	2500	120	TRUE
	Inspection BX	9	93	102	2500	120	TRUE
	Inspection CX	9	116	125	1692	120	FALSE
Packing	Packing AX100	2	68	70	100	120	TRUE
	Packing AX200	4	70	74	200	120	TRUE
	Packing BX100	2	102	104	100	120	TRUE
	Packing BX200	4	104	108	200	120	TRUE
	Packing CX100	2	125	127	100	120	FALSE
	Packing CX200	4	127	131	200	120	FALSE

Table 1. Applied date for simulating the production model using spreadsheets

After calculating which job will be done on time, it is necessary to generate a Gantt chart in order to visualize the result. "Excel" spreadsheets can be used to generate such chart. Part of the generated Gantt chart is show in 'fig.3'.
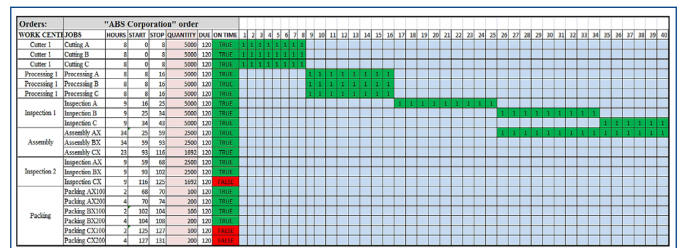

Figure 3. Generating a Gantt chart using "Excel" spreadsheets

Every square is equal to one hour. The jobs that are going to be late are presented in different color. After visualizing the result, the manufacturer can easily decide what changes needs to be made.

2.3 Production planning and scheduling using 'Asprova'

At the beginning of planning and scheduling the production with 'Asprova®' (Asprova Corporation) the manufacturer have to pick a type of production module. The software product' Asprova' is divided into different modules. The objectives vary by each module. The module that is going to be used to schedule the production is 'Advance Planning and Scheduling (APS)'. Data that Asprova requires for scheduling can be input directly, imported from an external system or text files, or copied and pasted from 'Microsoft Excel'.

The 'Integrated Master Editor' is a table for maintaining master data. It is especially convenient for creating and editing master data because it combines master settings and related information in a single table. The 'Asprova APS' master data is created using the 'Integrated Master Editor'. Basically inputting data into the 'Integrate Master' is like inputting data into the 'Excel' spreadsheets (fig.4).

Asprova has the possibility to create and maintain production orders. The full list of the orders is shown in 'fig.4'

In the "Order" table manufacturer adds settings about every information regarding the production of the items, such are sales or resource purchases, due dates, quantites, ect. Using the order table provided in 'Asprova', scheduling and managing of the productions is a lot more easy and clear.

