



## METHODS AND TOOLS FOR DYNAMIC CAPACITY PLANNING AND CONTROL

Invited Paper

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### *Abstract*

*This article discusses material flow management. More specifically, it presents methods and tools used for capacity dynamic planning and control. Such resources are focused on the reduction or elimination of static and dynamic bottlenecks. Practical applications are made using the FAST/pro, a software which associates the concepts presented through a demand-orientated, capacity dynamic regulation.*

**Key words:** *capacity planning and control, bottlenecks reduction, input-output charts, material flow simulation.*

### **1. Introduction**

The market requirements of shorter delivery times in connection with increased schedule performance and the integration of businesses into multi-stage delivery chains demand a continuous improvement of production responsiveness.

In the past, delivery ability was balanced using inventories, especially by providing

certain stock or work in process (WIP) levels. Current conditions, such as increasing product variety, fluctuating market demand and the reduction of innovation cycles require a new perspective on the logistical interpretation of production systems, aiming at higher flexibility and responsiveness. These challenges demand new and enhanced features for systems for Production Planning and Control (PPC).

The current PPC methods and systems are mainly focused on order control with the main target of balancing loads and WIP (Nyhuis, 1989). If they have special features like APS (Advanced Planning and Scheduling), they concentrate on shifting load to the future when there is not enough capacity available. Normally, these systems only consider a limited part of the required resources for the whole order processing. Therefore, the planning results will be hardly reached. When looking at Production Planning and Control assignments from a market/logistic-oriented view, the task that primarily emerges is the dynamic coordination of the available capacity/resources with the capacity/resources requirements (Wiendahl, 1987). After reaching the ideal condition with a complete adaptation of the capacity offer to the dynamic capacity demand, the tasks of the PPC systems are reduced to a simple order scheduling and to the logistical configuration and supervision (or monitoring) of material flow (Nyhuis, 1995).

## 2. Some considerations about material flow management

According to Goldratt & Cox (1990) bottleneck is every resource of which capacity is lower than the demand placed on it. Bottlenecks are very common and can occur for controllable and uncontrollable reasons. Maintenance can reduce the capacity of one resource, changing it into a bottleneck. Lack of electricity can do the same. Several examples could be given, but the most important is to highlight that bottlenecks can generate backlogs and extended lead times. To avoid these kind of situations, material flow management is very important and normally used.

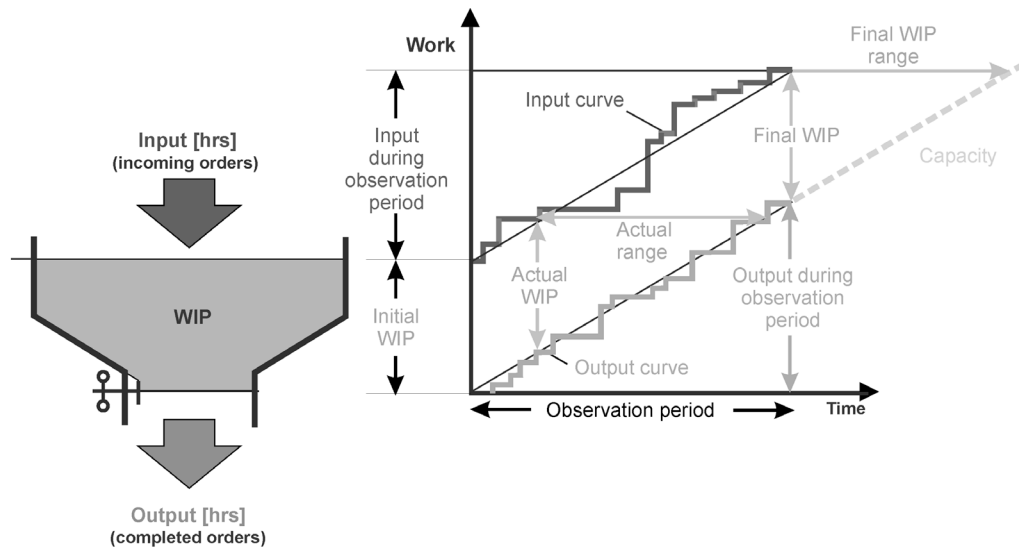
The Theory of Constraints (TOC) is largely adopted, normally with the five-step process or with the rope-drum-buffer technique (Narasimhan *et al.*, 1995). With this approach, one question is why some researches consider TOC being used separately from other PPC philosophies, as JIT, for example (Hurley & Whybark, 1999). Other point is that dynamic capacity planning is one kind of material flow management with growing academic

interest. However, publications concerning this topic are yet scarce and normally characterized by a theoretical focus and/or by an emphasis on a particular type of production system (Kingsman, 2000). Methods and tools for dynamic capacity planning and control are discussed on this paper. They are features of FAST/pro, a software which has TOC as background, but in a way that it can be used with other PPC concepts as KANBAN (Bakke & Nyhuis, 1992) or MRP (Nyhuis, 2000). It was also developed for different production systems (from make-to-order manufacturing to mass production) and it fits in properly with a large variety of industrial activities. The following use of the software is also an attempt to bring a practical view of material flow management through dynamic capacity planning and control.

## 3. Using the input-output chart technique to analyze and schedule production order flow

The funnel model and the input-output chart are tools used to visualize process parameters of order flow at work centers (Wiendahl & Nyhuis, 1984). The funnel model shows the current order processing situation at a reference date or as average values for a defined time span (Figure 1, left side). The funnel filling represents the WIP in front of the machine (this value is usually calculated in standard hours). The funnel output is calculated in standard hours per time unit (day or week, for example). The input parameters are also calculated in standard hours per time unit which, in this case, means the standard hours which have to be processed. The quotient WIP/output describes the queue length in front of the work center (WIP range).

While the funnel model shows process parameters at a certain time or for a time span, the input-output chart is an ideal tool for visualizing dynamic processes at work centers, especially WIP, utilization, lead time and due date deviation. Figure 1 indicates how to derive the input-output chart from the funnel model. Starting with the actual WIP at the work center, the input and output slopes are plotted as accumulated curves.



**Figure 1 – The funnel model and the input-output chart.**

Every step on the output curve represents a ready message of the work center. The step height shows the amount of standard hours used for the recorded operation. Work centers consisting of several sub work centers may generate more than one ready message at the same time. In this case, a step on the output curve represents several single ready messages of different operations at this work system. On the input curve, each step indicates an operation finishing date at a predecessor work center or the material release for the first operation of an order. A step on the input curve represents the work content which has to be processed at the analyzed work center.

