International Journal of Engineering & Technology, 7 (4.10) (2018) 118-123

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Smart Manufacturing through TOC based Efficiency Monitoring System (TBEMS)

Balaji V [1]*, P. Venkumar[2], Sabitha MS[3]

[1] *ZF Electronics TVS India Private Ltd., & Research scholar, Kalasalingam University, balaji.v@zftvs.com*
[2] *Kalasalingam academy of research and education ,University of Sussex, p.venkumar@klu.ac.in*
[3] *ZF Electronics TVS India private Ltd., & Research Scholar,R & D center,Bharathiar University, muralisabi@gmail.com*
** Corresponding author E-mail: muralisabi@gmail.com*

Abstract

The very purpose of business is to devise profitability and enhance it in all possible avenues sustainable. In a manufacturing environment, thus, there had been a number of techniques and concepts adapted to improvise the effectiveness thereby profits continuously. Theory of Constraints (TOC) adopts a unique con-cept exploiting the constraint to deliver the customer needs. TOC is built on the premise that the weakest link determines the strength of the whole chain. With the advent of Industry 4.0, the manufacturing systems could be exploited to the next best level, leveraging the interaction of cyber physical systems and human beings over the internet. This paper deals with a novel idea of implementing TOC concept blended with Internet of Things (IoT), thereby, the speed of implementation could be augmented for early results. Evidently, the smartness of Things is derived based on the possibility of informed and proactive decisions. Hence all the productivity improvement techniques and concepts could be complemented with such concurrent information and analytics, thereby the learning and decisions are much smarter and proactive. A real time industrial environment has been chosen to experiment this approach and the results are furnished paving way for future research and improvisation globally on the industrial environment and on many other competing productivity concepts

Keywords: *Smart manufacturing, Internet of Things, Theory of Constraints, Cyber physical systems, Industry 4.0*

1. Introduction

In the complex ecosystem of competitiveness, a large number of organisations suffer from both cost escalation and negative sales trends. While the immediate counter management could be cutting costs and avoid investments, at the cost of survival, future competitiveness would be lost. Those organisations that have implemented ToC, however, continue to survive and grow even at hard times by means of im-proved productivity and bettered revenues. The enterprises which could shorten the throughput time and quicken the inventory turnover are distinctly successful. Among three approaches of MRP (Material Resource Planning), JIT (Just in Time) and ToC (Theory of Constraint), TOC emerges as a unique concept [10] due to its systemic approach that focuses on actively managing the scarce resources otherwise termed as bottlenecks that impact the organisation's progress towards maximising the profits.
On Enhancing of operational effectiveness, TOC (Theory of Constraints) has played a significant role since 1980s. Very few techniques match ToC because of its funda-mental approach to understand the relationship of each resource & its impact on whole system goal. In a production planning environment, TOC seeks to identify and manage the bottleneck operations, which is popularly termed as DBR (Drum Buffer Rope) concept.
The Internet of Things(IoT) is widely accepted as the enabler of 4th industrial revolu-tion by means of the worldwide network containing heterogeneous physical devices. It is predicted that more than 50 billion Things would be on the network by 2020. McKinsey global institute predicted that the overall impact of the IoT in 2015 on the global economy to amount to US$ 11 trillion [11]. This undoubtedly indicates the abundant role in sphereheading technical advancements which would necessarily open fresh avenues of productivity with agility and customization.
The aim of this paper is to propose a model to optimize the IoT implementation in the manufacturing setup. The challenge is to dynamically assess the changes in the process environment that could shift the constraint from station to station, process to process and seek managing such constraint resources with optimised application of IoT. While the end to end digitisation of production processes would definitely be superior in terms of gaining system knowledge and change management possibilities, it comes with challenges in both cost of initial outlay and much more importantly managing the exploding data. Principally by applying ToC concept to IoT implemen-tation itself, only the constraint process has to be managed and exploited to meet the desired goal. Hence, by empracing IoT to manage such constraint processes that are performing lesser than desired outcome results not only tune down capital cost but also in bringing down challenges in network traffic and managing huge data that would seek bettering every process and seek enhanced utilisation without any impact on global goal. Thus the emphasis is to clarify that the local best is not the same as global best, rather the constraint resources alone would impact the global outcome hence that alone needs to be worked through.
While many tools exist for Lean enhancement and productivity improvement, TOC distinctly differs from the standpoint of cause effect approach, demonstrating the dominance of Constraint resource on the outcome and aligning non constraint re-sources by the Drum buffer Rope methodology. In a nutshell, TOC does not seek to exploit the best out of each process, which would cost

