# The Factory Physics for the Scheduling: Application to Footwear Industry

John Reyes[1], Darwin Aldas[2], Kevin Alvarez[1], Mario García[1] and Mery Ruíz[2]
[1]*Faculty of Engineering Systems, Electronics and Industrial, Universidad Técnica de Ambato, Chasquis Avenue and Río Payamino Street, Huachi Campus, Ambato, Tungurahua, Ecuador*
[2]*Faculty of Accounting and Auditing, Universidad Técnica de Ambato, Chasquis Avenue and Río Payamino Street, Huachi Campus, Ambato, Tungurahua, Ecuador*

Keywords: Productivity, Job Scheduling, Theory of Constraints, Work in Process, Cycle Time, Little Law, Promodel, Process Simulation.

Abstract: In this paper, an analysis is made of variables such as inventory in process, cycle time and rate of production of salable units proposed in the theory of constraints and applied in a case study in the manufacture of safety footwear. The methodology used to evaluate these parameters is an experimental design with application of Plant Physics laws in a simulation scenario with PROMODEL. The results reflect that the optimum quantities of production for a cycle of work are achieved by adding 8.1% to the rate units that can be sold per unit of time and reducing cycle time by 6.5%. It was determined that to produce a transfer batch the inventory in process for each order hour is equivalent to 64% of the total of the units programmed for production based on the maximum capacity of the manufacturing system.

## 1 INTRODUCTION

Effective production scheduling is essential for successful operations that allocate resources over time for specific tasks (Krajewski, et al., 2016), so an unbalanced workload causes uncertainty in organizations (Zhang & Wang, 2016).

In this context, optimal planning efficiency is achieved by coordinating the production schedule with Just in Time (JIT) distribution planning to customers (Johar, et al., 2016), meeting deadlines, optimizing resources, reducing time that does not add value and increasing the production rate of the system. By implementing operational planning, scheduling, and production control strategies organizations can make money today and in the future (Goldratt & Cox, 2014).

Successful companies offer products and services with optimal times of production and inventory turnover, so three production management approaches are important to achieve this goal: Material requirements planning (MRPI, and MRPII), Just in Time production and Theory of Constraints (TOC).

TOC as a systematic management approach focuses on eliminating the bottlenecks that prevent a company's progress towards its goal of maximizing profits and effectively utilizing the resources of the production system (Mahapatra & Amit Sahu, 2006). The productivity of a production system must increase while its inventory and operating costs are reduced, limited by the performance in the constraint using TOC in the weakest link in the supply chain (Günay, et al., 2014).

Factory physics provides a systematic description expressed as laws of the underlying behavior of a system. It helps to decide what performance measures to collect and what alternatives to evaluate, as well as in the interpretation of simulation results (Standridge, 2004).

To obtain a synchronized manufacturing process, techniques are applied that analyze the constraints of the production system, such as cycle time (CT), which is the time a product spends since it enters the system until it leaves, work in process (WIP) defined by the inventory in process in the system and the throughput (TH) referred to the rate units that can be sold per unit of time. These techniques are based on the approach proposed by Li, et al. (2005), mentioning that the CT is an important indicator to measure the performance of the factory. Sometimes it is possible to lower the WIP level; however, excess



Reyes, J., Aldas, D., Alvarez, K., García, M. and Ruíz, M.
The Factory Physics for the Scheduling: Application to Footwear Industry.
DOI: 10.5220/0006403402480254
In *Proceedings of the 7th International Conference on Simulation and Modeling Methodologies, Technologies and Applications (SIMULTECH 2017)*, pages 248-254
ISBN: 978-989-758-265-3

WIP reduction can lead to decreased throughput. Applying the Principles of Factory Physics, which integrates Little's Law and the Operation Curve to quantify the interdependence between operating factors such as the Overall Equipment Efficiency (OEE), CT, and WIP can be reduced the WIP level by up to 10%.

Managing production scheduling has always been a major challenge not only in the footwear industry but in any field of production or service (Li, 2010). Reyes, et al. (2016), when applying the TOC model, proposes a management methodology for the inventory of materials in the footwear industry, which generates 18.7% of annual cost savings. However, even today, footwear production processes continue being totally artisan and the industries still follow the conventional make to order production (Cocuzza, et al., 2012).

Production planning and scheduling must evolve and adopt new tools that help gain a deeper control of what must be produced to efficiently meet customer needs (Zangiacomi, et al., 2007). One of the tools currently used to visualize the results that propose strategies and methodologies of process improvement, is the use of simulation software.

