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PAPIYA BHOWMIK
National Institute of Technology, Silchar, Assam, India., papiya.nita@gmail.com

SUJIT KUMAR PATTANAYAK
National Institute of Technology, Silchar, Assam, India., sujupat@gmail.com

SHIBAMAY MITRA
National Institute of Technology, Silchar, Assam, India., shibamay07@gmail.com

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GUIDING THE IMPLEMENTATION OF QUALITY IMPROVEMENT PROJECTS: A TOC APPROACH

PAPIYA BHOWMIK[1], SUJIT KUMAR PATTANAYAK[2] & SHIBAMAY MITRA[3]

[1,2&3]Dept. of Mechanical Engineering, National Institute of Technology, Silchar, Assam, India.
E-mail: [1]papiya.nita@gmail.com, [2]sujupat@gmail.com, [3]shibamay07@gmail.com

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Abstract- Many research has shown that approximately 70% of every medium to large scale industries have some type of quality improvement (QI) program. Depending on various independent studies, researchers have concluded that only one-fifth of all QI projects show attractive output. The reason for this disappointing result is most of the QI programs are not result oriented. The main aim of this paper is to elaborate the value of using the Theory of Constraints (TOC), so that a result-oriented QI program can be achieved with a better bottom-line impact, which will be better than the traditional cost based selection process.

Keywords *- Quality Improvement(QI); Theory of Constraints (TOC); Throughput.*

I. INTRODUCTION

Now-a-days QI programs have become extremely popular. Many researches have shown that approximately 70% of all medium to large scale industries have some sort of QI application in every field, though the percentage of success rates of these programs are alarmingly low but again different studies have shown that one fifth of all QI programs achieve expected results in form of quality, productivity & financial improvements.

The failure of most of the projects puts the importance of QI under a question mark. It is also a question why industries continue to implement QI programs where most of the time it does not put any value to the system. However, the answer to these questions is easy & simple. When many of the QI programs have gone to dust, some of them are shining in the queue. Quality improvement is one of the fundamental strategies of business without which no business will survive in the global market place. The main question which arises here is not that whether QI programs have any value, but why some programs are immensely successful while others are not?

Recent researches have shown a strong belief that most of the QI efforts fail only because of their lack of focus on results. Instead of concentrating on specific improvements, most specialists of QI programs recommend focusing on education & changing the corporate culture in short term. Also these specialists of QI warn that QI is a long term process and bottom line effects should not be expected for five years or more. No one can deny that a total makeover of a company is a long term process, but it does not mean that tangible results from a QI effort should not be visible in a shorter period.

One way of focusing on manufacturing improvements is by implementing the theory of constrains. TOC the famous tool of management is developed by Dr. Eliyahu Goldratt. Since publication of the book, The Goal, which highlighted many of the basic principles of TOC, the interest and application of TOC among the users are rapidly growing. The purpose of this paper is to describe how to apply the principle of TOC to select a QI project which will achieve comparatively better bottom-line results for an operation, as compared to other traditional cost based selection process.

II. THEORY OF CONSTRAINTS

Dr. E. Goldratt, the founder of the Theory of Constraints has made a very important contribution to management, based on a very simple observation: A chain is as strong as its link. There can be no dispute of the observation. One can say it is trivial, but when derives his conclusion they are simple, striking & far from trivial. The weakest link is the real limiting factor. When applied to a business organization, it is a factor that limits its ability to achieve more of its goal and according to Goldratt it’s a constraint. He said, “Because a constraint is a factor that limits the system for getting more of whatever it strives for, a business manager who wants more profits must manage the constraints. There is no choice in the matter. Either you manage constraints or they manage you.” The process used by TOC, to improve the health of an organization is almost identical to what the physician does, but the terminology is changed to better suit the language problem-solving in organizations. In TOC, the process is described via the use of three questions: What to change, what to change to and How to cause the change?