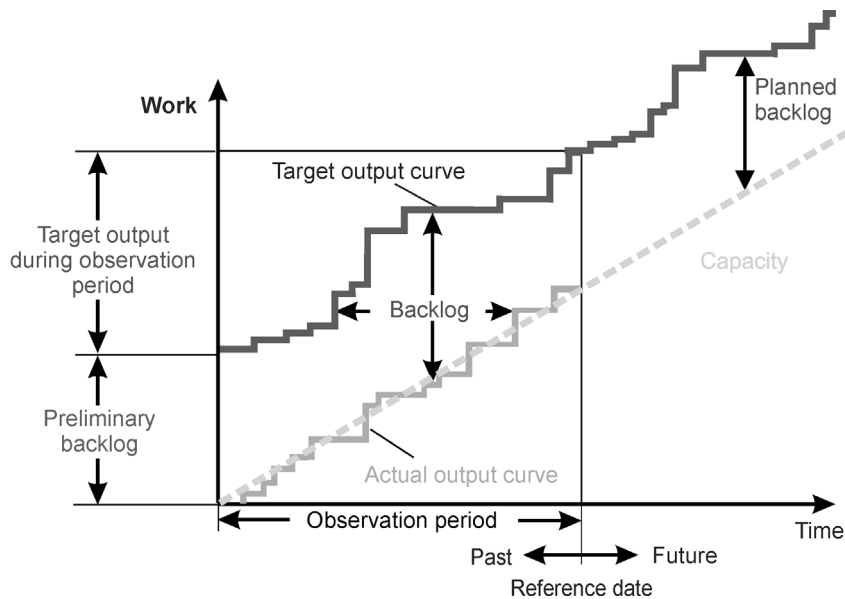
The WIP at a work center is equal to the vertical distance between the input and output curves at any given time. In Figure 1, the observed work center has enough WIP so there is no idle time caused by missing materials. Since there is no capacity loss, the output curve can be defined as the work center capacity and can be used as the potential capacity for future planning. These values will be correct if no influencing parameters at the work center are changed, such as the number of workers, their working hours, the technology used and order queuing.

The average work center lead time or throughput time (or the average WIP range) is

equal to the horizontal distance between the average input and output slopes. Order sequencing changes at the work center may result in different lead time values than those defined by the individual finishing and starting dates of an order. The deviations can vary depending on the observed time span length and on WIP peculiarities.

Besides the analysis of actual throughput process parameters, the input-output chart gives an overview of the work center due date situation. Figure 2 shows, in addition to the actual output curve, the target output curve, which is given as a result of backward scheduling of orders and operations.

The target output curve lies above the actual output curve and it is nearly parallel to the capacity curve. This location above the actual output curve shows that there is a backlog situation. The vertical distance between target and actual output curves is equal to the backlog, calculated in standard hours. The horizontal distance represents the backlog range (calculated in days). This value can also be reached by dividing the vertical distance by the work center capacity. The backlog range shows how many days the work center has to process delayed orders to reduce the backlog to zero, with the current capacity and without receiving any new WIP.



**Figure 2 – Representation of the due date situation in the input-output chart.**

Since the target and the actual output curves are nearly parallel, it can be concluded that the backlog will not be reduced for the adopted parameter values. If we want to reduce the backlog, we have to increase the capacity or reduce the work center load. The best choice of measures to be taken depends on the current situation of the company. The input-output chart can only highlight that something has to be done if backlog elimination is desired.

#### **4. Scheduling and planning methods to calculate needed capacity**

It is not possible to calculate the needed capacity of a work center using the input-output chart when there is a predecessor work center with a backlog situation, as shown in Figure 2. In this case, the input at the analyzed work center will not occur at the times which are calculated by traditional backward or forward scheduling methods. It is necessary to evaluate the future input using dynamic material flow simulation, which considers different priorities for the orders

that have to be scheduled. Before describing how to perform dynamic material flow simulations, the traditional methods of order throughput scheduling will be explained (see Figure 3).

#### **4.1 Traditional scheduling methods**

All of these methods differ with regard to process time, (which is the sum of set-up and operation times), transit time and minimum transit time.

##### **Backward scheduling**

Backward scheduling is focused on the target end of the order. Beginning from this target end, the starting date of each single operation is calculated. The final result is the target starting date of the first operation which is the target starting date of the total order.

##### **Forward scheduling**

Forward scheduling does exactly the opposite. It begins at the target starting date of the first operation and then calculates the finishing dates of different operations. The final result is the target finishing date of the last operation, which is the target end of the total order.

### Transit time reduction

Transit time reduction is used when the starting date of an order (obtained with backward scheduling) is actually in the past and when the target finishing date should not be shifted to the future. With the traditional transit time reduction, there is the same percentage of reduction for all operations of an order.

### Load scheduling

Load scheduling is a special type of transit time reduction developed by GTT. In this case, reductions are not made in the same percentage for every operation. Starting with the first operation, the transit times are reduced to the minimum, which is done until the first target finishing date of an operation is reached. The transit time for this operation is reduced to a value between the minimum and the target transit time. The following operations do not have reduced transit times. When comparing these different types of scheduling, we find that the traditional backward scheduling cannot be used to support capacity planning when there are operations which are already backlog operations. On the other hand, with a customer oriented production

it is not possible to plan the capacity with forward scheduling because the customer wants to have the products at specific due dates.

Transit time reduction and load scheduling will deliver realistic capacity loads and needed capacity when there are no bottlenecks in the material flow. Load scheduling has the advantage that it tries to reduce the backlog as soon as possible, adapting the planned throughput time to the minimum transit times.

The example in Figure 3 shows that operation C is scheduled to the same time by backward and load scheduling while it is postponed by transit time reduction. Load scheduling supports an order flow which is close to the FIFO principle (First In First Out).

## 4.2 Using material flow simulation (MFS) as a tool for dynamic capacity planning

Simulation of the material flow (MFS) is a feature used within the FAST/pro software as a tool for final capacity scheduling. MFS considers available resources like materials, machines and labor.