	Order code	Order type	Order class	Item	EST	Due date	Order quanti	Priority	Customer	Display color
1	⊞ Sale AX	Sales ord	Regist	AX		016/06/12 12:00:00	100	80		1
2	⊞ Sale AX100	Sales ord	Regist	AX100		016/06/12 12:00:00	5	80		1
3	⊞ Sale AX200	Sales ord	Regist	AX200		016/06/12 12:00:00	5	80		1
4	⊞ Sale BX	Sales ord	Regist	BX		016/06/21 12:00:00	100	80		1
5	⊞ Sale BX100	Sales ord	Regist	BX100		016/06/21 12:00:00	5	80		1
6	⊞ Sale BX200	Sales ord	Regist	BX200		016/06/21 12:00:00	5	80		1
7	⊞ Sale CX	Sales ord	Regist	CX		016/06/18 12:00:00	100	80		1
8	⊞ Sale CX100	Sales ord	Regist	CX100		016/06/18 12:00:00	5	80		1
9	⊞ Sale CX200	Sales ord	Regist	CX200		016/06/18 12:00:00	5	80		1
10	⊞ AX	Manufact	Reple	AX		016/06/12 12:00:00	100			2
11	⊞ AX	Manufact	Reple	AX		016/06/12 12:00:00	500			2
12	⊞ AX	Manufact	Reple	AX		016/06/12 12:00:00	1000			2
13	⊞ AX100	Manufact	Reple	AX100		016/06/12 12:00:00	5			2
14	⊞ AX200	Manufact	Reple	AX200		016/06/12 12:00:00	5			2
15	⊞ BX	Manufact	Reple	BX		016/06/21 12:00:00	100			2
16	⊞ BX	Manufact	Reple	BX		016/06/21 12:00:00	500			2
17	⊞ BX	Manufact	Reple	BX		016/06/21 12:00:00	1000			2
18	⊞ BX100	Manufact	Reple	BX100		016/06/21 12:00:00	5			2
19	⊞ BX200	Manufact	Reple	BX200		016/06/21 12:00:00	5			2
20	⊞ CX	Manufact	Reple	CX		016/06/18 12:00:00	100			2
21	⊞ CX	Manufact	Reple	CX		016/06/18 12:00:00	500			2
22	⊞ CX	Manufact	Reple	CX		016/06/18 12:00:00	1000			2
23	⊞ CX100	Manufact	Reple	CX100		016/06/18 12:00:00	5			2
24	⊞ CX200	Manufact	Reple	CX200		016/06/18 12:00:00	5			2
25	⊞ Shaft-A	Manufact	Reple	Shaft-A			1600			2
26	⊞ Shaft-B	Manufact	Reple	Shaft-B			1600			2
27	⊞ Shaft-C	Manufact	Reple	Shaft-C			1600			2
28	⊞ Gear-X	Purchase	Reple	Gear-X			300	80		3
29	⊞ Gear-X	Purchase	Reple	Gear-X			1500	80		3
30	⊞ Gear-X	Purchase	Reple	Gear-X			1500	80		3
31	⊞ Gear-X	Purchase	Reple	Gear-X			1500	80		3
32	⊞ Steel-M1	Purchase	Reple	Steel-M			38	80		3
33	⊞ M1-Inventor	Inventory	Regist	Steel-M		016/06/03 00:00:00	10	80		5

Figure 4. Order table

After all the needed data is entered the finale result can be displayed in different Gantt charts. On 'fig.5' is presented the 'Resource Gantt Chart' showing all the needed information about the flow of loads and which load is not going to be done on time.
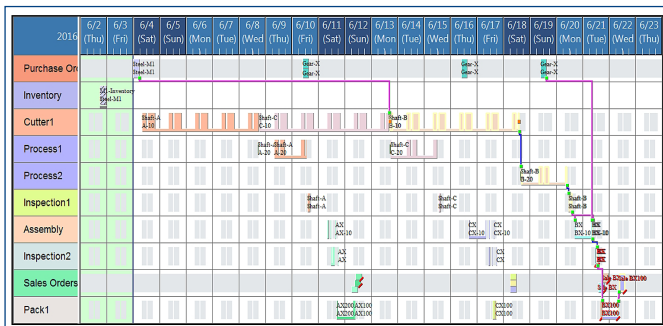

Figure 5. 'Resource Gantt Chart' of the production mode

The software product Asprova also provides other features, like generating inventory chart that can help with the maintaining the items in inventories. Asprova is a powerful product, which helps to control the processes in factories or companies.

3. ANALYZING OUTPUTS FROM THE ASPROVA SIMULATION MODEL OF PRODUCTION SYSTEM

After setting which of the items is going to be for sale, in the 'Order table' of the program, Asprova automatically generates manufacturing and purchasing orders. Asprova assigns end times for the manufacturing orders also. The program generates an assignment list for the orders. On 'fig.6' is shown the full list of the orders of the simulation model. In such way the manufacturer can check the starting time and the finishing time for every order. On the assignment list is also shown the time needed, with these manufacturing settings, for every order to be done. As shown on the figure, the longest job is for manufacturing 'Shaft-B' and it requires 6 days 22 hours and 20 minutes. The last order, that is going to be executed, is for the order „Sale BX1" and it is going to be done on 2016/06/22 at 15:05:00 o'clock.

