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A TOC-OEE Based Scheme to Improve Productivity

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Abstract

A highly competitive environment is forcing companies to implement various productivity improvement efforts. Implementation of total productive maintenance (TPM) concepts has led to important improvements at the equipment level. Even though, these are significant, they are insufficient because what a company needs is to improve at the plant level. In order to achieve this result an approach based on the overall equipment effectiveness (OEE) with the purpose of increasing productivity at the manufacturing system level is required. This paper suggests a hybrid approach structured with Theory of Constraints (TOC) and OEE concepts. It also illustrates it with an application in a Mexican firm.

Keywords
Overall equipment effectiveness, Overall throughput effectiveness, Theory of constraints, Continuous productivity improvement

1. Introduction
The evolution towards a global economy has increased the level of competition for virtually all businesses. In order to maintain the level of competitiveness, it is required that firms get better at what they do and at satisfying customers' expectation. As noted by Fleischer *et al* (2006), the competitiveness of manufacturing companies depends on the availability and productivity of their production facilities. Huang *et al* (2003) also states that due to intense global competition, companies are looking to improve and optimize their productivity in order to remain competitive. This would be possible if production losses are identified and eliminated so that the manufacturers can bring their products to the market at a minimum cost. This situation has also led to the need for a performance measurement system that account for the different important elements of productivity in a manufacturing process.

As Hansen (2002) states, the Overall Equipment Effectiveness (OEE) has been recognized as a fundamental method for measuring equipment performance. The OEE measure attempts to identify wastes and the costs associated with a piece of equipment. However, as Scott et al., (1998) point out the gains made in OEE at the equipment level, are not enough. It is necessary to focus beyond the performance of individual machines towards the performance of the whole factory. The main goal is to have a very efficient integrated system. They recommend the concept of overall factory effectiveness (OFE). Under this concept the purpose is about identifying opportunity areas for improving the manufacturing system as a whole.

This paper is focused on the development and application of an alternate productivity improvement scheme to the one provided by Huang, et al., 2002. This suggested scheme is based on Theory of Constraints and the OEE concept. The document is divided into various sections. The following section makes a review of relevant literature. Then, a description of the suggested scheme is given in section three. Section four provides a summary of the application of the scheme in a Mexican company. Finally, the last section provides conclusions and suggestions for future research.

2. Relevant Literature
There is considerable amount of literature on manufacturing system productivity measurement and improvement. Muthiah, et al., (2006) reviewed several productivity improvement methods. Some of them based on Operations research and control theory. Others are based on System analysis. Continuous productivity improvement methods such as lean manufacturing and six Sigma are empirical methods established by practice.

The total productive maintenance (TPM) concept, proposed by Nakajima (1988) can also be used as the basis for defining productivity improvement strategies. This concept suggests a quantitative metric called Overall Equipment Effectiveness (OEE) for measuring productivity of individual equipment in a factory. It identifies and measures losses of important aspects of manufacturing operations such as availability, performance and quality rate.

The three measures (availability rate, performance rate and quality rate) captured by the OEE measure indicate the degree of satisfaction to output requirements. As pointed out by Williamson (2006), the OEE measures the degree to which the equipment is doing what it is supposed to do based on availability, performance and quality rate. The OEE tool is designed to identify losses that impact on equipment effectiveness. The six big losses considered by OEE are breakdown losses, Set-up and adjustment losses, idling and minor stoppage losses, reduced speed losses, quality defects and rework, and finally, reduced yield during start-up. The value of OEE, which is a function of availability (A), performance (P) and Quality rate (Q) is obtained by the product of their values.

2.1 Evolution of OEE

Though the OEE tool has become increasingly popular, it is only limited to measure productivity behavior of individual equipment (Huang *et al*, 2003). As Oechsner *et al*, (2003) state, the final goal of any factory is to have a highly efficient integrated system. This weakness of the OEE tool has led to its modification to fit different and broader perspectives in the manufacturing systems. Therefore, different modified formulations have emerged in the literature. Some of these are the Total Equipment Effectiveness Performance (TEEP) proposed by Invancic (1998) and the Production Equipment Effectiveness (PEE) formulated by Raouf (1994).

Oechsner *et al*, (2003) extended the OEE concept to measure the factory level effectiveness, where several production steps or machines are included to form a production process. The authors suggested a new measure called overall factory effectiveness (OFE). Another approach proposed by Huang *et al (2003)* considers simulation analysis as the most reliable method in studying the dynamic performance of manufacturing systems. The authors define another metric, overall throughput effectiveness (OTE), developed on the basis of OEE metric, for complex connected manufacturing systems. These metrics are integrated with simulation analysis for manufacturing productivity improvement.