Simulation is a necessary tool to represent this reality and make decisions that further reduce manufacturing costs by validating the design or redesign of any complex system such as footwear. In this particular case the simulation is necessary for the initial estimation of the throughput since a single worker must perform multiple operations in several workstations and the controls on the quantity of inventory in process must be validated as well as the costs of production (Grimard, et al., 2005).

The footwear industry presents WIP accumulation caused by incorrect distribution of work areas, inadequate production schedules and orders of products not released on time (Marcelo, et al., 2016). The accumulation of WIP generated by improper use of job measurement techniques and erroneous sales forecasts implies the execution of production orders with long delivery times and orders that are not met. The congestion of the productive system with the presence of constraints finally reduces throughput and business productivity.

This research proposes a study of the parameters for shoe production through the detection of manufacturing system constraints and their evaluation with the laws of factory physics.

Using simulation with PROMODEL in a case study, optimal results of TH, WIP and CT are obtained with standard values of inventory in process that an optimum shoe manufacturing system must maintain to achieve the shortest cycle time and the highest rate of production.

## 2 METHODOLOGY

The footwear industry in Ecuador has strengthened in the last 6 years and generates in the country some 100,000 direct and indirect jobs, currently has about 5,000 Ecuadorian producers in the whole country, being Tungurahua the province where concentrates 50% of the national production (Reyes Vasquez, et al., 2016). From this sector of the country is taken as case study an industry that produces safety footwear because it is the product of greater demand.

For the study the corresponding manufacturing processes are considered: punching, polishing, trimming, fixing of eyelets, forming, assembly and finished. The timing of the process is taken through the chronometer technique with assessment of the rhythm established in the leveling method proposed in the Westinghouse system (Cevikcan & Kilic, 2016) and calculation of supplements through a bi-objective approach of assessment with fatigue standards (Glock, et al., 2016). For the case study, the largest overall time is taken for each of the processes to encode in a Simulation model.

The timing and sequence of operations are entered into the Promodel® process simulation software version 7.0, which models the flow rate in the manufacturing system, cycle times and the work in process on a production line. Through simulated experimentation it is proposes to validate the hypothesis, which seeks to show that by keeping an inventory in a constant process and reducing the cycle time it is possible to increase the rate of production in a situation in which the manufactured products go to inventory. Reducing the size of process batches has a much deeper effect than increasing the number of transfer batches because the product mix is much larger and generates reductions of WIP and waiting times in production.

The parameters used in the simulation are Throughput (TH) for machines, workstations, production line and industrial installation per unit of time, work in process (WIP) and cycle time (CT) from the path between the beginning and end of processes. One of the main restrictions of modeling is to determine the bottleneck (Rb) which is the rate (parts per unit time or jobs per unit time) of the workstation that has the highest long-term utilization (Hopp & Spearman, 2011).

In the Promodel simulation software, it is enter the units that arrive to the system with a frequency distribution of discrete random variable with probability behavior of Poisson to obtain an approximation to the reality of the manufacturing system. This distribution is obtained with the Promodel Stat Fit library comparing frequency distributions. The experimentation is carried out through simulation scenarios where the behavior of the study variables is obtained.

For the evaluation of the relationship between the productions parameters of plant physics, the Little Law is used which establishes that there is a close relationship between throughput (TH), cycle time (CT) and work in process (WIP) defined by equation (1). This equation shows that the longer the cycle time will lower throughput with a constant level of inventory. The research also seeks to obtain the critical WIP of the line (Wo) which is the inventory with the line produces the maximum throughput. From this level, inventory only produces congestion and storage costs. See equation (2) (Hopp & Spearman, 2011)

$$TH = (WIP / CT) \quad (1)$$

$$Wo = (rb) .To \quad (2)$$

An adequate production program involves that industries must adjust to the lower performance of the rate of production. This is achieved by equations (3), (4) and (5), where w is the WIP level.

$$TH\ best = w/To \ \ si\ w < Wo \quad (3)$$

$$TH\ best = rb \ \ si\ w < Wo \quad (4)$$

$$w = Wo \quad (5)$$

The best performance law states that for a given inventory level (w) and the highest throughput, are obtained when the inventory level is equal to or greater than the critical level (Wo). The result is equal to the bottleneck rate (rb). The law of best performance can also be formulated with equations (6) and (7).

$$CT\ best = To\ si\ w < Wo\ \ o\ \ w = Wo \quad (6)$$

$$CT\ best = w/rb,\ si\ w > Wo \quad (7)$$

In order for companies to avoid developing their manufacturing processes with the worst performance, Plant Physics also evaluates this factor through equations (8) and (9) for any level of inventory w.