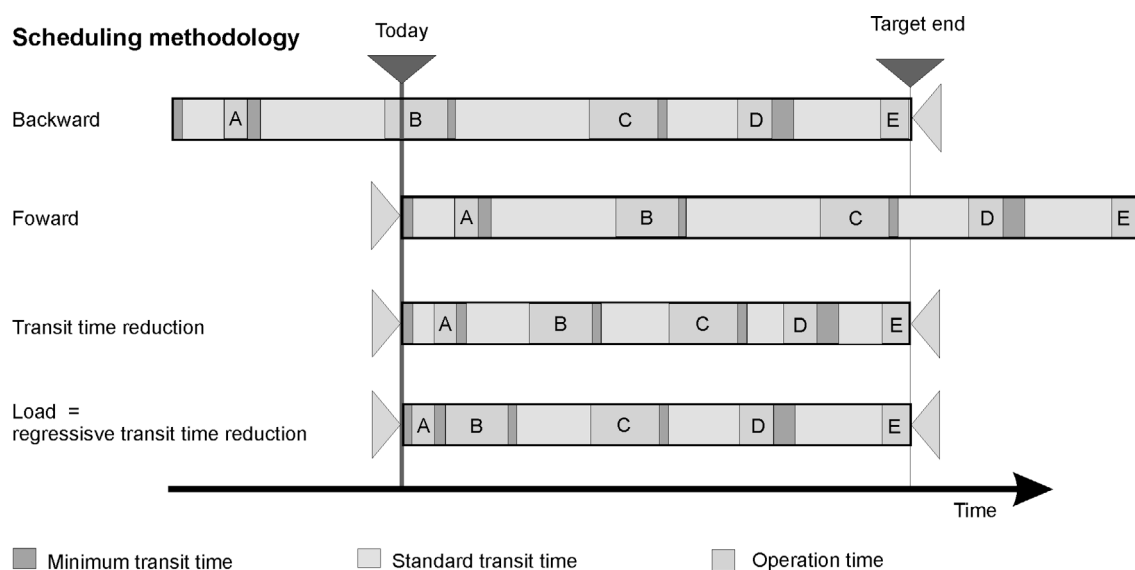


Figure 3 – Traditional scheduling methods for determining the needed capacity.

The scheduling sequence during MFS is done according to the urgency of orders, which is calculated automatically before the scheduling starts. The order urgency is obtained by dividing the remaining transit time by the number of unfinished operations. The user may also define individual priorities for the orders which override other sorting criteria.

During the scheduling of orders and operations, MFS checks if the different operations could be finished under a given capacity situation at the work center. This inspection considers the arrival date of the order, the amount of standard hours which have to be processed at the work center, the work center dynamic capacity and operations which must be processed earlier because the orders are more urgent. If MFS leads to an estimated order finishing date which is later than the target date, the software evaluates whether it could be better to start the order earlier than the target starting date to try to reduce due date deviation.

On the other hand, when the simulation indicates a planned transit or queuing time in front of a bottleneck machine that is longer than the target transit time, the software checks whether it is possible to start the order later without missing the planned finishing date at the bottleneck work center. In this case, it's better to start the order later, because there might be other more urgent orders that could be processed at the work center which are freed from those operations of the postponed order. This method is called load oriented order control.

The results of MFS are realistic finishing dates of orders and individual operations. MFS provides transparent information about bottlenecks and idle time situations due to missing orders in front of the machines. Based on MFS, various key data (which will be explained later) are produced, to evaluate static and dynamic bottlenecks of work centers. These key data enable us to obtain the dynamic capacity which is needed to fulfill the total of orders in the best way.

## 5. Practical procedures for dynamic capacity planning within the FAST/pro software

Dynamic capacity planning is done according to the following sequence:

- definition and configuration of capacity data;
- lead time order scheduling;
- evaluation of static bottlenecks;
- material flow simulation;
- evaluation of dynamic capacity needs and bottlenecks.

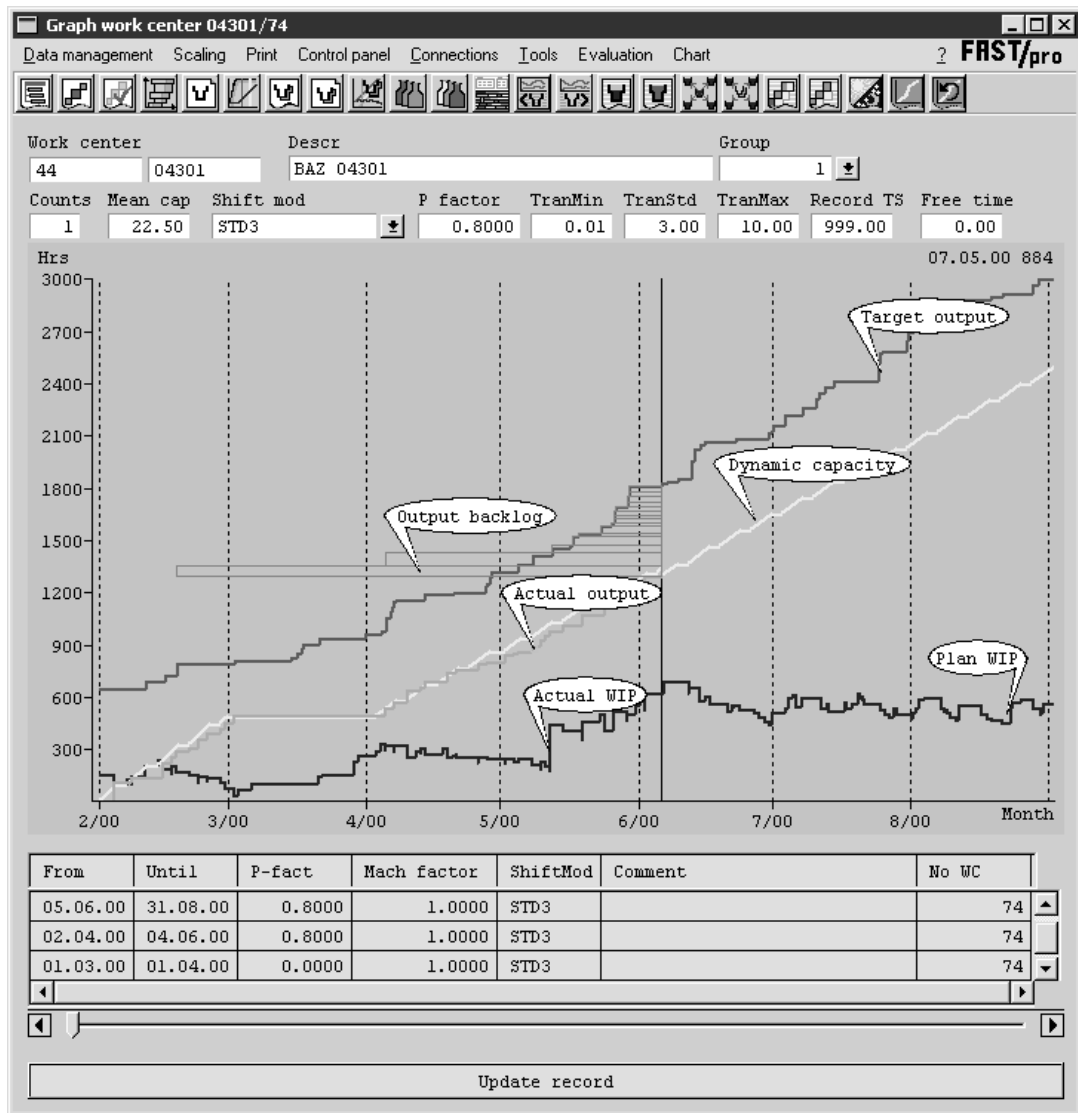
These different steps are explained using some practical data which were extracted from a FAST/pro testing database.