These three questions provide the framework for what’s called the TOC thinking processes. The thinking processes are a set of tools and processes that allows an individual or group to solve a problem and/or develop a holistic, integrated strategy using the rigor and logic of cause-and- effect, beginning with symptoms and ending with a detailed action plan that coordinates the activities of all those involved in implementing the solution/strategy. A constraint is anything in an organization that limits it from moving towards its goal. Of course, this assumes that an appropriate goal has been defined. For most of the organization the goal is to make money now as well as future. There are two basic types of constraints: physical constraints and non-physical constraints. A physical constraint is something like the physical capacity of machine. A non-physical constraint might be something like demand for a product, a corporate procedure, or an individual's paradigm for looking at the world. The steps in applying TOC are as follows:

1) Identify the system's constraints. Of necessity this included prioritization so that just the ones that limit system towards the goal.
2) Decide how to exploit the system's constraints. Once we have decided how it manages the constraints within the system, how about the majority of the resources that are not constraints? The answer of the question is that we manage them so that they just provide which is needed to match the output of the constrained resources. We never let them supply more output than is needed because doing so moves us no closer to the goal.
3) Subordinate everything else to the above decision in the step 2. Since the constraints are keeping us from moving towards our goal, we apply all of the resources that we can to assist in breaking them. Constraints are not acts of God. In practically all cases their limiting impact can be reduced or eliminated.
4) Elevate the system constraints. If we continue to work toward breaking a constraint (also called elevating a constraint) at some point the constraint will no longer be a constraint. The constraint will be broken.
5) If the constraint is broken return to step 1. What that happens, there will be another constraint, somewhere else in the system that is limiting the process.

One unique aspect of TOC is the emphasis it places on increasing throughput rather than decreasing the cost. Under the TOC approach, throughput is defined as the revenue generated by the system. The throughput contribution of a product is calculated as follows:

$$T_i = [(SP_i \times S_i) - \sum_{j=1}^{k}(RM_j \times P_i)] \qquad (1)$$

T_i = Throughput value of product i.
SP_i = selling price for product i.
S_i = number of sold units of products I produced within the specified time frame.
RM_i = the quantity of raw material j used in product i.
P_j = the purchase price of raw material j used in product i.
K = the number of different raw material used.

The difference between the product's selling price and its raw material costs represents the money generated within the company by its manufacturing operation. The total throughput for the system (T_s) over a specified time frame is merely:

$$\sum_{i=1}^{l} T_i \qquad (2)$$

T_i = Throughput generated by i^{th} product.
l = Total number of products.

There are two key points to recognize here. First an unsold product does not generate any revenue, so products built for inventory do not count as throughput under TOC. In addition, unsold inventory is only valued at its raw material cost, for internal reporting purposes. This is done to discourage the buildup inventory. Second is, total cost other than raw material (e.g., direct labor, factory overhead) are treated as operating expenses for the period.

III. CASE COMAPANY BACKGROUND

To illustrate the application of TOC principle for the selection of a QI project, a basic case study has been considered based on the data, collected from ABC company, who are a Manufacturer of EMU Coaches & various types of wagons. The data here is concerned with the manufacturing process of E.M.U Coaches only. Figure 1 is a diagram of a simple operation which produces three products labeled under frame (U/F), Side body (S/B) and End Body (E/B). U/F has a selling price Rs 3.225 million & an average demand of 18U/F per year. Similarly S/B & E/B sell for Rs 3.1 million & Rs 3.055 million with average demands of 36S/B per year & 36E/B per year respectively. The operation is composed of 4 work stations. Figure also shows the raw material requirements, material routing, yield rate and average processing time at each work centers for each product. Each work center is having (278 days x 0.5 x 1 shift x 6 hour) 834 hour a year of capacity in an average work year to process these products (i.e. each work center has one resource and 1shift/day, 6hours/shift and 5.5days/week).