$$TH\ worst = 1/To \quad (8)$$

$$CT\ worst = w.To \quad (9)$$

There is also the evaluation of the parameters under a practical performance where an additional time of CT by contingencies is considered. For this, we use equations (10), (11), (12) and (13).

$$TH\ practical = (w/(Wo+w-1))rb \quad (10)$$

$$CT\ practical = To+(w-1)/rb \quad (11)$$

$$CT\ practical = ((w-1)/N)\ t + t \quad (12)$$

$$CT\ practical = (1 + (w-1)/N)\ t \quad (13)$$

The variable w represents the works in the manufacturing system, N is the number of stations in the production line, t refers to the process time in each station, To = Nt is the system process time and rb = 1 / T corresponds to the bottleneck. When a job arrives at a station, the number of jobs waiting at this station is (w-1) / N.

To the three cases proposed in Plant Physics, the current case study is added, the equations for the CT, TH and WIP of the four possible cases are modeled in the Promodel® simulator: the best, the practical, the worst and the current one. These results allow to know the current state of the production system with respect to the studied parameters in order to compare through the generation of scenarios the variation of the size of the order or the time of the simulation that allows to obtain the greatest benefit for the organization.

## 3 RESULTS

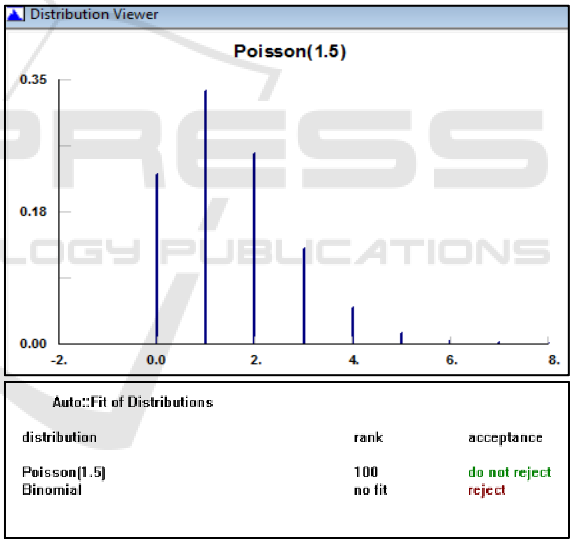


Figure 1: Distribution of probability of arrivals.

To program the attributes defined in the methodology the Distributed Simulation (DS) method is used (Anagnostou & Taylor, 2017). Locations are created corresponding to each of the jobs where manufacturing activities are developed and also 5 temporary storage areas that allow to know how many units remain in process after a work shift.

The entity considered for the study is called Model S15 which is the product in process. The arrivals occur in defined trajectories from warehouse of raw material to the production system with an established frequency detailed in Figure 1. The number of occurrences or units that arrive to the system is infinite since in the first instance it is simulated as a function of the time that is of 8 hours. In total, the basic model generates 47 variables to measure the key performance indicators (KPIs) such as bottleneck rates (rb), process times (tp), cycle times (CT), system efficiency, work in process WIP) and trougthput (TH) for the three cases analyzed with Little's Law (Hopp & Spearman, 2011).

5 networks of movements are traced in which the 14 operators cross each of the locations with a node of the network through interconnections or interfaces, in the displacements the distance measured in the plant between the different jobs is taken into account. Attributes of type real numbers are used for the entity defined as att_S15, a subroutine named id is programmed in order to avoid a division between zero in the process, because the cycle time is only calculated after the first one Part, this programmed code is shown below:

```
IF CT_ModelS15 <>0 THEN
TH_ModelS15=wip_ModelS15/CT_ModelS15
ELSE
TH_ModelS15=0
```

To program the processes, you enter data such as: input entity, output entity, input and output location, route, movement logic.

It creates a variable Real x that is internal where an operation time will be stored. The id subroutine checks if the cycle times of each entity are different from zero.