### 5.1 Definition and configuration of capacity data

Using an input-output chart of a bottleneck work center, some features of FAST/pro will be explained. The example in Figure 4 shows a work center processing complex parts, in a traditional production line and on a three shift model.

The input-output chart shows WIP, actual output, needed capacity (target output) and dynamic capacity, calculated in standard hours. The output curves and the capacity are shown as accumulated slopes to highlight the dynamic development of values and deviations when comparing different parameters. The actual output curve on the graph shows a nearly constant output during February, April and May while there was no activity in March. This missing output was caused by machine repair works. The total output during the February-May period (of about 1300 standard hours) allows us to conclude that the work center has been processing on a three shift model with about 22 standard hours per day.

The needed capacity is nearly parallel to the actual output curve. The backlog of today (June 5, 2000), with the height of 600 standard hours has been caused by the output loss observed in March.



**Figure 4 – View of the capacity data with help of the input-output chart.**

Each backlog element (red rectangle) shows the actual backlog of a different operation (length of the rectangle). The rectangle height represents the amount of standard hours of the backlog operation and the rectangle length indicates the operation delay. The longest backlog of an operation corresponds to a delay of more than 3 months.

The dynamic development of WIP shows that the work center is a bottleneck, because of increasing WIP range. At the beginning of April, WIP divided by average capacity is more than 10 days. The actual backlog is about 600 hours,

which represents a backlog range of more than 5 weeks.

The future backlog situation is given by the vertical distance between the dynamic capacity curve and the target output curve. The actual capacity curve is given by an output extrapolation calculated by the software. If it is not possible to increase the capacity (e.g. with special actions such as additional weekend shifts) and/or to transfer the actual work center load to other non-bottleneck work centers, the bottleneck will grow until the end of July based on the current situation.

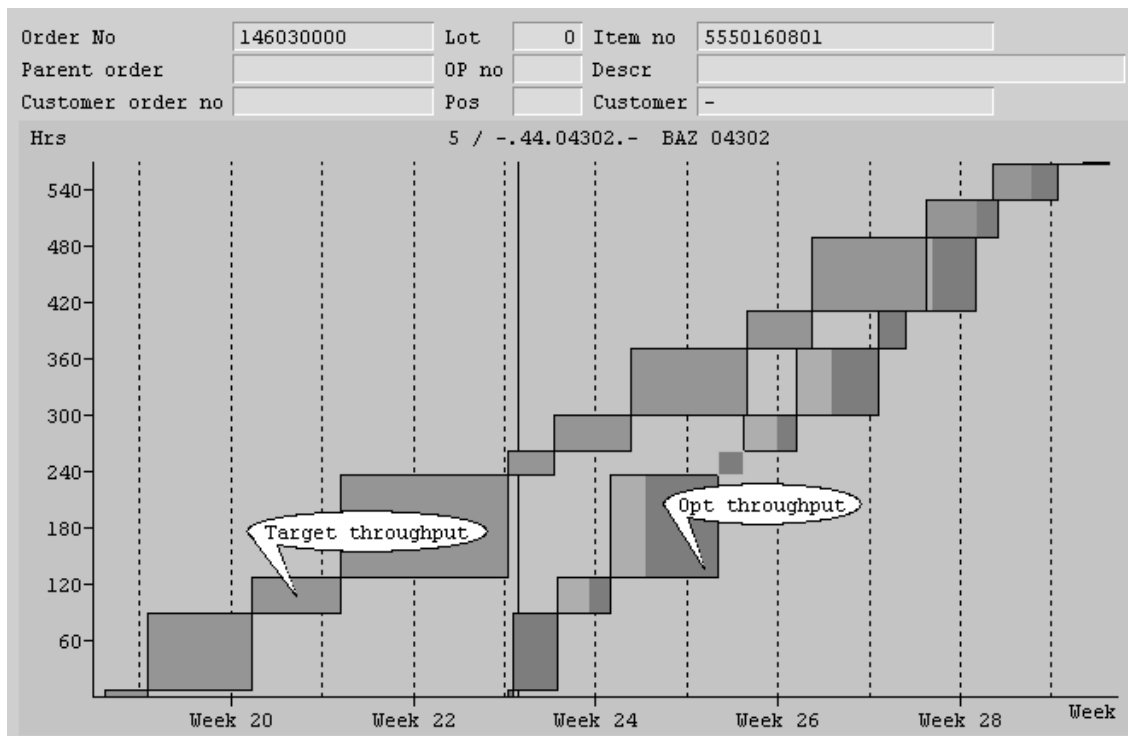
This example gives a first impression about different possibilities of using the input-output chart to manage work center capacity and to check whether the current load is leading to a bottleneck situation or not.

The actual output curve, which represents the ready messages of the past, and the shift models of the work center enable us to define the so called work center utilization or performance factor. The performance factor is the recorded output (in standard hours) divided by the amount of working hours. In the last example, the work center has a performance factor of 0.8 or 80%. In March, the factor was set to zero because of the machine repair. Looking at the last 8 weeks, the performance factor of 0.8 is representative because during that time there was enough WIP in front of the machine and the output was very constant. The future shift models multiplied by the performance factor will provide realistic capacity values which can be used to analyze work center capacity to evaluate bottleneck situations and to simulate the order flow.

### 5.2 Lead time order scheduling

Lead time order scheduling is done as backward scheduling to evaluate the current due date situation (target throughput), and also as load scheduling to calculate the optimum order flow and capacity needs.