The previous concepts can be included into a general framework with two levels of effectiveness measurement, one at the equipment level and another at the business level. This framework can be further extended one more level upwards to incorporate the supply chain. At this level, the effectiveness measure has to be adapted to consider not only manufacturing plants but distribution installations such as warehouses and cross-docking points and transportation assets such as trucks and railroad equipment. Transport efficiency was originally suggested by Simmons et al., (2004) for truck transportation. They suggested the Overall Vehicle Effectiveness (OVE) as the effectiveness measure for trucks. This measure is very similar to the OEE. It also considers the estimation of the availability, performance and quality efficiency factors. These are then multiplied to produce an overall OVE percentage rate. This measure converted the OEE losses from manufacturing to transport operations. Villarreal (2012) suggested an alternate transport efficiency measure called Total Operational Vehicle Effectiveness (TOVE) which includes additional loss concepts, recommends total calendar time and separates the availability factor into administrative and operational availability factors.

3. Description of Improvement Scheme

The improvement scheme of interest in this work uses the effectiveness measure at the plant or factory level. In particular, we are interested on the concept suggested by Huang, et al., (2002). The authors developed a procedure to estimate the OTE metrics for a series manufacturing system. They also designed an improvement procedure based on Theory of Constraints (TOC) and information provided by the OEE values of each Production Process. Further, Muthiah, et al., (2007) extended these concepts to other manufacturing sub-systems based on a system constraint approach. These sub-systems could be set in parallel, assembly and expansion types.

As Goldratt, et al., (2012) suggest, the productivity of the manufacturing system is determined by a bottleneck or the most constrained capacity resource. Huang et al., (2002) state that this type of resource is the one with the highest OEE value. Thus, the procedure they develop is fit into the five-step improvement cycle designed by

Goldratt et al., (2012). The first two phases are designed to estimate the OEE values for each production resource. The third phase consists of the identification of the bottleneck or most constrained resource. This is done by identifying the resource with the highest OEE value. Once this is carried out, the identification of wastes or losses is the next task. These are associated with the availability, performance and quality efficiency factors of the bottleneck. The final phase of the procedure includes the definition of projects or actions with the purpose of eliminating the wastes found. This is done until the constraint is broken. The process is repeated if a new constraint is identified and it is desirable to continue improving the productivity of the manufacturing system. The previous procedure is constructed such that it is required to have all the OEE values for each capacity resource of the operations system. This is so because the identification of the bottleneck is done with this information.

The procedure suggested in this paper is very similar. However, it does not require all the OEE values for each capacity resource. The determination of the bottleneck or capacity constrained resource is carried out through a load analysis and the elaboration of a value stream map. Thus, the only OEE value required is the associated with this resource. This alternate procedure is described as follows:

(1) Elaborate the Value Stream Map and a capacity load analysis for the process of interest.
(2) Identify the bottleneck or more restrictive resource. Estimate its OEE index and corresponding efficiency factors.
(3) Exploit and elevate the bottleneck by identifying and implementing waste elimination initiatives for the undesirable efficiency factors.
(4) The previous step continues until a new bottleneck is found or management decides to stop. If a new bottleneck is found, continue to step 2. Otherwise, the process ends.

The application of the previous methodology is described in the following section.

4. Application of the Scheme

The implementation of the alternate procedure is exemplified using information provided in Garza, et al., (2010) on the warehousing operations of a Mexican company that produces and distributes frozen and refrigerated food. This company is experiencing a high pressure to decrease operating cost and improve its customer response time.

The company´s distribution network has a primary distribution network that sends product from plants to Central Distribution Centers (CDC´s), and from these to Regional Distribution Centers (RDC´s). This network includes thirteen plants, five CDC´s and seventy four RDC´s located across México. It is divided into five geographical regions. This paper focuses on the application on the Northeastern region.

For this case, the OEE measure is adapted to identify wastes to improve warehousing operations. Figure 1 illustrates the relevant losses involved in this measure. Four components for the efficiency measure are included; Administrative or strategic availability, operating availability, performance and quality. Waste identification is supported by the elaboration of a Value Stream Map (WVSM) for all warehousing operations including specific efficiency information for the bottleneck resource.