	Order code	Lead time	Start time	End time	Total calculated EST	Total calculated LET	Assignment flag
1	⊞ Sale AX	6H	016/06/12 06:00:00	016/06/12 12:00:00	016/06/11 18:00:00	016/06/12 12:00:00	Assigned
2	⊞ Sale AX1	6H	016/06/12 10:05:00	016/06/12 16:05:00	016/06/12 10:05:00	016/06/12 12:00:00	Assigned
3	⊞ Sale AX2	6H	016/06/12 08:50:00	016/06/12 14:50:00	016/06/12 08:50:00	016/06/12 12:00:00	Assigned
4	⊞ Sale BX	6H	016/06/21 14:20:00	016/06/21 20:20:00	016/06/21 14:20:00	016/06/21 12:00:00	Assigned
5	⊞ Sale BX1	6H	016/06/22 09:05:00	016/06/22 15:05:00	016/06/22 09:05:00	016/06/21 12:00:00	Assigned
6	⊞ Sale BX2	6H	016/06/21 17:50:00	016/06/21 23:50:00	016/06/21 17:50:00	016/06/21 12:00:00	Assigned
7	⊞ Sale CX	6H	016/06/18 06:00:00	016/06/18 12:00:00	016/06/17 18:00:00	016/06/18 12:00:00	Assigned
8	⊞ Sale CX1	6H	016/06/18 06:00:00	016/06/18 12:00:00	016/06/17 18:00:00	016/06/18 12:00:00	Assigned
9	⊞ Sale CX2	6H	016/06/18 06:00:00	016/06/18 12:00:00	016/06/17 16:45:00	016/06/18 12:00:00	Assigned
10	⊞ AX	2H20M	016/06/11 15:40:00	016/06/11 18:00:00	016/06/10 19:00:00	016/06/12 06:00:00	Assigned
11	⊞ AX	4H5M	016/06/11 11:05:00	016/06/11 15:10:00	016/06/10 19:00:00	016/06/12 06:50:00	Assigned
12	⊞ AX	6H20M	016/06/11 08:00:00	016/06/11 14:20:00	016/06/10 19:00:00	016/06/11 14:20:00	Assigned
13	⊞ AX100	1H15M	016/06/12 08:50:00	016/06/12 10:05:00	016/06/11 17:10:00	016/06/12 10:05:00	Assigned
14	⊞ AX200	16H30M	016/06/11 16:20:00	016/06/12 08:50:00	016/06/11 16:20:00	016/06/12 08:50:00	Assigned
15	⊞ BX	4H50M	016/06/21 09:30:00	016/06/21 14:20:00	016/06/20 17:00:00	016/06/21 12:00:00	Assigned
16	⊞ BX	5H30M	016/06/21 08:40:00	016/06/21 14:10:00	016/06/20 17:00:00	016/06/21 12:00:00	Assigned
17	⊞ BX	20H20M	016/06/20 17:00:00	016/06/21 13:20:00	016/06/20 17:00:00	016/06/21 12:00:00	Assigned
18	⊞ BX100	15H15M	016/06/21 17:50:00	016/06/22 09:05:00	016/06/21 16:10:00	016/06/21 12:00:00	Assigned
19	⊞ BX200	2H30M	016/06/21 15:20:00	016/06/21 17:50:00	016/06/21 15:20:00	016/06/21 12:00:00	Assigned
20	⊞ CX	2H20M	016/06/17 15:40:00	016/06/17 18:00:00	016/06/16 16:40:00	016/06/18 06:00:00	Assigned
21	⊞ CX	3H40M	016/06/17 11:05:00	016/06/17 14:45:00	016/06/16 16:40:00	016/06/17 14:45:00	Assigned
22	⊞ CX	19H20M	016/06/16 16:40:00	016/06/17 12:00:00	016/06/16 16:40:00	016/06/17 12:15:00	Assigned
23	⊞ CX100	1H15M	016/06/17 16:45:00	016/06/17 18:00:00	016/06/17 16:45:00	016/06/18 06:00:00	Assigned
24	⊞ CX200	2H30M	016/06/17 14:15:00	016/06/17 16:45:00	016/06/17 14:00:00	016/06/18 06:00:00	Assigned
25	⊞ Shaft-A	6D9H	016/06/04 08:00:00	016/06/10 17:00:00	016/06/04 06:00:00	016/06/11 06:00:00	Assigned
26	⊞ Shaft-B	6D22H20M	016/06/13 16:40:00	016/06/20 15:00:00	016/06/04 06:00:00	016/06/20 15:00:00	Assigned
27	⊞ Shaft-C	6D21H20M	016/06/08 18:20:00	016/06/15 15:40:00	016/06/04 06:00:00	016/06/16 14:40:00	Assigned
28	⊞ Gear-X	6H	016/06/10 09:40:00	016/06/10 15:40:00	016/06/04 00:00:00	016/06/11 07:00:00	Assigned
29	⊞ Gear-X	6H	016/06/10 09:40:00	016/06/10 15:40:00	016/06/04 00:00:00	016/06/11 07:00:00	Assigned
30	⊞ Gear-X	6H	016/06/09 09:40:00	016/06/15 15:40:00	016/06/04 00:00:00	016/06/16 15:40:00	Assigned
31	⊞ Gear-X	6H	016/06/19 09:40:00	016/06/19 15:40:00	016/06/04 00:00:00	016/06/20 16:00:00	Assigned
32	⊞ Steel-M1	6H	016/06/04 00:00:00	016/06/04 06:00:00	016/06/04 00:00:00	016/06/04 08:00:00	Assigned
33	⊞ M1-Inve	0S	016/06/03 00:00:00	016/06/03 00:00:00		016/06/03 00:00:00	Assigned