The example in Figure 5 shows order number 146030000 with the target starting date on week 18. The actual starting date is on week 23, which means a backlog of several weeks. The transit time reduction was done with load scheduling, and then the transit times of all operations were reduced to the minimum. The figure shows that the remaining orange transit time portions are the weekends when the work center isn't working. Although the order has a backlog of about 5 weeks, it is basically possible to finish it on time, if the order gets the needed capacity at the appropriate time. This appropriate time is defined by the minimum transit times and the process times of the operations. So, in this case, the order is extremely urgent and it is not allowed any waiting time at different work centers.



**Figure 5 – Representation of the throughput scheduling results at the single order input-output chart.**



### 5.3 Evaluation of static bottlenecks (capacity analysis)

The comparison of capacities needed in the future with the current capacity for a predefined time span (40 workdays, for example), delivers a first impression regarding the work center bottleneck. Different types of key data are evaluated, which help us to analyze capacity and bottleneck situations in the production process.

#### Capacity rate

The work center is considered a static bottleneck when the needed capacity is higher than the actual capacity for a given time span. In this case, the capacity rate is more than 100%. The capacity rate is based on order due dates defined by backward scheduling.

#### Capacity rate without backlog

The capacity rate without backlog is represented by the vertical distance between the target output curve and the actual capacity curve. The current backlog of the work center is not considered in the calculation. When this capacity rate is higher than 100% and there is a backlog, it will increase. On the other hand, when there is no backlog at a certain moment and the capacity

rate is higher than 100%, it is possible to conclude that a backlog situation might occur in the future.

#### Utilization rate

The utilization rate compares planned output with actual capacity. When there is a bottleneck work center with a utilization rate lower than 100%, there is apparently a preceding bottleneck work center causing the problem of not getting enough load to the analyzed work center.

#### Load rate

The load rate shows whether there could be enough load at the work center if there were no bottlenecks at preceding work centers. To calculate the optimum work center load, minimum transit times, process times and material dates of the orders are considered. To evaluate the current capacity situation, a rating list of the work centers is done first according to their bottleneck situation (see Figure 6). This list shows the needed capacity and the capacity utilization for the next 40 workdays. Two of the work centers with a load rate higher than 130% (work centers 04301 and 04303) are real bottleneck work centers because they are already working on a 3 shift model and even if they work additional shifts during weekends they couldn't resolve the bottleneck situation.

Work center	Descr	Per start	Capacity [Hrs]	No WC	Std Shift-Mod	Capacity rate [%]	Capacity share	Utilization rate [%]	Utilization share	Load rate [%]
04301	BAZ 04301	05.06.00	752	1	STD3	172.71		99.19		203.89
04302	BAZ 04302	05.06.00	563	1	STD1+4	171.36		78.55		186.61
04303	BAZ 04303	05.06.00	940	1	STD3	132.66		83.89		144.65
03364	Drehen 03364	05.06.00	640	1	STD2	120.34		82.97		120.34
04186	Bohren 04186	05.06.00	640	1	STD2	116.16		95.79		116.95
05365	BAZ 05365	05.06.00	2256	3	STD3	110.61		56.11		131.98
56471	Pressen	05.06.00	640	1	STD2	110.52		89.86		116.32
07193	Schleifen	05.06.00	368	1	STD1	106.23		98.59		118.76
00000	Kontrolle	05.06.00	3760	5	STD3	101.08		78.99		103.57
05101	Feinbohren	05.06.00	320	1	STD	95.40		81.41		114.52
50000	Pressen	05.06.00	320	1	STD	94.95		78.28		102.52
05000	BAZ	05.06.00	640	1	STD2	93.17		93.17		93.47
01243	Drehen 01243	05.06.00	736	1	STD2	89.54		70.99		92.00
05364	BAZ 05364	05.06.00	1880	2	STD3	87.16		84.14		93.16
05112	Feindrehen	05.06.00	576	1	STD2	86.98		75.42		89.04

Figure 6 – Determination of static bottlenecks using capacity key data.

On the other hand, for work center 04302 it should not be a problem to adapt the current capacity to the needed capacity because this work center works on a 1 shift+ model which means 1 shift with additional four hours per day.

When we look at the utilization rate of the work centers, we recognize that the work center 05365 is a bottleneck, with a capacity rate of more than 110%. It also has an idle risk because of a planned utilization rate lower than 60%. The conclusion is that this is a bottleneck work center located after one or more other bottleneck work centers, when we look at the order flow. This situation is also shown in the input-output chart (see Figure 7). Looking at the planning of this work center, it is possible to see that the dynamic capacity curve is located below the target output curve, indicating that this work center will be a bottleneck in the future.

On the other hand, the planned input curve is located below the capacity curve, which means that the utilization will be lower than the capacity. So, what we have to do is to analyze where the bottlenecks are which of them are

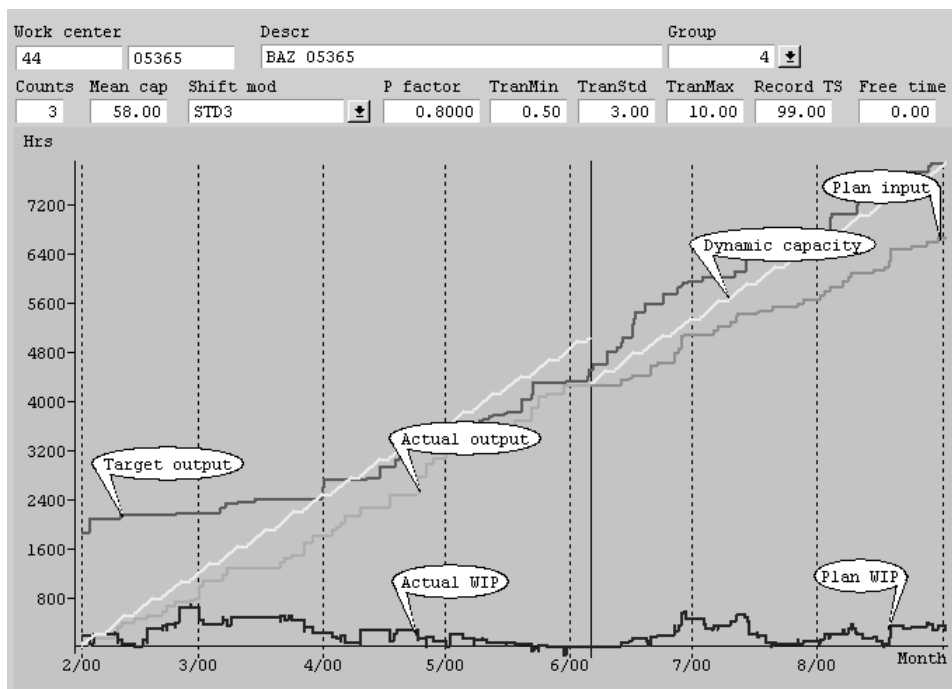
reducing the input flow of this work center. We also have to check whether the capacity can be adapted to increase the work center load.