enormous. Rather TOC laser focuses on the constraint to subordinate others. This approach not only improves the outcome, but ensures reduced inventory and operation expenses thereby enhanced profitability.
In this paper, Section 2 discusses the IoT and ToC related research references, Section 3 explains the architecture of the existing SBEMS (Sensor based efficiency monitoring system) system [6] the problem specification, Section 4 describes the proposed TBEMS system, Section 5 elaborates the experimental setup and results and the last section 6 infers the conclusion and possible future work..

2. Previous Work

Internet of Things (IoT) [1],[2],[3],[4],[5] is predicted to provide promising solutions to change the operation and the role of various industrial systems such as manufactur-ing and transportation systems.Niu Ling et al.,[5] proposed an IoT based remote data acquisition system. The real time monitoring, visualization and alerts for the abnor-mal occasion are handled automatically and remotely. Balaji.v et al.,[6] suggested a sensor based efficiency monitoring system (SBEMS) model which leads to smart manufacturing. This model provides an integrated solution for sensor fixed machines, data acquisition setup and data analytics to improve the shop floor visibility.
The concept of TOC was invented and popularised by Eli Goldratt later known as Optimized Production technology commercially. Kamal Ukay et al., [7] applied the TOC concept to identify the bottleneck process in a job work furniture shop that would determine the throughput with a vision to exploit them better and subordinate other processes for optimum inventory. The DBR concept has been applied for capacity planning and the time and workload on each process centre has been calculated for the given situation of job orders thereby identifying the constraint processes.
Suleiman et al., [8] attempted to recognise the requirements and also measures for applying ToC in the Jordanian Industrial companies and how ToC could impact the development and improvement of operations with bettered productivity and prof-its.The framework has taken into consideration the Customer expectations in terms of better services and competitive costs, the flexibility of operations to meet target costs, value identification and clean up non value activities to slim down bottlenecks and developing and enhancing cost management systems for profitability sought after by implementing TOC in an industrial environment. Roberto Panizzolo [9] has empirically studied the relationship between production that employed ToC and the outcome of operational performance in manufacturing companies. A Survey was conducted among a sample of 61 European companies that have implemented ToC approach.
Shamuvel et al [10], in their work “Application of Theory of constraints on Schedul-ing of DBR systems” deal with ToC and the scheduling DBR system and derive im-proved throughputs, reduction of WIP inventory and enhance on time deliveries to Customers by better utilisation of constraint resources. By its fundamental & generic approach, ToC could be applied to any industry and real time situations.

3. Existing SBEMS (Sensor based Efficiency Monitoring System)

SBEMS model provides an integrated solution to monitor the efficiency in a shop floor by implementing the connectivity between sensor affixed machines, data acquisition and data analytics. In manufacturing industries, shop floor is a zone where assembly or production is carried out by machines or by individuals. Modern approaches are required in this area to proactively act and improve the productivity and to mitigate the risks in the manufacturing plant.

An industrial IoT setup has been implemented in a manufacturing shop floor. The architecture of the IoT setup is represented in Figure 1.1.