Figure 6. The assignment list with the time needed for the orders to be done

Either the engineer or the manufacturer, using Asprova, is able to monitor the status, of every order, at any given time. Using the generated Gantt chart (fig.5), production managers receive visualized manufacturing model. That way, the final results are easily understood. The final result for selling the items of 'AX' series is shown in 'fig.7'. As shown on the figure the orders that are not going to be done on the time are shown with color red. In this case the selling of items 'AX100' and 'AX200' is going to be delayed. The result does not satisfy the demand.
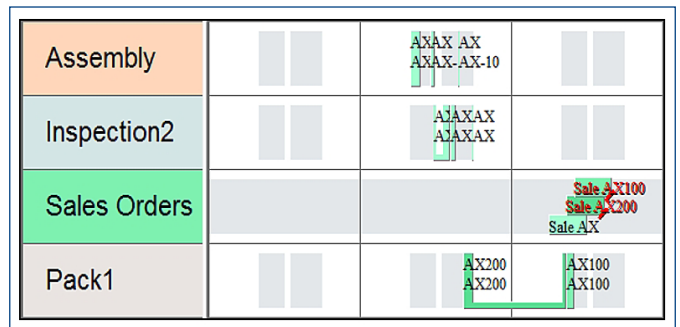

Figure 7. Gantt chart for selling the constructions with Shaft-A

The final result for selling the items of 'CX' series is shown in 'fig.8'. In this case the orders are going to be done on time. The result shows that the production schedule satisfies the demand.
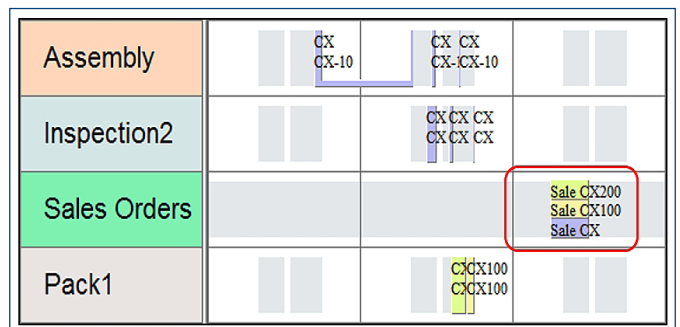

Figure 8. Gantt chart for selling the constructions with Shaft-C

The final result for selling the items of 'BX' series is shown in "fig. 9". In this case the orders are also going to be delayed. The result does not satisfy the demand. On the figure is also shown, that in certain time, the whole production starts to delay. Thanks to the visual result, provided from 'Asprova', manufacturer can trace back along the production line to see in which moment the production is slowed, and to take measure. The graph shows that the production starts to delay at the moment of the inspection of the assembled 'BX' items (fig. 9).
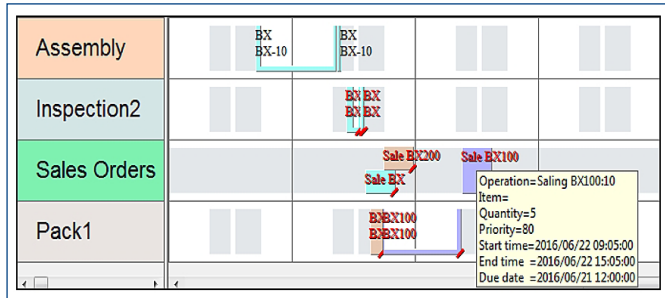
Figure 9. Gantt chart for selling the constructions with Shaft-B

4. USING 'ASPROVA' FOR OPTIMIZING THE PRODUCTION SCHEDULES

The final results that the simulation from 'Asprova' shows is not always the optimum, since some orders are not going to be done on time. That is why it is necessary, after the final model of the production is ready, to perform additional optimization for finding the best possible solution.

