Operations Decision System Based on Drum-Buffer-Rope Method

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Abstract: The production operations planning methodology called Drum-Buffer-Rope (DBR) is based on the Theory of Constraints that is focused on the principle that the goal of any industrial organization is to make money, now and in the future, and that a system's constraints determine its capacity and rhythm to make money.

The paper presents an operations decision [support] system (ODS) that deals with the constraint(s) handling decision during the manufacturing operations, providing two optimization techniques and their application to production planning. The system is developed with a friendly graphical user interface that guides the user during the decision process, providing comparative reports between the marginal analysis and a report called the "product contribution".

Keywords: capacity, constraint, optimization, decision, operations, planning.

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1. Introduction

In the 80's, Goldratt and Cox (1984), Goldratt (1997) proposed the Drum-Rope-Buffer (DBR) method based on the Theory of Constraints (Goldratt, 1990) for managing production operations planning and scheduling. The concept of DBR is focused on the five steps oriented process to make feasible a process of ongoing improvement: the system's constraint identification, the decision for the constraint exploitation, the subordination of all the other capacities at the level of the exploitation decision from the previous step, constraint(s) elevation and new constraint identification.

The DBR method is designed to optimize a flow shop type process, obtaining the full capacity of the most constrained capacity machine (CCM) in the manufacturing chain. The rhythm of CCM represents the *drum* for the rest of the system. The *rope* represents the mechanism of releasing the raw material into the manufacturing process, protecting the CCM from being swamped with work in progress. The rope regulates the rate of inserting the raw material into the manufacturing process. The inserting rate is no faster than that impose by the drum. The *rope* is connected with the *drum* with the help of the time *buffer* that protects the CCM from starving because of the work during the process. The purpose of the time *buffer* is to shorten the flow times.

The efficient and effective manufacturing operations planning require the assistance of methodologies and information systems meant for decision support. The main features of decision support systems are described in (Filip, 2002, 2004).

This paper presents the main features of integrating the paradigm of deciding for the optimum flow within an Operations Decision System (ODS) that takes into account the current production rate of the most CCM, synchronizing it with the entry of the raw materials into the manufacturing process. ODS optimizes the production operations planning, establishing the resource allocation reports in connection with the DBR method.

There are a number of issues that no DBR software can handle totally. The ODS is designed first to decide for the best report that determines what sequence of different operations should pass through the production facilities. Next to the accepted report, ODS computes the time *buffer* within DBR method combining the Goldratt's (1997) theory with the well-known PERT techniques (Program Evaluation and Review Technique), which is calculated according to the following rule: there is calculated the lead time as the sum of the optimistic estimations for the selected operations sequence. ODS obtains the operations sequence time estimation according to the selected report at the first step of the decision process, that generates a lot of idle time intervals for the facilities. In the sequel, the remaining part of this paper is organized as follows: First the decision system modules with the prime functioning are exposed; next the basic assumption for describing the object-oriented program development is made. There follows the presentation of the steps of the DBR method integrated in the ODS system by means of an application for the optimization of the decision concerning the production operations planning. Finally, the concluding remarks are made.

2. The Modules of the ODS

ODS has been designed as a modular structure, and the functions ensured by each module integrate the Drum-Buffer-Rope method for the planning of the production operations, as follows:

The Process initialization module which enables the establishing of the technological flow, the entering of all the process initialization data, respectively, for instance: the number of the products, the weekly demand for each final product, the specifications for the allotment of the raw material required for the manufacture of each product, the cost of the raw material, etc.

The Drum-Buffer-Rope module, which identifies the machine; by having the most constrained capacity at a certain moment, this module establishes the exploiting rhythm of the constraint (Drum), calculates the time Buffer and plans the flow of the raw materials.

The Decision module identifies the best exploiting procedure for the constrained machine. The decision process is based on the comparative analysis between the marginal analysis report and the so-called « Product Contribution/constraint» report.