Then the program places the time that the clock of the simulation is marking the moment the entity enters the production system in attribute att_S15, the equation to obtain the production capacity and the respective bottleneck is also determined. A logic is also proposed in order to obtain an increase in the zones of temporary storage and at the same time a decrease while they go on to the next process of the system. Finally the equations are codified for the analysis of the constraints with Little's Law, as shown below:

```
REAL x
id
att_S15=CLOCK()
tp_1=1.30x=(tp_1)
rb1=1/x
WAIT x
INC WIP_Zona1
tp_2=1.90x=(tp_2)
rb2=1/x
WAIT x
DEC WIP_Zona1
IF rb1<rb2 AND rb1<rb3 AND rb1<rb4
AND rb1<rb5 AND rb1<rb6 AND rb1<rb7
THEN
{
TH_General= rb1
}
ELSE
IF rb2<rb3 AND rb2<rb4 AND rb2<rb5
AND rb2<rb6 AND rb1<rb7 THEN
{
TH_General= rb2
}
ELSE

IF rb3<rb4 AND rb3<rb5 AND rb3<rb6
AND rb3<rb7 THEN
{
TH_General= rb3
}
ELSE
IF  rb4<rb5 AND rb4<rb6 AND rb4<rb7
THEN
{
TH_General= rb4
}
ELSE
IF rb5<rb6 AND rb5<rb7 THEN
{
TH_General= rb5
}
ELSE
IF rb6<rb7 THEN
{
TH_General= rb6
}
ELSE
TH_General= rb7

WIP_critical_best=TH_General*CT_Mode
lS15
INC WIP_critical_best

CT_Worst=wip_ModelS15*CT_ModelS15
CT_Practical=(CT_ModelS15+((WIP_Mode
lS15-1)/TH_General))
CT_Best= (WIP_ModelS15/TH_General)

TH_Practical=((WIP_ModelS15/(WIP_cri
tical_best+WIP_ModelS15-
1))*TH_General)

Capacity_best=TH_General*60
Capacity_practica=TH_Practical*60
Capacity_actual=TH_ModelS15*60
Production_best=Capacity_best*(CT_Mo
delS15/60)
production_practica=Capacity_practic
a*(CT_ModelS15/60)
Capacity_worst=TH_Worst*60
production_worst=Capacity_worst*(CT_
ModelS15/60)
Efficiency=(TH_ModelS15/TH_General)*
100
```

For movements between jobs is coded according to the following:

```
MOVE WITH Operario1 FOR 2.28 THEN
FREE
```

With the data entered in the Simulator it is obtain the bottleneck rate (rb) of the system of 0.53 pairs per minute, as seen in Figure 2.

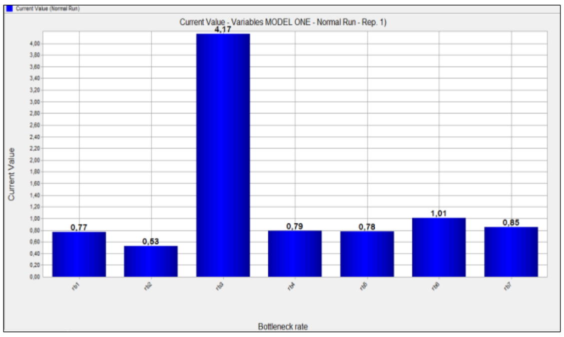


Figure 2: Bottleneck rate.

Table 1 shows the production parameters in the first column and in the first row are located the four cases analyzed from the theory of Plant Physics.

Table 1: Results of the four possible cases.

| | Best Case | Worst Case | Practical Case | Current Case | Units |
|---|---|---|---|---|---|
| WIP | 238 | 1 | 238 | 238 | Pairs |
| CT | 449 | 114240 | 915,4 | 480 | Minute |
| TH | 0,53 | 0,002 | 0,26 | 0,49 | Pairs/min |

The time (To) consider for the simulation is 480 minutes equivalent to a working day of 8 hours, in this time 238 pairs of shoes are produced with a production rate of 0.49 pairs per minute. With equation (2) it is obtain the critical Wip (Wo) whose value corresponds to 254 pairs per day. As expressed in equation (4), the best TH is found if the rate of production reaches the value of rb, therefore the value of TH = 0.53 pairs per minute is taken for the best possible case. Equation (7) calculates the best CT, this time is less than the planning of a working day. With these results, there was an increase of the TH by 8.1% and a reduction of the CT by 6.5%.

The worst case is determined that in a work cycle a pair of shoes is produced, with a production rate of 0.002 pairs / min and a cycle time of 114,240 minutes.

There is also a practical case that is calculated with the equations whose production rate is 0.26 pairs per minute where the company requires 915.4 minutes to fulfill the production of an order of 238 pairs.

This case is considered when there are unforeseen for which the company must reduce its rate by 50% and increase the time by 100%.

In order to determine the inventory in process that the company must maintain in each hour of work, the simulation is performed for a production of 50 pairs of shoes since the workers produce in each workstation in function of those quantities before passing the product to the following process.