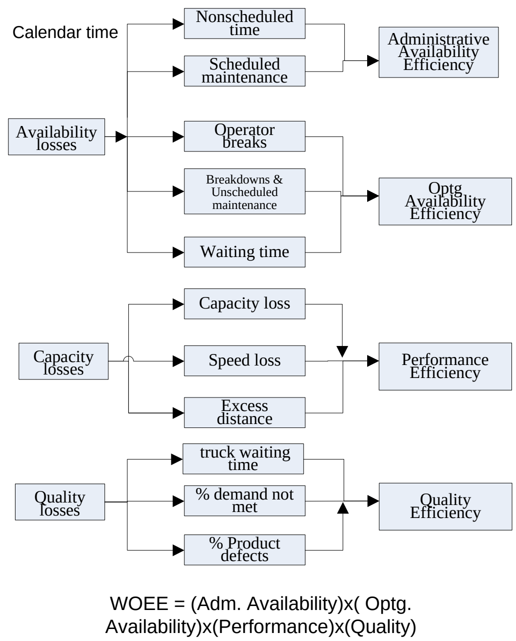
4.1 Mapping the warehousing process

Figure 2 illustrates the value stream map of the warehousing operations at the CDC. The main activities of the CDC are: Unloading, receiving, put-away, storing, picking, packaging and shipping. It works three shifts with an average daily demand level of about 350 pallets per day. Takt time is estimated at 3.8 minutes.

Initially, the bottleneck resource identified is the Automated Storage Retrieval System (AS/RS) with a current cycle time of 8.4 minutes. The main areas identified for improvement are associated to its performance and operating availability efficiency factors. It is important to mention that even the customer service provided by the CDC to its clients is satisfactory with a fill rate of 92.5%. However, current truck waiting times are significantly high due to a very deficient synchronization with the transportation system of the chain.

4.2 Exploiting and elevating the first bottleneck

A detailed analysis of the performance and availability efficiency factors of the Automated Storage Retrieval System (AS/RS) was carried out. The system is required to handle pallets between the reception area, the high-rise racks and the first-level racks where picking is done. The pallet storage scheme is originally random.



Adapted from Garza, et al., (2010)

Figure 1 Effectiveness Measure Elements

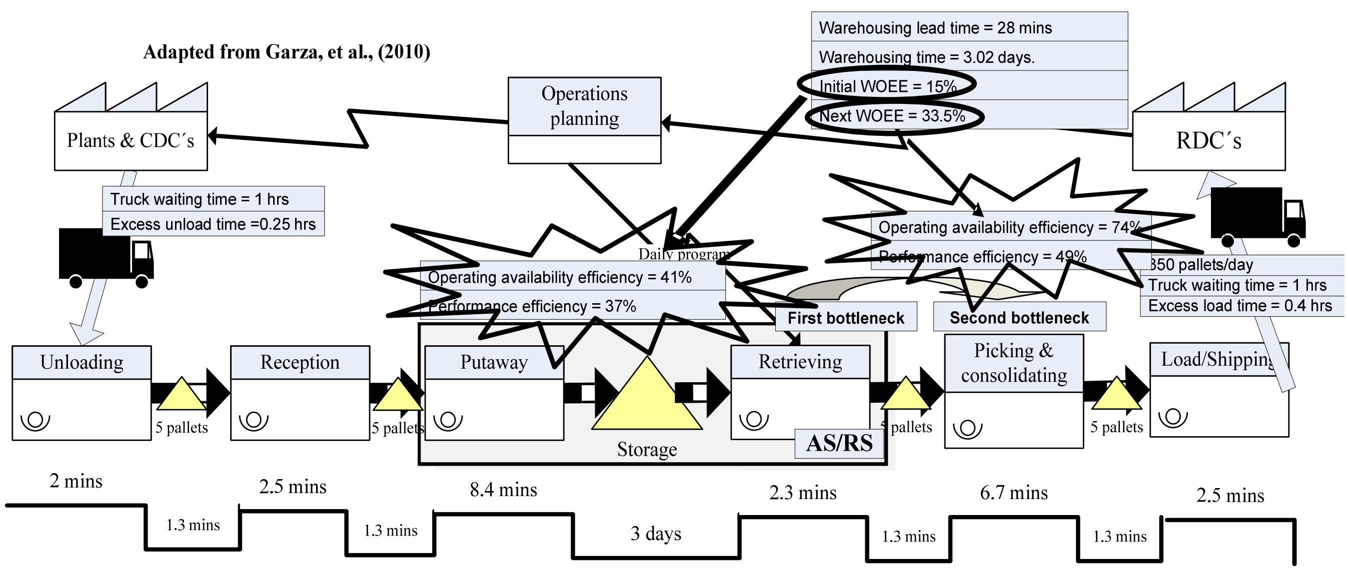


Figure 2 Value Stream Map of Distribution Center

The types of wastes that impact the performance efficiency factor are capacity, speed and distance losses. The capacity of the system is under- utilized because half of the moves carried out are empty. The ideal performance should consider every move of the system 100% loaded with pallets. Additionally, 13% of the moves are used to re-locate pallets among different rack positions. Due to the previous situation the system travelled distance in excess that was considered as a loss. The operating availability efficiency factor is estimated at 41%. About 13% of the time the system is down due to breakdowns and corrective maintenance. Additional idle time is caused by pallets incorrectly packaged that impede the AS/RS system to identify and locate them at the right position.