The Constraint (s) Elevation module suggests and manages possible investments for the elevation of the constraint, namely, it enables the updating of the technological flow. (Lee, 1993)

The Reports module creates useful reports on the basis of which the user communicates with the system for the final decision elaboration. (Hull and Wu, 1994), (Filip,2005), (Prostean, 2007)

3. Program Description

The program was implemented in Java using O.O.P (Object Oriented Programming), the graphical interface being developed with the help of AWT (Abstract Window Toolkit). AWT is a library, which contains all the classes for the creation of the user interface. The program is created with the MySQL data base included for storing the information that are specific for a defined process.

Each product is an object, storing the information that is specific (the weekly demand, the selling price, the raw material price, the units supplied, the weekly throughput, the throughput time required for each operation), and can be used later in the constraint handling decision, in the manufacturing operations, in operations planning, respectively.

Each machine is an object, storing the information that is specific (the machine number, the available time).

There are defined 2 arrays that store the objects, the first array is used for storing the object having the product class type and the second array is used for storing the object having the machine class type. These classes provide functions for data initialization and processing during the progress of the program (time, reports, verifying, a.s.o.).

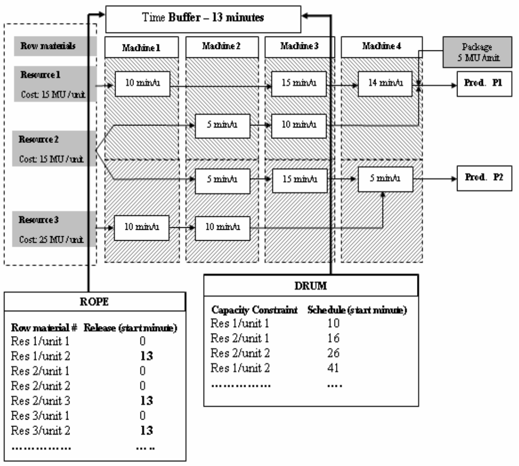
The algorithms follow the Goldratt's Theory of Constraints (1990, 1997) five steps focusing process (the constraint identification, the constraint exploitation, the reports for subordination, the constraints elevation, the new constraint identification); (Prostean, 2005, 2007).

4. Application

4.1 System initialization

Taking into account a simple process which produces two products, "P1" and "P2", the objective of the application is to establish a decision through which the process profit can be maximized.

The inputs for the manufacturing process consist in 3 raw materials which are combined and processed by means of the machines 1 – 4, based on the technological process (Fig. 1).



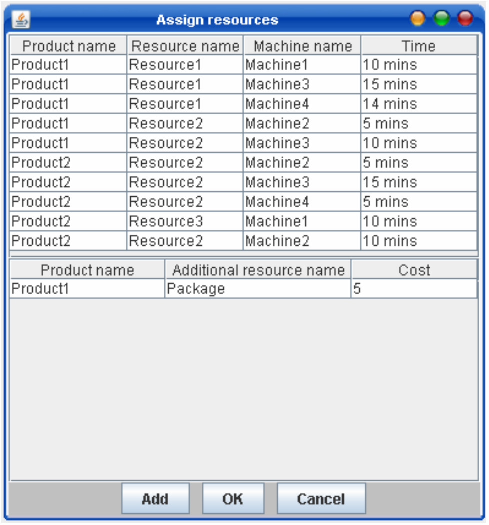
ROPE

Row material #	Release (start minute)
Res 1/unit 1	0
Res 1/unit 2	**13**
Res 2/unit 1	0
Res 2/unit 2	0
Res 2/unit 3	**13**
Res 3/unit 1	0
Res 3/unit 2	**13**
……………	……

DRUM

Capacity Constraint	Schedule (start minute)
Res 1/unit 1	10
Res 2/unit 1	16
Res 2/unit 2	26
Res 1/unit 2	41
……………	….