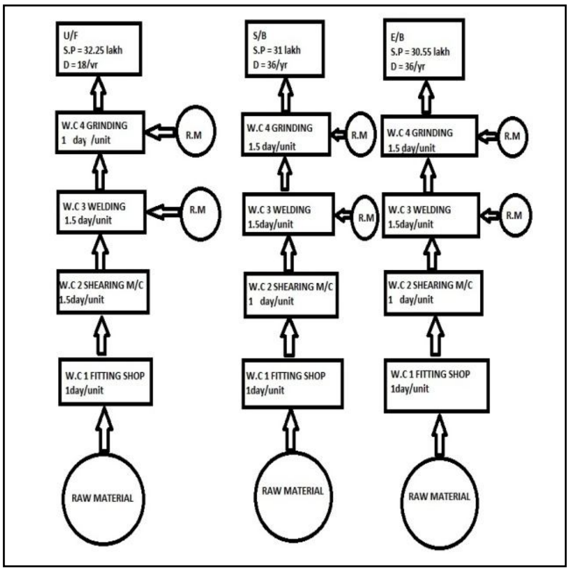
IV. METHODOLOGY

Capacity check of the work centre's can be performed using the formula given bellow:

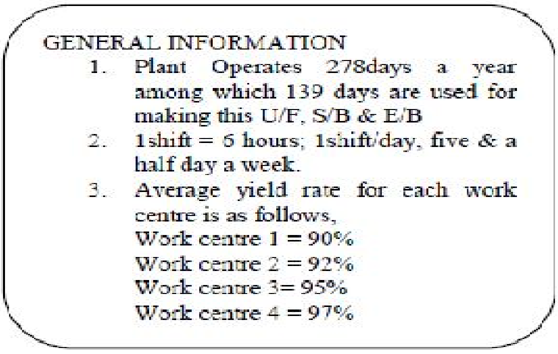
$$C_{WC_m} = \sum_{i=1}^{l}(D_i \times t_{iWC_m} \qquad (3)$$

C_{WCm} = Capacity needed for work centre m to satisfy demand for all products;
D_i= Market demand for product i ;
t_{iWCm}= Time per unit at work centre m for product i.

Using equation (3) the capacity check indicates that all the work centers are having sufficient capacity to fulfill the market demand. Table 1 shows all the related calculations.



But it is unlikely that after considering the yield factor at each work centers, work center (3) may face a great difficulty to meet the market demand.



GENERAL INFORMATION

1. Plant Operates 278days a year among which 139 days are used for making this U/F, S/B & E/B
2. 1shift = 6 hours; 1shift/day, five & a half day a week.
3. Average yield rate for each work centre is as follows,
   Work centre 1 = 90%
   Work centre 2 = 92%
   Work centre 3= 95%
   Work centre 4 = 97%

Figure 1: The four work centers

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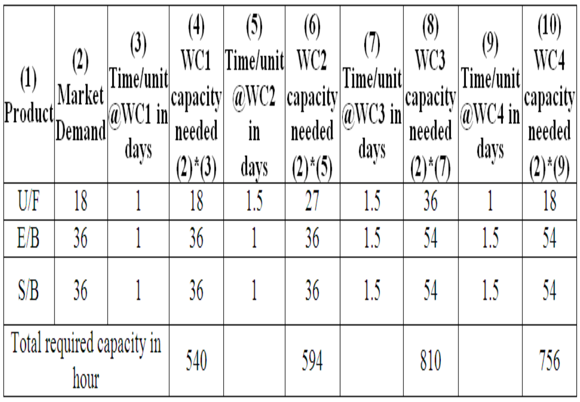
Table 1 : Capacity Required at Each Workcentre Without Yield Consideration