There is also incoming pallets with a mix of food items that need to be des-palletized to be stored afterwards. Table 1 illustrates a summary of the selected waste elimination initiatives.

Table 1 Summary of waste reduction initiatives for first bottleneck

Initiative	Impact
- Redesign layout according to ABC on sales. - Program truck arrivals and departures.	Increased performance factor 39%.
- Reinforce preventive maintenance program. - Program truck arrivals and departures.	Increased availability 24%.

After implementing these initiatives cycle time per pallet decreased to 4.2 minutes breaking the initial bottleneck. Now, the picking operation becomes the next bottleneck.

4.3 Identify and exploit next bottleneck

The warehousing efficiency is now based on the efficiency factors of the new bottleneck (see Figure 2). This is estimated at 33.5% with a performance efficiency of 49% and an operating availability factor of 74%.

The picking activity is executed in the first level of the warehouse. It starts with the identification of the items that will be shipped to the RDC´s from the orders placed by each of them. These are retrieved by the AS/RS system from the second and third levels and relocated at the first level. The fork lift operator moves the items to the picking and consolidation area where each RDC order is consolidated and palletized. These are then moved to the shipping area. The improvement options in this operation are the distance travelled in excess by the fork lift due to an inefficient layout and picking procedure, and the waiting time originated by the deficient supply of packaging materials. Table 2 shows a summary of the implemented initiatives and the expected impact on performance and availability. The new cycle time per pallet obtained was 3.6 minutes.

Table 2 Summary of waste elimination initiatives for picking operation

Initiative	Impact
- Redesign layout according to ABC on sales. - Redesign of picking scheme.	Increased performance factor to 95%.
- Define packaging materials inventory system	Increased availability to 95%

Figure 3 presents both; the original and the new picking layouts and schemes. In summary, the proposed option decreases picking time per pallet in 33%.

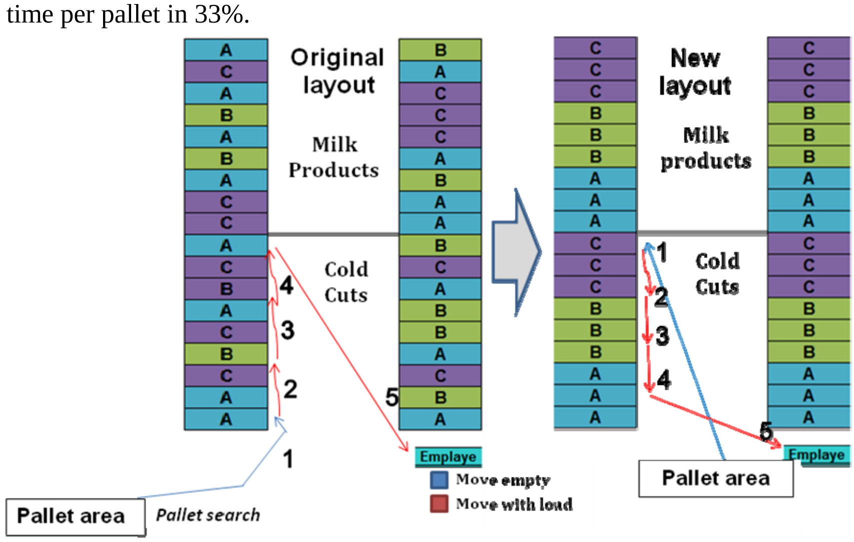


Figure 3 Redesign of picking layout and scheme

The packaging materials were originally supplied every morning considering a lot size that would satisfy daily demand. This procedure was changed for a Kanban system designed to pull materials as needed to cover current demand.

4.4 Improving the last bottleneck

The improvement process may continue until there are not bottlenecks in the warehouse or a goal established by Management has been reached. For this application, the operation with the AS/RS becomes again the bottleneck. Now, the performance efficiency factor is 76% and the availability efficiency is 65%. The projects considered for reducing waste have the objective of improving availability. These are: A poka-yoke procedure to identify incoming pallets with mixed items and those incorrectly palletized, and a new area for re-palletizing items was also designed. The poka-yoke considered is a sensing device similar to the one used in the AS/RS system to identify the position to store each pallet. However, this will now be located at the T-51 car that feeds the pallets to the AS/RS system. This will prevent feeding incorrect pallets into the system. The second initiative consists of a new redesigned layout to palletize items coming in mixed pallets. These efforts improved availability 15% and cycle time is decreased to 3.4 minutes. Figure 4 presents the new WVSM. There is not bottleneck operation this time.