Figure 1. The operations flow - logical diagram



Product name	Resource name	Machine name	Time
Product1	Resource1	Machine1	10 mins
Product1	Resource1	Machine3	15 mins
Product1	Resource1	Machine4	14 mins
Product1	Resource2	Machine2	5 mins
Product1	Resource2	Machine3	10 mins
Product2	Resource2	Machine2	5 mins
Product2	Resource2	Machine3	15 mins
Product2	Resource2	Machine4	5 mins
Product2	Resource3	Machine1	10 mins
Product2	Resource2	Machine2	10 mins

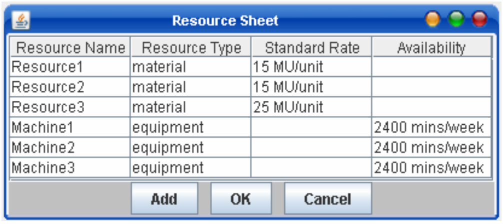
Product name	Additional resource name	Cost
Product1	Package	5

Figure 2. Material specifications

Resource 1 is processed by means of machines 1, 3 and 4, but not by means of machine 2. Resource 2 is processed by means of machines 2, 3 and 4, but not by means of machine 1. Resource 1 and 2 are taken in quantities of one unit each, being processed up to the final stage by means of machine 4, and then packed within the same compartment, so that at the output of the process there results product P1. Resource 2 is processed by means of machines 2, 3 and 4, but not by means of machine 1. Resource 3 is processed by means of machines 1, 2, but not by means of machines 3 and 4. One unit from raw material 2 and one unit from raw material 3 are combined on machine 4 in order to obtain product P2.

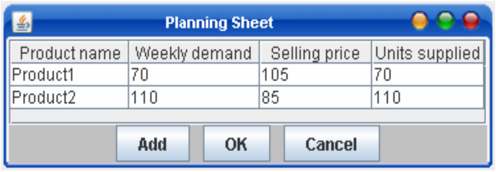
The input data of the manufacturing process represent the initializing data of the system for the decision process optimization. The user provides the primary data to the system to identify the production bottleneck, and the assignment of materials and operations for each machine and the operations time, respectively. There is no waiting time. At the end of one step, the following step begins at once.

The availability of the machines is of: 60 minutes/hour, 8 hours/day, 5 days/week, i.e. 2400 minutes/week, respectively (Fig. 2, Fig. 3).



Resource Name	Resource Type	Standard Rate	Availability
Resource1	material	15 MU/unit	
Resource2	material	15 MU/unit	
Resource3	material	25 MU/unit	
Machine1	equipment		2400 mins/week
Machine2	equipment		2400 mins/week
Machine3	equipment		2400 mins/week

Figure 3. The technological flow initialization

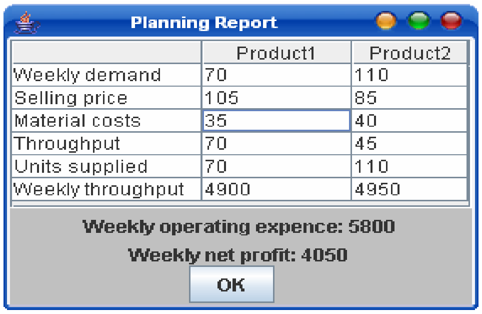


Product name	Weekly demand	Selling price	Units supplied
Product1	70	105	70
Product2	110	85	110

Figure 4. Process initialization

In the initializing process, the user also supplies the following data: the selling price, (Monetary Units/piece), the weekly market demand, the units supplied and the operation costs for the whole process (5800 MU /week) (Fig. 3), (Fig. 4).