(1) Product	(2) Market Demand	(3) Time/unit @WC1 in days	(4) WC1 capacity needed (2)*(3)	(5) Time/unit @WC2 in days	(6) WC2 capacity needed (2)*(5)	(7) Time/unit @WC3 in days	(8) WC3 capacity needed (2)*(7)	(9) Time/unit @WC4 in days	(10) WC4 capacity needed (2)*(9)
U/F	18	1	18	1.5	27	1.5	36	1	18
E/B	36	1	36	1	36	1.5	54	1.5	54
S/B	36	1	36	1	36	1.5	54	1.5	54
Total required capacity in hour			540		594		810		756

To find out the actual capacity requirement for every work centre yield factors must be considered. As we can see from table 2, to manufacture 18 U/F, almost 19 U/F must be processed at work centre 4, and almost 20 U/F at work centre 3. How many units must be processed at each work centre is calculated by the formula:

$$R_{jiWC_m} = \frac{R_{jiWC_{m+1}}}{Y_{WC_m}} \qquad (4)$$

R_{jiWCm} = raw material (j) demand at work centre m to satisfy production requirement for product i.
$R_{jiWCm+1}$ = material requirement for the next work centre in the process to make product i.

Y_{WCm} = Yield percentage of work centre m.

If we begin with the market demand of each of the product & we go backward through the routing of each product, equation (4) is used to determine RM_{jiWCm} for the raw material used at every work centre. The actual capacity of each work centre is counted by substituting RM_{jiWCn} (in a ounded form to the closest number) for D_i in equation 3. Table 2 provides the processing requirements of each work centre considering each work centre’s yield considerations.

Table 3 give the confirmation of the earlier suspicion about work centre 3 is correct, as it is unable to fulfill the market demand. Work centre 3 requires 873 hours where it has only 834 hours available with it. Using the TOC approach, to manufacture the products with the highest contribution per constraint utilization C/CU, the production priority can be determined. It is calculated as follows,

$$C/CU=T_i/t_{iWC3} \qquad (5)$$

T_i = system throughput
T_{iWC3}=Time required on constraint WC3.

The results of these calculations are presented at table 4. Table 4 shows that product U/F has a C/CU value of Rs 1.4166 million. Product E/B and S/B has C/CU value of Rs 1.4166 million and Rs 1.4033 million respectively. Depending on this C/CU values U/F should be made first, followed by E/B & S/B. Table 5 shows all the calculations and gives a clear view of the optimal quantity produced.

The optimal product mix that will be most profitable for this operation can be determined using information already provided in Table 1, 2 and 3. Equation (6) is used for calculating the percentage of required units that can be processed at work centre 3,

$$P_i= C_a/C_{ri} \qquad (6)$$

P_i= percentage of required units that can be produced at work centre (3) to satisfy demand for product i.

C_a= Capacity available at work centre (3) to process material for product i, netting out any capacity already used to process other products.

C_{ri}= Capacity required at work centre (3) to process material for product i.

Table 5 gives us a clear idea of the optimal product mix at work centre (3).

The total throughput of this process can now be calculated (Table 6). In the first step, the required raw material calculation can be done using equation (4) by going backward. In the second step the throughput value of each product can be calculated using equation (1). Using equation (4) and going backward the actual quantity of raw material needed to produce 18 good units of U/B is determined to be approximately 24 units. The selling price of one U/B is Rs 3.225 million. Putting these values into equation (1) the yearly throughput contribution of product U/F is determined as Rs 31.65 million. The same process reveals the throughput contribution of E/B and S/B to be Rs 65.75 million and Rs 57.86 million. Equation (2) reveals the total yearly throughput for this system. These calculations are provided in Table 6 in more detailed form.