One possible solution to this problem could be to find preceding bottleneck work centers which are responsible for the input backlog at 05365/80. Once they are found, we have to adapt their capacity to improve utilization at the analyzed work center.

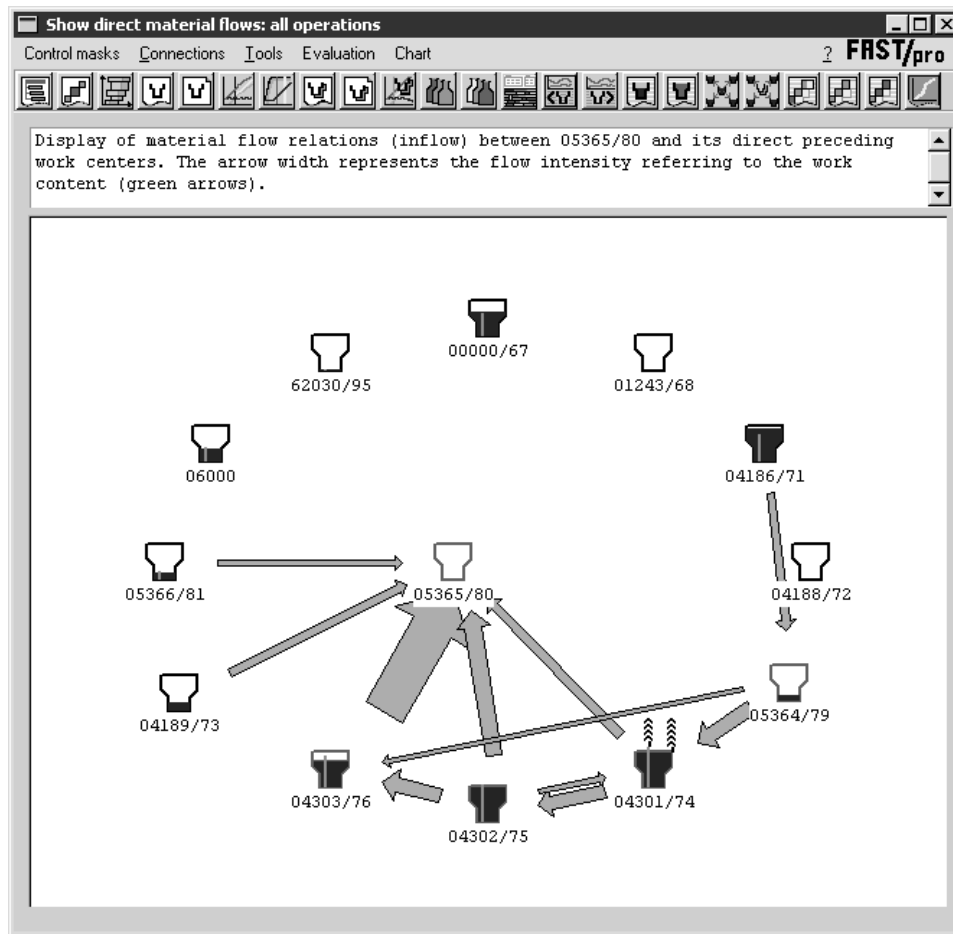
There are several tools to answer these questions. The use of each tool depends on the production structure of the company and on the current order situation.

### 5.3.1 Material flow analysis to evaluate bottleneck situations

Figure 8 shows material flow between work center 05365/80 and its direct predecessors, according to the planned orders. In this graph, work centers are shown as funnels. The arrow width equals the amount of standard hours which have to be processed. The output material flow from 05365/80 is not shown in the graph.



**Figure 7 – Representation of a bottleneck work center with idle risk because of preceding bottlenecks.**



**Figure 8 – Material flow to the work center with high risk of idle time.**

The actual WIP of a work center is shown as the blue funnel filling. The funnel height represents a pre-defined range. In Figure 8, this range is set to 5 days. The graph shows that 05365/80 gets load from several direct predecessor work centers. 04303/76 has a direct load of about 4 days and it is the work center which gives, in total, the highest load to our focused work center.

When we take a detailed look at 04303/76, we find that it is also located behind a bottleneck and that the throughput to 05365/80 will only be increased if the bottleneck of 04301/74 is reduced or eliminated.

Work center 04301/74 has a high overload, with five overload arrowheads (on the right side of the funnel). Each arrowhead corresponds to

one funnel filling. This means that the WIP range is more than 25 days. Because of high direct WIP and backlog at this work center, we can conclude that it is the actual bottleneck in the flow to our focus (05365/80).

### 5.3.2 Rating list of inflow bottlenecks

The rating list of inflow bottlenecks is another feature that can be used to find preceding bottleneck work centers. This rating list is based on material flow simulation and on the evaluation of differences between optimum and planned order output. For every work center we get a list which is sorted according to the number of days the orders are delayed at a preceding work center.

Preceding work center	Description	No of op scheduled	No of prec op	Throughput time dev scheduled [Days]	Target total throughput time [Days]	Relative throughput time deviation [%]	Order time scheduled [Hrs]	Quantity scheduled
04301	BAZ 04301	26	2.8	893.85	121	839.0	2008.51	3466
04302	BAZ 04302	32	2.4	273.40	99	376.8	2032.70	4775
05364	BAZ 05364	15	5.2	125.22	61	306.9	1081.34	1499
04303	BAZ 04303	11	3.8	54.03	36	250.0	1174.11	1409
56263	Pressen	15	9.9	50.86	18	379.4	918.74	1700
05365	BAZ 05365	7	2.4	42.11	38	209.5	323.17	911
01243	Drehen 01243	6	8.3	35.17	14	344.5	151.34	306
04186	Bohren 04186	7	27.7	24.99	13	295.8	183.23	633
03364	Drehen 03364	5	19.2	23.57	10	325.3	127.76	419
50000	Pressen	2	26.8	18.17	5	479.9	31.07	93
56471	Pressen	2	4.0	7.78	5	253.7	53.79	172
62026	Handarbeit	2	3.3	1.36	4	134.8	160.27	408
00000	Kontrolle	1	35.5	0.97	1	165.2	24.66	76
01451	Drehen 01451	2	15.0	0.54	5	110.0	49.32	202
06000	Fräsen	2	15.3	0.04	1	106.3	49.99	117

**Figure 9 – Inflow bottlenecks of work centers with idle time risk.**

The list includes the following key data:

**No of op scheduled**

Number of operations which have a backlog related to the analyzed work center.