4.2 Process optimization

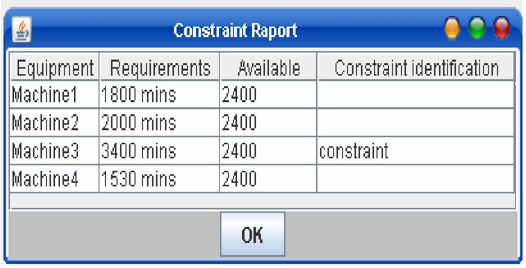


	Product1	Product2
Weekly demand	70	110
Selling price	105	85
Material costs	35	40
Throughput	70	45
Units supplied	70	110
Weekly throughput	4900	4950

Weekly operating expence: 5800

Weekly net profit: 4050

Figure 5. Report – units supplied in accordance with the weekly demand



Equipment	Requirements	Available	Constraint identification
Machine1	1800 mins	2400	
Machine2	2000 mins	2400	
Machine3	3400 mins	2400	constraint
Machine4	1530 mins	2400	

Figure 6. Constraint(s) identification

The first planning report of the operations drawn up by ODS is that of the weekly profit, in case there could be ensured the whole weekly demand. The algorithm for this type of report drawing up takes into account the following relations for each product:

The profit = "throughput" – operation costs

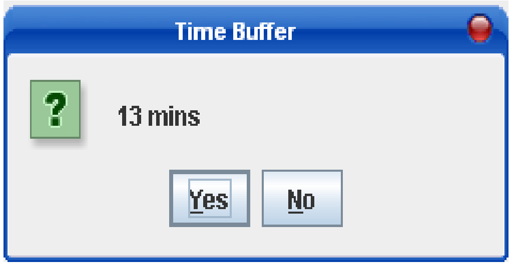
The throughput= the selling price – the cost of the materials (URL 1), (Fig. 5).

Within the decisional process optimization, ODS observes the 5 steps of DBR method based on the theory of constraints proposed by Goldratt, identifying the constraint that has occurred in the system, the CCM, respectively. (Atwater, 1995).

There is checked whether the capacity of the processing machines is enough to cover the demand. Thus, there is checked whether the time required at each processing machine is not longer than the available time. In this stage the system identifies the constrained machine, resulting in the over-allocated time capacity, Following the calculation of the capacity required for each machine, there has been identified a constraint concerning machine 3 (Fig. 6).

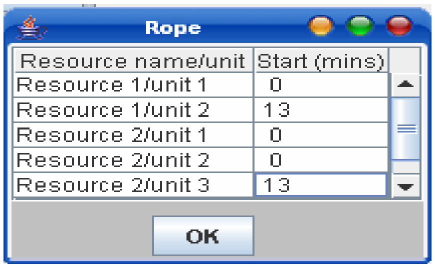
The second step of DBR method is that of establishing the CCM exploiting decision, more precisely the exploiting schedule of machine 3, which represents the CCM for the system. The resulting schedule becomes the *Drum* of the system (Fig. 1).

The third step of DBR method is that of subordinating the other manufacturing facilities to the exploiting rhythm established by the *Drum* in the previous step. In this way, ODS calculates the time *Buffer, and the Rope* (Fig. 1, Fig. 7, Fig. 8), for the protection of CCM, the thinning of the materials flow, respectively.



13 mins

Figure 7. The Time Buffer



Resource name/unit	Start (mins)
Resource 1/unit 1	0
Resource 1/unit 2	13
Resource 2/unit 1	0
Resource 2/unit 2	0
Resource 2/unit 3	13

Figure 8. The Rope- schedule for the raw material flow

By applying this step, ODS plans the optimum exploiting rhythm for the system, but the constraint of the time availability identified on machine 3, in case the whole weekly demand could be produced, is not yet solved.

The target of the exploiting is to maximize the capacity of machine 3 and to continue to deliver a good profit by the end of the week. ODS elaborates the optimum exploiting decision of the constraint on the basis of the comparative analysis between two reports.

The system provides first the analysis carried out according to the marginal cost of the throughputs obtained through the difference between the selling price and the cost of the materials: for product P1, the marginal cost is Cmp = 105-35=70 MU and for product P2, the marginal cost is Cmq= 85-40=45 MU.

If this problem is solved, as far as the costs analysis is concerned, the maximization of the process is obtained by identifying the product with the lowest cost.