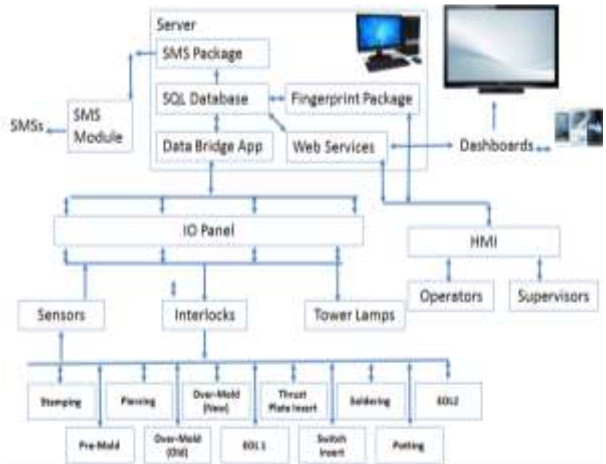

Figure 1.1: SBEMS IoT setup

The bottom most layer shows the machines like Piercing, Moulding, Stamping, Over molding, Thurst plate insertion, soldering, potting, over moulding and End of Line testers in a shop floor. In every machine, different types of sensors are attached to gather the machine related activities. A sensor is an object that triggers for the actions of machines. It converts the physical parameters to electrical signals. Even though various sensors are available in the market, infrared (IR), Reed and proximity sensors are chosen in this model to sense the activities. The shop floor machine communicates to the I/O panel with the help of sensors fitted in every machine. The purpose of the I/O panel is to convert the received signal into digital form. This will transfer the data to the data bridge application. With the collected data, the abnormal condition of the machines is notified with the help of tower lamp and interlock. This system provides web based monitoring system and sends SMS to the relevant people.
Even though the SBEMS model brings more benefits, the following problems need to addressed during large scale IoT implementation.
•Sensor and address related issues
•Network related problems
•Congestion Control
•Data buffers
•Network traffic and overloading
•Selection of relevant Software and Algorithm
•Storage and power problem
•Connectivity issues
To derive more benefit from the IoT setup in a real manufacturing plant, some optimisation needs to be done during the implementation process.

4. Proposed TBEMS – TOC based Efficiency Monitoring System

Even though the SBEMS model brings out intelligent insights and more benefits, it is not feasible for every organisation to implement such an online data analytics system due to its higher implementation and maintenance cost. Moreover, the IoT implementation need to handle the problems related to sensors, network related issues, control of network traffic, data standardisation , security issues and selection of an algorithm for the huge volume of data. Ultimately, it requires huge hardware investment, efficient algorithms, data standardization techniques, network setup, data management techniques and many others as listed in the previous section.

The SBEMS model of IoT setup is introduced to monitor all the machines in the par-ticular production line. In the TBEMS model, to extend the IoT facility to the entire factory, the TOC principle is applied to get the benefit of SBEMS at a lesser cost. Instead of introducing the IoT setup to the entire shop floor, the machine will be se-lected based on the bottleneck operations as the outcome of the ToC principle. The proposed system will be achieved in two steps

•Identification of bottleneck operations based on TOC principle
•Setting up IoT for the selected machines

The selection of bottleneck operation is depicted in Figure 1.2. ToC principle is used for the selection of bottleneck operation.

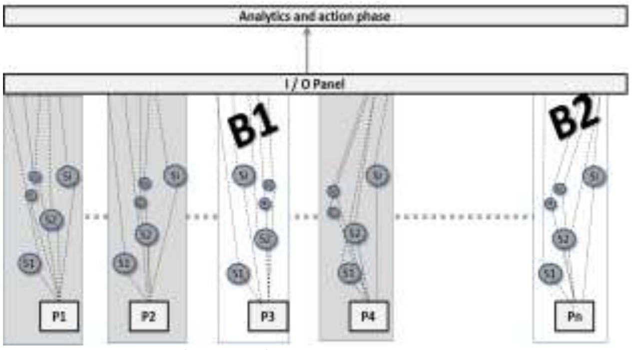

Figure 1.2: Identification of bottleneck operation in the assembly line

Figure 1.2 represents the assembly line layout. This plant is run-ning in three shifts and five days. It represents

P – Processes, P = P1, P2, P3,….. Pn – n number of processes where n – total of processes on the shop floor

B –Bottleneck operations, B = B1, B2, B3…Bm - m number of bottleneck opera-tions. m-number of bottleneck operations identi-fied. where m< n

S – Sensors, S = S1,S2, S3….Si – i number of sensors attached to each process – i – total number of sensors in each machine

Different types of Sensors attached to the machines.

The bottleneck operation (B) is identified in the assembly line. The selection is based on the ToC principle. The experiment re-sults are discussed in the next section.

TOC principles are introduced in the proposed TBEMS model which will automatically reduce the number of resources utilised in the IoT implementation. This is depicted in the below Figure 1.3.