The optimization of the production model is based on 'Local Search' algorithms. The objective of the optimization is to fit the requested due dates for every one order. The function that is going to be used, from the 'Asprova' program, is operation split size (fig.10). What the function does is a splitting the operation, if the operation quantity is larger than a specific value. Like 'Local Search' algorithms, a number of tests will be done, until the wanted result is achieved. The new data is added into the operation split size column of the 'Item table' [fig.10].

Figure 10. Using operation split size function in 'Asprova'

The parameters "Operation split size MAX" shown on 'fig.10' presents the final quantity that is going to be used for optimizing the production model. This quantity is achieved after several numbers of simulations runs using different input data. The function was applied for larger processes (manufacturing Shaft-A, B and C). Optimized Gantt chart is shown on 'fig.11'.
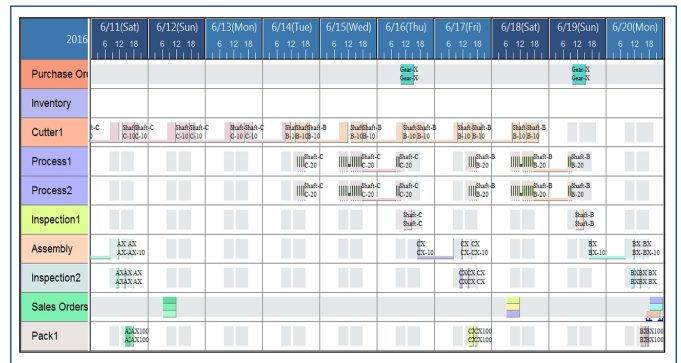

Figure 11. Resource Gantt chart after optimization

Applying the 'Local Search' algorithm method and using the "Asprova" function "Operation split size", led to optimizing the production model and setting every order to be done on time. The end date for the last order (BX100) is until 2016/06/21 00:00 o'clock (fig.12). Thanks to this optimization the production schedule fit perfectly to the due date plan. The schedules are generated for every workcenter or process, according to the manufacturing plan, for the whole production period.
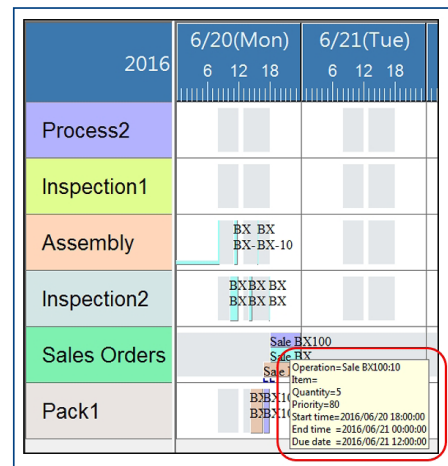

Figure 12. End time of the final order in the simulation model of production

5. CONCLUSION

On the market there are a lot of different software products that can be used for planning and scheduling purpose. Such products are:
- EnterpriseIQ Scheduling;
- Synchro PRO;
- Resourse Manager DB;
- SMARTer Manager;
- Orchestrate Scheduling;
- Planvisage SCM;

But those 3 APS systems mentioned in the paper have been studied because of their relative good availability.

Presented modern management methods for planning and scheduling of production processes are reliable, easy and allow quickly dealing with certain problems. Scheduling of the company's orders is displayed in three different software products. Through the visual presentation of the results, it was found that production will not be executed on time and where in fact began the delaying of the production process.

Using the software "Asprova" and its built-in features, optimization is performed on the results. The optimization led to rapid resolution of the problem of the late work. Generation of production plans allows the manufacturing processes to start immediately.

Positive and negative features of the consider systems can be briefly summarized:

- Excel – cheap way to manage a production but hard to use and needs knowledge about the formulas;
- Lekin – easy to use but useful only for one order and has a lack of optimization algorithms;
- Asprova – a lot of good functions but expensive product. The product has the possibility to generate different optimization variations.

The use of "Advanced planning and scheduling (APS)" management systems and proper selection of software, significantly reducing the time required for production planning and scheduling, and enables the prediction of potential production problems and their quickly solving.

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