TABLE – II : PROCESSING REQUIREMENT AT EACH WORKCENTRE

(1) Product	(2) Market Demand	(3) Units needed at WC4 (2)/0.97	(4) Units needed at WC3 (3)/0.95	(5) Units needed at WC2 (4)/0.92	(6) Units needed at WC1 (5)/0.90
U/F	18	19	20	21	24
E/B	36	37	39	43	47
S/B	36	37	39	43	47

Table-III : Capacity Requiired At Each Workcentre With Yield Consideration

(1) Product	(2) Units needed at WC1	(3) Time/unit @WC1 in day	(4) WC1 capacity needed (2)*(3)	(5) Units needed at WC2	(6) Time/unit @WC2 in day	(7) WC2 capacity needed (5)*(6)	(8) Units needed at WC3	(9) Time/unit @WC3 in day	(10) WC3 capacity needed (8)*(9)	(11) Units needed at WC4	(12) Time/unit 9@WC4 in day	(13) WC4 capacity needed (11)*(12)
U/F	24	1	24	21	1.5	31.5	19	1.5	13.5	19	1	19
E/B	47	1	47	43	1	43	39	1.5	58.5	37	1.5	55.5
S/B	47	1	47	43	1	43	39	1.5	58.5	37	1.5	55.5
Total required capacity in hour			708			705			873			780

Table – IV : Production Priority Using Contribution Per Constraint

(1) product	(2) Selling price (in millions)	(3) Total cost of raw material investment (in millions)	(4) Throughput value (2)-(3) (in millions)	(5) Time on constraint in days	(6) C/CU (4)/(5) (in millions)	(7) Production Priority
U/F	3.225	1.1	2.125	1.5	1.4166	1
E/B	3.1	0.975	2.125	1.5	1.4166	2
S/B	3.055	0.95	2.105	1.5	1.4033	3

Table V . Optimal product mix

(1) Product	(2) Cap Available	(3) Units needed WC3	(4) Processing time/unit in hour	(5) Capacity Required (3)*(4)	(6) % of Market Demand	(7) Optimal quantity produced
U/F	834	19	9	171	487.71%	18
E/B	663	39	9	351	188.88%	36
S/B	312	39	9	351	88.88%	32

Table VI : Throughput Of Base System Before Quality Improvement

(1) product	**(2) Raw material**	**(3) Total raw material cost (in millions)**	**(4) Finished goods req.**	**(5) Selling price (in millions)**	**(6) WC4 req. (4)/0.97**	**(7) WC3 req. (6)/0.95**	**(8) WC2 req. (7)/0.92**	**(9) WC1 req. (8)/0.90**	**(10)Raw material purchase (9)*(3) (in millions)**	**(11) Yearly sales (4)*(5) (in millions)**	**(12) Yearly throughput (11)-(10) (in millions)**
U/F	All	1.1	18	3.225	19	20	21	24	26.4	58.05	31.65
E/B	All	0.975	36	3.1	37	39	43	47	45.85	111.6	65.75
S/B	All	0.95	32	3.055	33	35	38	42	39.9	97.76	57.86
Total:									112.15	267.41	155.26

V. QUALITY IMPROVEMENT: A COST PERSPECTIVE VERSUS TOC

The importance of implementing a QI project at each of the station will now be analyzed from a cost savings perspective and TOC perspective. As work centre (1) has the highest scrap rate, eliminating scrap from work centre (1) results in the reduction in the purchase of raw material. Table 7 shows that needs only 21 units of raw material to produce all 18 units of U/F. similar calculation for product E/B and S/B shows that purchases of raw material to support their throughput are also reduces from 47 units of E/B and 42 units of S/B to 43 and 38 respectively. In addition to a reduction in the amount of raw material requirement the above calculation also reveals another point. The amount of raw material which must be processed at WC3 is not changed. Therefore, the optimal product mix for the operation does not change. As the total yearly purchases of raw material are reduced, the entire increase in throughput from this QI project occurred.

Eliminating scrap at work centre (2) reveals a similar situation. Using equation (4) raw material purchases are calculated. Once again the optimal product mix does not change as the number of units processed at work centre (3) does not change. The new throughput calculated here is Rs 164.42 millions. A detailed study is shown in Table 8.