**No of prec op**

Number of operations which have to be processed before the order arrives at the focused work center.

**Throughput time dev scheduled**

Deviation between target and planned throughput times. The planned throughput time is obtained by simulation.

**Target total throughput time**

Sum of target throughput times of operations which have a planned throughput time with deviation.

**Relative throughput time deviation**

Throughput time deviation related to the target.

**Order time scheduled**

Planned order time of operations which are delayed at a work center. This is the order quantity which has to be processed later at the analyzed work center.

**Quantity scheduled**

Number of parts which will be delayed in the flow.

With this list is possible to identify bottlenecks located far before the focused work center, even if there are very complex material flow structures.

### 5.4 Evaluating dynamic bottlenecks

Besides static bottlenecks, we can analyze dynamic bottlenecks using the simulation features of the software. Static bottlenecks are work centers where available capacity is lower than the needed capacity for a defined time span. Dynamic bottlenecks are work centers where the needed capacity is lower than the available capacity in total, but during a certain period there will be higher load than capacity. So there will be a queue of orders in front of the machine for a certain time.

In real industrial life, dynamic bottlenecks occur very often, because of dynamic fluctuations of the capacity needed and also because of insufficient capacity adaptation to the load. The dynamic bottleneck analysis uses the difference between planned and target throughput times. When the simulation results in a planned

throughput time which is longer than the target, we can conclude that there will be a queue in front of the machine. This means that there will be a bottleneck situation because the work center will not reach the target output. Evaluating the sum of throughput time deviations for all orders or for all operations of those orders which will be too late leads to a ranking list of bottlenecks.

The evaluation of dynamic bottlenecks (see Figure 10) shows that besides the static bottleneck of work center 04301 (shown in Figure 8) there is an inspection work center (00000) with 821 operations for 284 orders. The delay does not seem very large when calculating the average delay per operation (0.7 day), but the total delay of 578 days is a very large time span for the total order flow.

Using this method of finding and analyzing dynamic bottlenecks, we can evaluate the importance of a specific work center according to the total order throughput and we can determine which kind of capacity action should be chosen at the bottleneck work centers which are not traditional static bottleneck work centers.

Work center	Descr	No of production orders	No of operations	Throughput time dev abs [Days]	Throughput time dev abs	Total throughput time [Days]	Throughput time share [%]	Throughput time share	Target total throughput time [Days]	Target throughput share [%]	Target throughput share
04301	BAZ 04301	50	56	1475		1688	27.4		299	3.4	
00000	Kontrolle	284	821	578		788	12.8		880	10.0	
04302	BAZ 04302	59	72	426		545	8.8		227	2.6	
05112	Feindreihen	124	129	342		484	7.9		324	3.7	
05000	BAZ	32	50	201		237	3.9		134	1.5	
07193	Schleifen	64	70	189		264	4.3		254	2.9	
01451	Drehen 01451	21	29	140		194	3.2		98	1.1	
04186	Bohren 04186	35	91	139		185	3.0		155	1.8	
56471	Pressen	82	103	131		229	3.7		303	3.5	
05435	BAZ	16	43	88		121	2.0		74	0.8	
56263	Pressen	58	59	76		100	1.6		73	0.8	
03364	Drehen 03364	11	23	76		115	1.9		92	1.0	
05364	BAZ 05364	75	84	73		127	2.1		287	3.3	
50000	Pressen	42	92	67		133	2.2		209	2.4	

Figure 10 – List of dynamic bottlenecks.

## 6. Evaluating actions to adapt the capacity

The needed adaptations of the capacity are done based on the explained methods for analyzing static and dynamic bottlenecks. In our example, the capacity of 3 work centers was increased. With this capacity adaptation, a new capacity and order flow simulation was done to check and evaluate the results of the capacity alterations.

In Figure 11, the simulated input curve is much closer to the capacity curve, which means that there is less risk of idle time at work center 05365. This is due to the backlog reduction at the preceding work centers.

We can see in Figure 12 that the capacity adaptation allows us to reduce throughput time deviation. The throughput time at the inspection work center (00000) is longer than before but the total throughput time is considerably shorter. Figure 13 gives an overview of the whole

production area. The simulated output is considerably higher than the plan output and is closer to the target output curve which shows that we have less backlog. This proves that the overall order throughput situation could be improved.

## 7. Summary

A regular capacity planning, as well as static and dynamic bottleneck analysis, is an important function to control and plan the order throughput in a company. The scheduling, monitoring and simulation features of FAST/pro are flexible tools to support current ERP and other PPC systems. Numerous projects have been done with the software, proving its high benefit in practice, as described, for example, for Bakke *et al.* (1992). These projects have been carried out in different branches, order structures and company sizes. It has been used in all hierarchical levels, from general management to production level.