5. Conclusions

This paper is focused on the description and application of an alternate productivity improvement scheme to the one provided by Huang, et al., 2002. This suggested scheme is based on Theory of Constraints and the OEE concept. This scheme differs from in the manner that the bottleneck resource is identified. This simplifies the need to gather information to estimate OEE values for all the production resources of the operations system. The scheme is exemplified applying it to improve the productivity of warehousing operations of a Mexican company. The firm required a decrease of distribution cost by increasing warehousing productivity by at least 20%. The goal established by the firm was attained and after reviewing the results they decided to continue further the efforts with the new objective of decreasing the cycle time to reduce the operating daily time from three to two shifts.

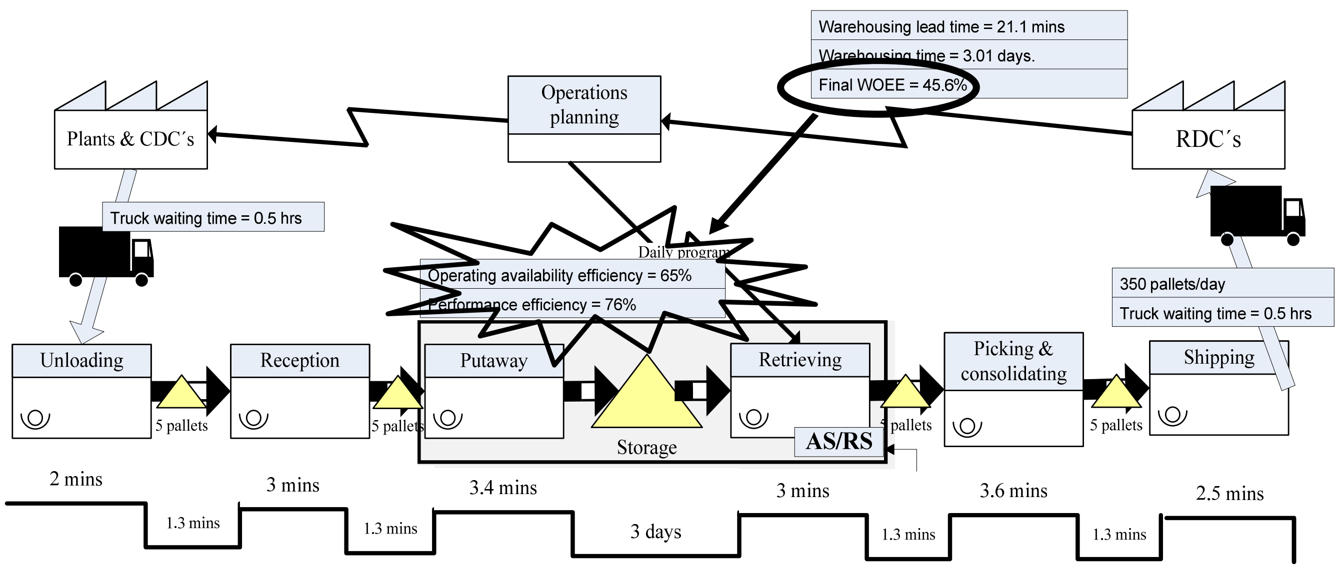


Figure 4 Final Value Stream Map of Distribution Center

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Biography

Bernardo Villarreal is a Full Professor in the Department of Industrial Engineering at the Universidad de Monterrey, México. He earned a B.S. in Industrial Engineering from the Universidad Autonoma de Nuevo León, an MSc and a PhD in Industrial Engineering from State University of New York at Buffalo. He has about 17 years of professional experience in the areas of operations management and strategic planning for several Mexican companies. His academic experience extends for about 20 years in institutions such as the Universidad Autonoma de Nuevo Leon, Instituto Tecnológico y de Estudios Superiores de Monterrey y la Universidad de Monterrey. He has published journal and conference papers in the areas of operations management, industrial engineering, logistics and operations research. He is a member of IIE, ASQ, INFORMS and POMS.

Nancy Lopez is a recent former student of the Universidad de Monterrey (UDEM). She holds a BS in Industrial Engineering and is currently and MBA student from this institution. Nancy is currently working as a Logistics and Traffic Manager for the Sigma Foods Conglomerate.