Eliminating scrap at work centre (3) has a more complicated impact on the system. Eliminating scrap at work centre (3) means none of its capacity is wasted processing bad material and at the same time the optimal product mix changes. Now only 19 units of U/F are needed at work centre (3) to produce all 18 units. Similarly for E/B only 37 units needed to produce all 36 units. Finally moving to S/B, we find the real impact of eliminating scrap at work centre (3). The amount of raw material needed to support U/F is reduced by (20-19) 1 unit, releasing (1x1.5x6) 9 hours of capacity. Similarly reduction in raw material, necessary to support product E/B again releases another ([39-37) x1.5x6) 18 hours. Now the amount of capacity for producing S/B is increased from 312 hour to 339 hour. This enables work centre (3) to produce 36 S/B. Table 9 shows these calculations thoroughly. Allowing for the 97% of yield at work centre (4) results in a new output of 35 units of S/B & this gives a throughput of Rs 167.525 million that means a net increase in throughput from the base situation of (167.525-155.26) Rs 12.265 million, and a substantial improvement over the Rs 0.779 million cost saving generated from the elimination of scrap at work centre 1. Next we push our attention to work centre (4). Like work centre (3) it has a complex impact on the system. As work centre (4) depends on work centre (3) eliminating scrap at work centre (4) results in a reduction in the amount of material that must be processed at work centre (3). The net effect is just like the previous situation. As there is no scrap at work centre (4) all the good units received there can be shipped. Table 10 shows that now only 19units to be processed at work centre (3) to produce 18 units of U/F. only 38 units of E/B to produce 36 units. This reduction in units increase the capacity ([20-19]x1.5x6+ [37-36]x1.5x6) 18 hour of capacity at work centre (3) which can be used to process more S/B. The throughput here is Rs 162.52 million. While this situation is not as good as eliminating scrap at work centre (3), it is still a significant improvement over either of the first two alternatives despite their higher scrap rates.

VI. OVERTIME IMPLEMENTATION

After applying QI at work centre (3) it has been seen that it is still unable to fulfill the whole demand. It lacks by 1 unit of S/B. In such situation overtime can be used to finish the required production in each period. The capacity of work centre (3) lack by 12 hours to fulfill the market demand. From the data collected we found that 2 people can make 2 unit of S/B within 48 hours. From this we get that 4 people will take 12 hours to make 1 S/B. If the over time expense is Rs 500/man hour and Rs 1250/hour. It means, 12 hours of overtime will cost (4x12x500 + 1250x12) Rs 99000 i.e. Rs 0.099 million. So the final throughput after applying QI at work centre (3) is Rs 167.426 million. The use of overtime not only broke the constraint but also costs a little in comparison with the total throughput.

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Table-VII: Throughput of Base System After Quality Improvement At Workcentre 1

(1) Product	(2) Raw material	(3) Raw material cost (in millions)	(4) Finished goods req.	(5) Selling price (in millions)	(6) WC4 req. (4)/0.97	(7) WC3 req. (6)/0.95	(8) WC2 req. (7)/0.92	(9) WC1 req. (8)/1	(10) Raw material purchases (9)*(3) (in millions)	(11) Yearly sales (4)*(5) (in millions)	(12) Yearly throughput (11)-(10) (in millions)
U/F	All	1.1	18	3.225	19	20	21	21	23.364	58.05	34.686
E/B	All	0.975	36	3.1	37	39	43	43	41.2	111.6	70.4
S/B	All	0.95	32	3.055	33	35	38	38	36.1	97.76	61.66
Total									100.664	267.41	166.746