If the identification is made as function of the raw material cost, then the answer is that product P1 at 35MU is to be preferred to product P2 at 40 MU.

If the identification is made as function of the execution operations cost, product P2 which is executed in 45 minutes (10+15+15+5) is to be preferred to product P1, executed in 54 minutes (10+5+25+14).

As far as the maximization of the selling price is concerned, namely of the final product sold, product P1, which is sold with 105 MU, is to be preferred to product P2, which is sold with 85 MU. As concerns the marginal price, the price of product P1 is 70 MU, and it is to be preferred to product P2 whose price is 45 MU.

By analyzing the costs involved in the execution of the two products, the marginal incomes, respectively, it is obvious that product P1 has prior claim to consideration, as far as its execution is concerned, in comparison with product P2.

The demand for product P1 is of 70 pieces. For machine 3 there are required 70x10 minutes (resource 2) and 70x15 minutes (resource 3). There results a total of 1750 minutes, required for product P1. If from the available time interval of 2400 minutes there is subtracted the requisite for product P1, i.e. 1750 minutes (2400-1750=650), there will remain 650 minutes for product P2. Product P2 is processed for 15 minutes on machine 3, and there result 650/15 = 43 units of product P2.

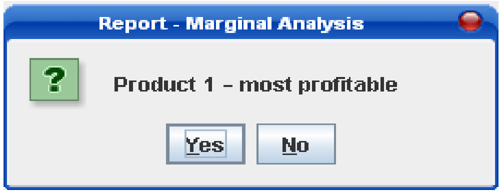
The result of the exploiting machine 3 decided through costs analysis is presented in Fig. 9, and there can be observed a weekly net profit of 1035 UM.

	Product1	Product2
Weekly demand	70	110
Selling price	105	85
Material costs	35	40
Throughput	70	45
Units supplied	70	43
Weekly throughput	4900	1935

Weekly operating expence: 5800

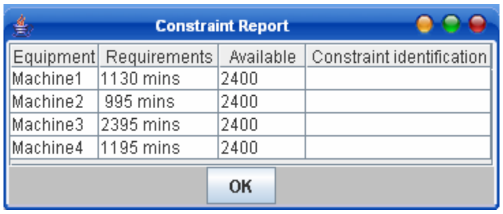
Weekly net profit: 1035

Figure 9. Report – units supplied in accordance with marginal analysis



Product 1 – most profitable

Figure 10. Final report in accordance with marginal analysis



Equipment	Requirements	Available	Constraint identification
Machine1	1130 mins	2400	
Machine2	995 mins	2400	
Machine3	2395 mins	2400	
Machine4	1195 mins	2400	

Figure 11. Constraint(s) identification

Conclusion: The weekly net profit in accordance with the marginal analysis is less than the weekly net profit for the units supplied in accordance with the weekly demand.

In the first part of the marginal analysis, there has been approached the exploitation of the constraint by maximizing the outputs of the constraint, where the following have been taken into account: the cost of the execution operations, the cost of the raw material, the highest selling price and the highest marginal price.

However, the constraint exploitation means to wholly exploit the constraint potential. The processing time for product P1 by means of machine 3 is 25 minutes and the processing time for product P2 by means of machine 3 is 15 minutes; How much throughput is there obtained during each processing time?

Product P1 gains 70 MU.
Product P2 gains 45 MU.

The report of the marginal analysis establishes that Product 1 is more profitable. In case the option “No” is selected by the user, ODS generates the calculation of the second report which will be compared with that of the marginal analysis (Fig. 10).

The user may also choose to display the planning report of the manufacturing operations, the situation of the constraints that have resulted according to the marginal analysis, respectively (Fig. 11).

There follows the calculation of the ratio throughput /number of minutes within the constraint (machine 3): for P1 – 70MU/25 minutes = 2.8MU/minute, and for P2 – 45MU/15 minutes = 3MU/minute.