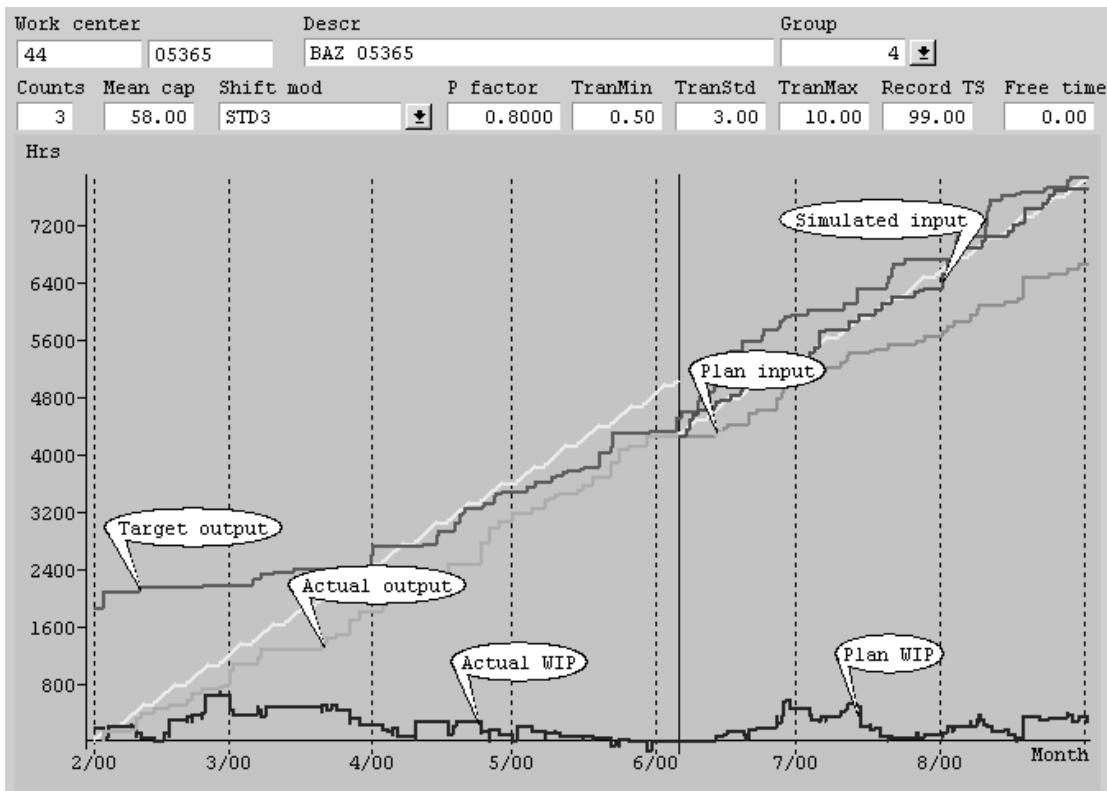


Figure 11 – Evaluating different capacity settings using the input-output chart.

**Bottlenecks hit list**

Sort Marking Selection Statistics Print Connections Tools Evaluation Chart **FAST/pro**

Work center	Descr	No of production orders	No of operations	Throughput time dev abs [Days]	Throughput time dev abs	Simulated throughput time dev abs [Days]	Simulated throughput time dev abs	Simulated throughput time dev rel [%]	Simulated throughput time dev rel	Simulated throughput time dev abs [Days]
04301	BAZ 04301	50	56	1475		337		-68.5		-1160
00000	Kontrolle	284	821	578		1078		58.9		512
04302	BAZ 04302	59	72	426		163		-52.6		-289
05112	Feindreihen	124	129	342		250		-20.9		-103
05000	BAZ	32	50	201		174		-11.2		-27
07193	Schleifen	64	70	189		216		9.7		28
01451	Drehen 01451	21	29	140		101		-23.8		-47
04186	Bohren 04186	35	91	139		144		0.7		1
56471	Pressen	82	103	131		103		-13.8		-32
05435	BAZ	16	43	88		85		-3.5		-4
56263	Pressen	58	59	76		65		-11.4		-11
03364	Drehen 03364	11	23	76		55		-21.9		-25
05364	BAZ 05364	75	84	73		74		2.8		4
50000	Pressen	42	92	67		56		-11.8		-16

Figure 12 – Using the dynamic bottleneck rating list to compare original capacity settings to adapted capacity settings.

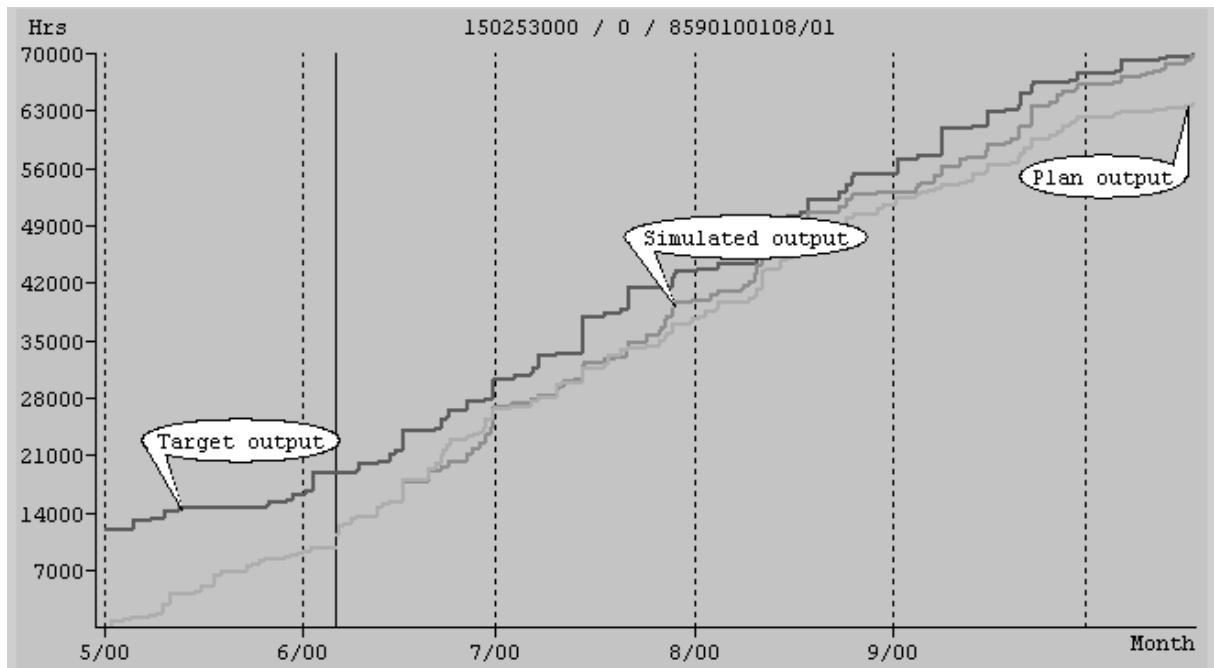


Figure 13 – Comparing capacity variance using the input-output chart.

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## MÉTODOS E FERRAMENTAS PARA PLANEJAMENTO E CONTROLE DINÂMICOS DE CAPACIDADE

### Resumo

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*Este artigo discute o gerenciamento de fluxo de materiais. Mais especificamente, apresenta métodos e ferramentas usados para o planejamento e controle dinâmicos de capacidade. Tais recursos estão focados na redução ou eliminação de gargalos estáticos e dinâmicos da produção. Aplicações práticas são feitas com o uso do FAST/pro, um software que agrega os conceitos apresentados por meio de uma regulação dinâmica da capacidade, orientada para a demanda.*

**Palavras-chave:** *planejamento e controle de capacidade, redução de gargalos, gráfico de input-output, simulação do fluxo de materiais.*