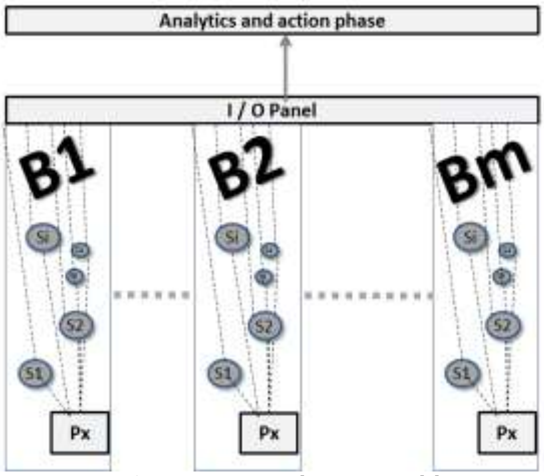

Figure 1.3: Proposed TBEMS model

In the proposed TBEMS model, the number of resources is mini-mised based on the selected bottleneck operations. Px are the pro-cesses identified as the bottleneck operations. The value of x var-ies between 1 to n. The setup cost is calculated based on SBEMS and TBEMS model.

SC – Sensor cost, SF – Sensor fitment cost and NL – Network laying cost

Uc is the implementation cost for the single unit. It sums up the SC, SF and NL for all the sensors connected to a single machine to perform the respective process. In SBEMS , Uc needs to be calculated for all the processes. However, in TBEMS this cost calculation is required only for the machines which come under the bottleneck process

$$Uc = \sum_{s=1}^{i}(SC + SF + NL) \quad (1)$$

TBEMS model of IoT implementation is represented in Figure 1.3. The implementation is carried out only for the bottleneck opera-tions identified with through ToC principle. Px are the processes selected as a bottleneck. B1 , B2.. Bm are the bottleneck opera-tions.

Additional semi variable charges required to be included in the cost calculation of SBEMS and TBEMS model along with the unit cost.

Svc – Semi variable cost Scr – Reduced semi variable cost Sd - Semi variable cost difference

The overall implementation cost of the SBEMS model is repre-sented as Oc. Svc cost is added Along with the sum of all Unit costs.

$$Oc = \sum_{P=1}^{n}(Uc) + Svc \quad (2)$$

The implementation cost for the bottleneck operations in the TBEMS model is represented as Bc. Instead of the semi varible cost addition, reduced semi variable costs need to be added in the cost calculation. Even though the semi variable cost is common for all the processes, based on the number of processes this will change and reduces the cost in terms of server, I/O panel, man-power and database management.

$$Bc = \sum_{B=1}^{m}(Uc) + Scr \quad (3)$$

The cost benefit of implementing IoT using TBEMS model over SBEMS model is represented in Rc .

$$Rc = \left(\sum_{P=1}^{n}(Uc) - \sum_{B=1}^{m}(Uc) \right) + Sd \quad (4)$$

$$Sd = Svc - Scr \quad (5)$$

Due to the lesser number of sensor connectivity in the proposed model, proportionately the I/O panel , server cost will become low. It involves lesser energy in terms of cost , computational method-ologies and database administration. The proposed TBEMS mod-el involves lower resource utilisation, lesser cost, simple computa-tional methodologies and easy database management.

4. Experimental Setup and Results

In this paper, a manufacturing assembly line is considered for IoT implementation with the TOC principle. In the selected assembly line, eleven machines are used to carry out 11 processes like Pre moulding, Over moulding, Soldering, Pre heating, Potting and etc., The initial step is to identify the bottleneck process using TOC prin-ciple. Bottleneck operation is a process which affects the throughput of the whole chain due to its limited capacity. In this experiment, the bottleneck operation is iden-tified as in 5.1.

5.1 Bottleneck Operation Identification

Step1: System constraint identification

The constraint is the weakest link in the chain, the factor that most limits throughput (T), the rate at which the organization generates 'goal units' Figure 1.4 indicates the demand, output produced in a shift and constraint operations.