Conclusion: product P2 generates money for the system with 7.14% quicker than product P1.

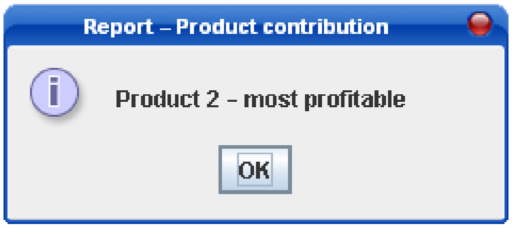
Consequently, product P2 is to be preferred for execution as compared to product P1.

The report called "Product contribution" is the key for reaching the goal to make money, i.e. to make feasible an ongoing improvement process, respectively (Fig. 12), (Fig. 13).

	Product1	Product2
Weekly demand	70	110
Selling price	105	85
Material costs	35	40
Throughput	70	45
Units supplied	30	110
Weekly throughput	2100	4950

Weekly operating expence: 5800

Weekly net profit: 1250

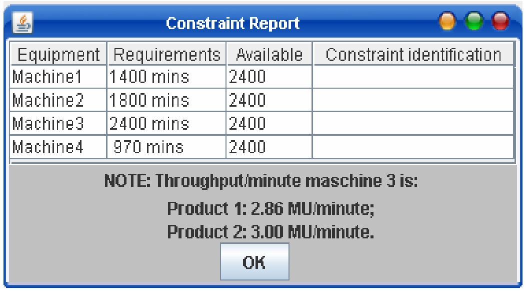


Product 2 - most profitable

Figure 12. Planning Report – in accordance with the "Product Contribution"

Figure 13. Final report in accordance with the "Product Contribution"

The situation of the constraints that have resulted according to the "Product Contribution" is presented in Fig. 14.



Equipment	Requirements	Available	Constraint identification
Machine1	1400 mins	2400	
Machine2	1800 mins	2400	
Machine3	2400 mins	2400	
Machine4	970 mins	2400	

NOTE: Throughput/minute maschine 3 is:

Product 1: 2.86 MU/minute;

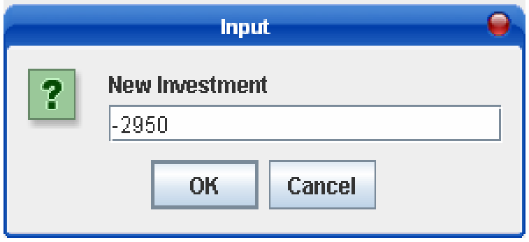
Product 2: 3.00 MU/minute.

Figure 14. Constraint(s) identification

4.3 Procedures for constraint elevation

Consequently, by going on in applying the DBR method, ODS establishes the operations planning according to " The Product Contribution" report, updating the rhythm required by the *Drum,* the time *Buffer,* and the planning of the raw materials entry into the process through the *Rope* updating. All the other equipments will be subordinated to this exploiting decision although their capacity has a greater volume.

The fourth step covered by applying the DBR method, is that of elevating the constraint. ODS has an integrated option for a new investment which will be taken into account in the algorithm for the profit calculation, it offers the option for the modification of the time allotted in the initialization process of the technological flow, respectively.