Table-VIII : Throughput Of base System After Quality Improvement At Workcentre 2

(1) Product	(2) Raw material	(3) Raw material cost (in millions)	(4) Finished goods req.	(5) Selling price (in millions)	(6) WC4 req. (4)/0.97	(7) WC3 req. (6)/0.95	(8) WC2 req. (7)/1	(9) WC1 req. (8)/0.9	(10) Raw material purchases (9)*(3) (in millions)	(11) Yearly sales (4)*(5) (in millions)	(12) Yearly throughput (11)-(10) (in millions)
U/F	All	1.1	18	3.225	19	20	19.54	21.7	23.87	58.05	34.18
E/B	All	0.975	36	3.1	37	39	39	43	42.22	111.6	69.38
S/B	All	0.95	32	3.055	33	35	35	39	36.9	97.76	60.86
Total									102.99	267.41	164.42

Table : IX : Throughput Of base System After Quality Improvement At Workcentre 3

(1) Product	(2) Raw material	(3) Raw material cost (in millions)	(4) Finished goods req.	(5) Selling price (in millions)	(6) WC4 req. (4)/0.97	(7) WC3 req. (6)/1	(8) WC2 req. (7)/0.92	(9) WC1 req. (8)/0.9	(10) RM purchases (9)*(3) (in millions)	(11) Yearly sales (4)*(5) (in millions)	(12) Yearly throughput (11)-(10) (in millions)
U/F	All	1.1	18	3.225	19	19	21	23	25.3	58.05	32.75
E/B	All	0.975	36	3.1	37	37	40	44	42.9	111.6	68.7
S/B	All	0.95	35	3.055	36	36	39	43	40.85	106.925	66.075
Total									107.95	276.575	167.525

Table - X : Throughput Of base System After Quality Improvement At Workcentre 4

(1) Product	(2) Raw material	(3) Raw material cost (in millions)	(4) Finished goods req.	(5) Selling price (in millions)	(6) WC4 req. (4)/1	(7) WC3 req. (6)/0.95	(8) WC2 req. (7)/0.92	(9) WC1 req. (8)/0.9	(10) Raw material purchases (9)*(3) (in millions)	(11) Yearly sales (4)*(5) (in millions)	(12) Yearly throughput (11)-(10) (in millions)
U/F	All	1.1	18	3.225	18	19	21	23	25.3	58.05	32.75
E/B	All	0.975	36	3.1	36	38	41	46	44.85	111.6	66.75
S/B	All	0.95	34	3.055	34	36	39	43	40.85	103.87	63.02
Total									111	273.52	162.52

VII. OBSERVATIONS

In the example, the first four steps were actually demonstrated. First, the constraint to the system was identified as work centre (3) (step 1). Next, the most profitable product mix was identified and benefit to the system from scrap reduction at each work centre was determined. Both of these steps illustrated ways to exploit an existing constraint (step 2). In the example we found that the best way to exploit the constraint was to eliminate the scrap there. Finally, decision concerning raw material purchase and processing at other work centers were all subordinated to support the constraint (step 3). At the end we use over time to break the constraint as it costs very little compared to the total throughput (step 4).

The last step is not elaborated here, as the continuous improvement process continues it would eventually come into play. For example, once the Initial project is implemented at work centre (3) it is only logical that the next step, from a quality improvement perspective, is to move to the next problem area with the greatest impact on the system.In the example that would be work centre (4). From there we would move to work centre (1) and so on.

VIII. CONCLUSION

The above example and discussion illustrates how TOC can be used to focus QI projects to achieve the highest money impact on the system. Clearly, many factors such as the margin between selling price and raw material cost; use of overtime; and responsiveness to the customers need to be considered when using the TOC approach for selecting a QI project. Managers should asses their own environment from a throughput perspective keeping these factors in mind.

Successful quality improvement programs are important for long term competition in business. Using the TOC methodology to assist with the implementation of QI program is one way to increase the possibilities of their success. As competition from all over the globe is growing high managers will need to develop innovative ideas to fix the business problems. Combining the concepts of different methods and philosophies like TQM, TOC, JIT, SIX SIGMA and SCM, some new tools can be developed to address various business problems.

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