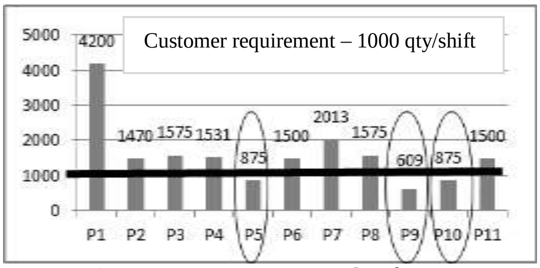

Figure 1.4: system constraint identification

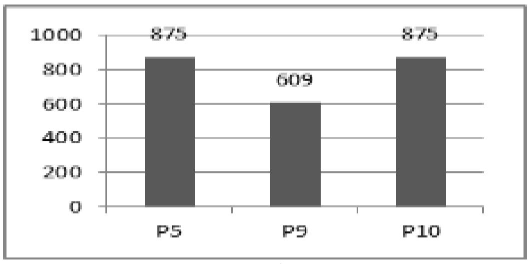

Figure 1.5: Identified bottlenecks

In Figure 1.4, the customer required quantity 1000 is compared with the output per shift for each process. Processes P5,P9 and P10 are identified as bottleneck opera-tions. P9's production quantity is lower than all other processes. Hence it is consid-ered as the first bottleneck. Though P5 and P9 have the same capacity constraint P5 is considered as the second bottleneck operation as it is in the upstream. However, no of constraints may dynamically vary based on the customer demand fluctuations.

Step 2 : Exploiting the System constraint.

Once the constraint is identified, the productivity to be maximized at the constraint. The following activities were carried in the bottleneck operation .

P9: Soldering:

a) Kaizen is introduced to avoid rework & Rejection

b) A cross functional team of people was formed and the rework reduced to 2% from 30%.

c) Resource Buffer created before the constraint process so that the constraint pro-cess is not starved for input and insulated from upstream process variation.

d) 15% cycle time and 25% change over time reduced through Kaizen activities.

e) Process parameters are further optimized by expert guidance.

P5: Overmoulding

a)Tooling was carried out to avoid secondary operation after the process.

b)Resource Buffer created before the constraint process so that the constraint process is not starved for input and insulated from upstream process variation.

P10: Preheating & Potting

a) A cross functional team of people was formed to reduce the rework and appropriate fixtures were modified to completely eliminate the rework and rejection.

b) 100% availability ensured at the constraint station by introducing predictive maintenance of the equipment.

Figure 1.6 shows the outcome of the results after introducing the actions recommend-ed in this step. After introducing the activities indicated in step 2, the capacity in the all three bottleneck operations has been improved.

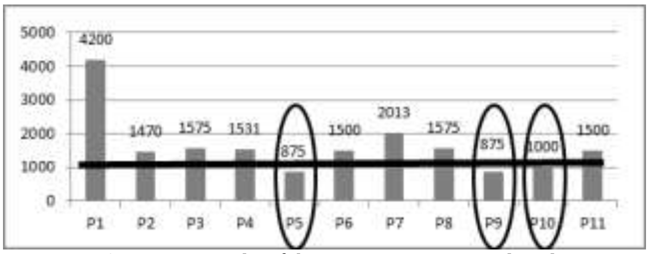

Figure 1.6: Results of the system constraint exploited

Even after executing the above modification, there is a gap between customer asking rate (1000 per shift) and the capacity of constraint operations (875 per shift). Hence, additional shifts have been planned on weekends to compensate the gap between the weekly customer demand and the bottleneck output. This means instead of 18 shifts per week, 19 shifts are organized which in turn brings down the asking rate per shift to 875 nos.

Step 3. Subordinate everything else to the above decision

All the upstream processes are to be subordinated to ensure the avoidance of imbalanced inventory build-up. The following activities were carried out to subordinate the bottleneck operation:

The Material is released in the assembly line at the same rate as the bottleneck operation can consume it.

Customer orders are shipped at the rate of bottleneck operation production out-put.

Upstream operations must provide only what the bottleneck operation can handle.

Bottleneck operation was kept operating at its full capacity.

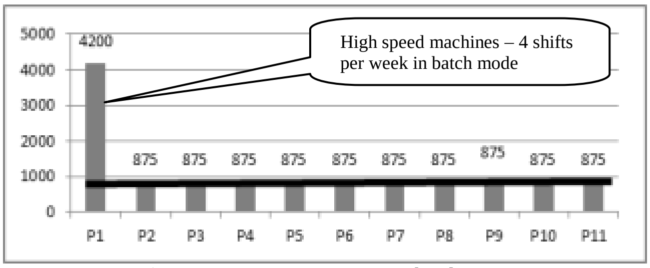

Figure 1.7: system constraint subordination

Step 4: Elevate the system's constraint(s)

Strengthening the bottleneck operation could be done by increasing its capacity (e.g. Hiring more people, buying a new machine). This is done in the fourth stage because it usually involves a high cost. Often exploitation of the constraint is sufficient as it was experienced in the process P10.

Step 5.If in the previous steps a constraint has been broken, go back to step 1.