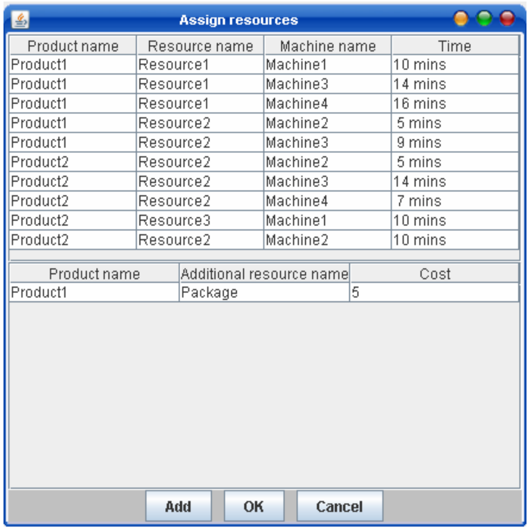
New Investment

-2950

Figure 15. The Investment for Constraint(s) elevation

In the application taken into account, there has been made an investment of 2950 MU (Fig. 15), the technological flow has suffered the following modifications, respectively: the time allotted for machine 3 has been decreased by 1 minute, and the time allotted for machine 4 has been increased by 2 minutes (Fig. 16). Consequently, there have been saved 25 minutes for the processing of resource 2 by machine 3, and thus additional units of product 1 can also be produced, with a rate of 2.8 MU/minute (Fig. 17). The weekly net profit has been increased.

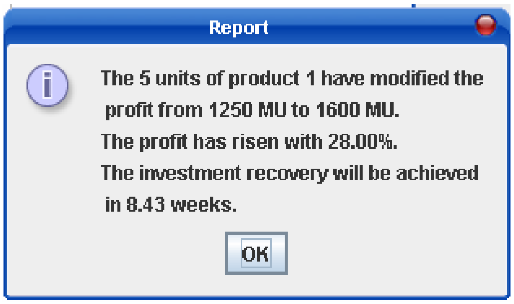
ODS provides useful reports for the entire decision process, it restarts the whole decision process, respectively, in case of the identification of a new constraint.



Product name	Resource name	Machine name	Time
Product1	Resource1	Machine1	10 mins
Product1	Resource1	Machine3	14 mins
Product1	Resource1	Machine4	16 mins
Product1	Resource2	Machine2	5 mins
Product1	Resource2	Machine3	9 mins
Product2	Resource2	Machine2	5 mins
Product2	Resource2	Machine3	14 mins
Product2	Resource2	Machine4	7 mins
Product2	Resource3	Machine1	10 mins
Product2	Resource2	Machine2	10 mins

Product name	Additional resource name	Cost
Product1	Package	5

Figure 16. Modified material specifications



The 5 units of product 1 have modified the profit from 1250 MU to 1600 MU.
The profit has risen with 28.00%.
The investment recovery will be achieved in 8.43 weeks.

Figure 17. Decision report

5. Conclusions

Drum-Buffer-Rope represents an approach for the balancing of the flow of the work in process in case of the most restricted resources from the manufacturing chain.

ODS is an experimental system which integrates the DBR method for the planning of the production operations, offering solutions for maintaining the inventory at a low level and for its releasing at the optimum moments, i.e. versatile solutions to answer, as well as possible, the market demand.

The Drum- Buffer – Rope and Decision modules establish a complex framework for deciding the best way of constraint exploitation, meaning to wholly exploit the constraint potential. These modules integrate Goldratt's (1997) theory that the rhythm of efficiency is generated by the constraint (s) and that to go on having the maximized possible profit up to the end of the week, means to identify the product that generates money on the constraint (s) quicker than other products.

ODS enables the elaboration of documented decisions for the planning of the production operations with the aim of maximizing the profit. It offers solutions for the avoidance of chaotic situations at the level of the production platform, when there occur several opportunities from the part of market demand.

ODS is an object oriented planning system, having the following advantages:

The Information is distributed – each product and machine stores the information (the weekly demand, the price, the required time, the available time, a.s.o) that is specifically related to it and can be used later in the constraint handling decision during the manufacturing operations, and the operations planning, respectively.

The Computation is distributed in time – the system continuously adjusts the planner as the environment changes.

Flexibility – once the flow shop behaviour is defined at the operation level, the adjusting and rescheduling decisions are more flexible.

The future work will focus on the evaluation and the exploration of the improved algorithms for the thinning of the materials flow after the CCM leaving, more precisely, the extension of the DRB method as far as shipping is concerned. There is also possible to extend the current design of the operation decision system to provide more functionality in establishing the time buffer, namely to furnish certain computation alternatives for the protection of the CCM in accordance with the materials flow thinning.

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