By strengthening a weakest link, it may not be the weakest link anymore. The new weakest link needs to be identified and reexamine all decisions regarding the exploita-tion and subordination. When the constraint shifts, a re-orientation of the entire pro-cess is required.

As per ToC principle, only the bottlenecks are managed to match the desired rate of output. Any eventualities in the non-constraint processes are compensated by creat-ing buffers just before the first constraint station and also just before the delivery station. Earlier studies on the processes would reveal the quantum of buffer that has to be managed at these two locations.

5.2 Resource Utilisation

The overall cost for the resource utilisation is calculated based on the formula in (2) and (3). This experiment in conducted in a product contains 11 processes and 3 processes are identified as bottleneck operations and the final cost is given below. The individual unit cost is calculated as $\sum_{s=1}^{i}(SC + SF + NL)$. The individual Unit cost values are considered for the calculation of Oc (overall cost) and Bc (Bottleneck cost) as given in (2) and (3).

Table 1: Resource utilisation for the SBEMS / TBEMS model

Resource	SBEMS qty	SBEMS cost	TBEMS qty	TBEMS cost
Sensors	33	82500	9	22500
HMI unit	11	275000	3	75000
Network connectivity		25000		7000
I/O Panels	2	40000	1	30000
Server	1	900000	1	265000
Tower lamp	11	22000	3	6000
Total Cost		1344500		405500

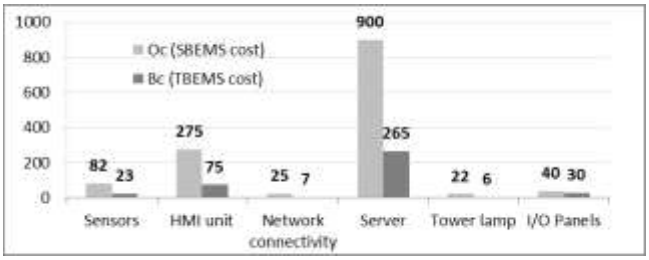

Figure 1.7: Existing / TBEMS implementation cost calculation

Figure 1.7 represents the cost comparison between SBEMS and TBEMS model. Due to security reasons and organization policies, on premises server is used for data storage. The IoT implementation for all the process generates huge volumes of data, thus it requires high process and high storage database server . But for the less volume of data , normal start up the server is sufficient to handle the data stream. The overall cost Oc (SBEMS) is Rs.1344 K and the proposed model cost Bc (TBEMS) is Rs.405 K. The Rc (Reduced cost)is calculated as per the below formula.

Rc = ($\sum_{P=1}^{n}(Uc)$ - $\sum_{B=1}^{m}(Uc)$) + Fd

The final cost saving as per the experiment is Rs . 939 K. The cost is reduced to approximately one third of the actual cost.

In this experiment, only three processes are identified as bottleneck operation out of 11 processes. But the cost is not exactly the multiples of the number of processes identified as a bottleneck. It involves additional Fcr for basic IoT setup. This work is evident that the implementation cost is much lower than the implementation of the IoT in the entire plant.

5.3 Data Inflow

This experimental setup liberates 3 sensor data from each machine for every milliseconds. It liberates data only when the machine is in the ON condition. The data inflow is monitored in the TBEMS system and the complete IoT set up stations The data inflow will vary depends on the availability of the machines. The number of records generated is listed in the Table 2.

Table 2: Resource utilisation for the existing model and TBEMS model

Number of records in Nos Lacs	1 day	7 days	15 days	20 days
SBEMS	3168	21200	45030	620500
TBEMS	860	5887	12286	168227

In Figure 1.8, Data inflow is monitored for the entire IoT setup (SBEMS) and TBEMS model of implementation. It clearly indicates that the data inflow is much lower in TBEMS model. Due to the lesser data inflow, this model will consume less energy , space and computational time for all kind of database related activities like query processing, storage and analytics.

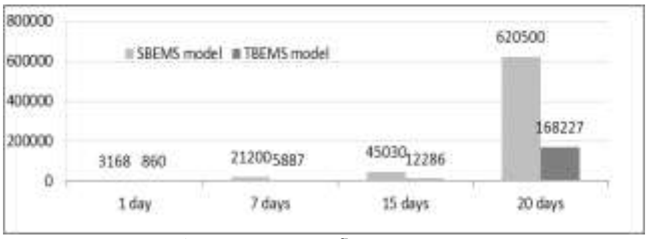

Figure 1.8: Data inflow comparison

5.4 Network Related Problems

Due to less consumption of network related resources , it lowers the network traffic, avoiding data loss, handling of data buffers and connectivity issues. The network related issues monitored in the experimental setup . The results are depicted in Figure 1.9.

Table 3: Network related issues

Network related issues	1 week	1 month	2 months	3 months
Entire IoT setup	0	2	3	5
TBEMS	0	0	0	0

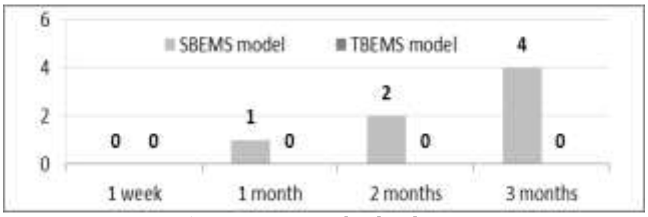

Figure 1.9: Network related issues

5. Conclusion and Future Work

To achieve competitive advantage, industries must use technological advances effectively. The unique approach discussed above combines ToC and IoT and practically seeks best of both worlds. On one hand ensuring smartness of the system is exploited for bettering productivity with the application of IoT, on other hand the installation of connectivity is effectively applied to constraints alone, thereby optimising the cost.

In future, further research on both physical layers and analytical domain and evaluating the ratio of cost Vs outcome would open new avenues of understanding more customised approach of applying IoT while exploiting best of ToC. For example, the user could selectively control spends on digitisation levels on physical things and / or customised analytical algorithms to deal constraint locations alone elabourately while seeking only the subordination of non- constraint processes thereby cutting down the scale of data handling and related challenges coupled with costs.

References

[1] Li Da Xu, Senior Member, IEEE, Wu He, and Shancang Li, Internet of Things in Industries: A Survey, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 10, NO. 4, NOVEMBER 2014,

[2] Zhuming Bi, Senior Member, IEEE, Li Da Xu, Senior Member, IEEE, and Chengen Wang, Senior Member, IEEE, Internet of Things for Enterprise Systems of Modern Manufacturing, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 10, NO. 2, MAY 2014

[3] Andrew Whitmore & Anurag Agarwal & Li Da Xu, The Internet of Things—A survey of topics and trends. Springer Science+Business Media New York 2014

[4] CHARITH PERERA1, (Member, IEEE), CHI HAROLD LIU2, (Member, IEEE),SRIMAL JAYAWARDENA1, (Member, IEEE), AND MIN CHEN3, (Senior Member, IEEE), A Survey on Internet of Things From Industrial Market Perspective, This work was sponsored by National Natural Science Foundation of China under

Grant 61300179. This work was also supported in part by the International Science and Technology Collaboration Program (2014DFT10070) funded by China Ministry of Science and Technology (MOST).

[5] NIU Ling, Design of Remote data acquisition system based on Internet of Things, Advanced Science and Technology Letters, Vol.79, pp.32-36, 2014

[6] Balaji V., Venkumar P., Sabitha M.S., Vijayalakshmi S., Rathikaa Sre R.M. (2018) Smart Manufacturing Through Sensor Based Efficiency Monitoring System (SBEMS). Proceedings of the Eighth International Conference on Soft Computing and Pattern Recognition (SoCPaR 2016). SoCPaR 2016. Advances in Intelligent Systems and Computing, vol 614. Springer, Cham

[7] Kamal Ukey, Pranay B Sawaitul,Organization planning using theory of constraints, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),e-ISSN: 2278-1684, p-ISSN: 2320-334X, PP 01-05

[8] Dr. Suleiman Hussein Al-Beshtawi,The Role of the Theory of Constraint (TOC) e Shares are Listed in Amman Stock Exchange Market,European Journal of Business and Management www.iiste.org ISSN 2222-1905 (Paper) ISSN 2222-2839 (Online) Vol.6, No.16, 2014

Roberto Panizzolo , Theory of Constraints (TOC) Production and Manufacturing Performance International Journal of Industrial Engineering and Management (IJIEM), Vol. 7 No 1, 2016, pp. 15-23 Available online at www.iim.ftn.uns.ac.rs/ijiem_journal.php ISSN 2217-2661