The Little Law that relates the production parameters analyzes the current case, the best case, the worst possible case and a practical case of production for different WIP values, in order to verify the dynamics of the process with different parameters.

To schedule the production it is necessary to know how the production flow values change over time and also to know the maximum value of WIP within the system in a set time so that there is no excess inventory in process. Finally know how many units can be produced in a given time.

Controlling inventories in process WIP also helps to fulfill the delivery of orders on time in addition to achieving an increase in productivity. It is necessary to know in which time the highest TH is obtained and how many units must be produced, for this the results of the TH vs the CT of Figure 4 are observed.

The "Best Possible" case generates the minimum cycle time and the maximum throughput for each WIP level.

The production dynamics of the case study are plotted in Figure 3 with the relationship between the TH and the WIP; And Figure 4 the TH and CT in the one-hour time cycle for the batch of 50 pairs, in order to know how many units should be kept each hour occurring in the system to meet the established goal and the sequence of income Of the units to the system.

Table 2: Comparison of the four cases.

| Case | WIP (pairs) | CT (min) | TH (pairs per min) |
|---|---|---|---|
| Worst | 32 | 1920 | 0,002 |
| Best | 32 | 60 | 0,53 |
| Practical | 32 | 123 | 0,26 |
| Current | 29 | 60 | 0,49 |

Table 2 shows that when a WIP of 32 pairs is in the system, it is possible to reach the maximum production rate, therefore it is the amount that the plant must maintain every hour as a minimum to fulfill the delivery of orders to time using the maximum capacity of the production line.

After this value of 32 pairs, the cycle time is increased in the time that is invested in producing a pair with the best production rate. The results for the other three cases are also presented.

Figure 3 shows that in the present case a production rate of 0.49 pairs per minute with a CT of 60 min is achieved keeping an inventory in process of 29 pairs. According to the study, the company should reach the best possible case by maintaining a production rate of 0.53 pairs per minute with a CT of 60 minutes keeping an inventory in process of 32 pairs as shown in the green lines in Figure 3. From these values the curve stops growing and the inventory increases but not the production rate. In the case study it is observed that in order to maintain an inventory in process of 32 pairs the CT must be increased to 123 min but the production rate decreases to 0.26 pairs per minute.

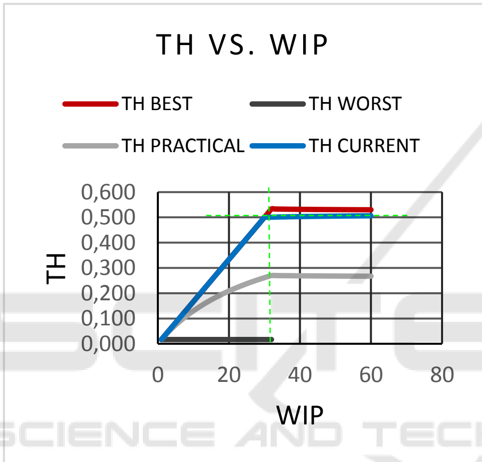


Figure 3: Relation TH vs. WIP.

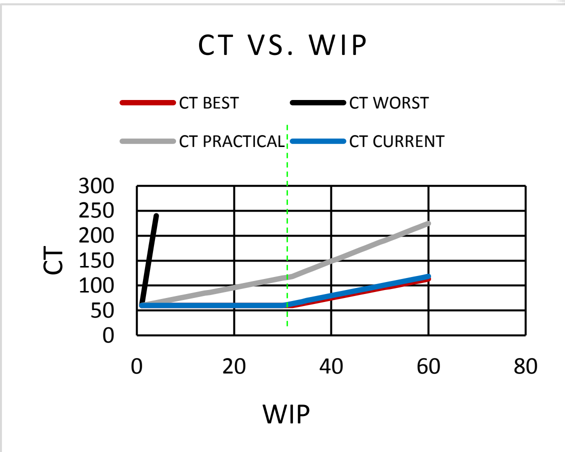


Figure 4: Comparison CT vs. WIP.

The results of Figure 4 indicate the variation of the CT as a function of the WIP, in the best case possible the time is kept constant in 60 minutes until an inventory of 32 pairs. From this inventory the time curve begins to grow which implies that to have more units in the system the cycle time increases and therefore the TH is reduced.

For every 50 pairs produced an inventory in process of 32 pairs should be maintained every hour within the system which implies that the inventory in process should not exceed 64% of the total production.

Figure 5 shows the behavior of the TH in the time where the upper line shows the best possible case, it is the only one that remains constant since it is the case to which the system must tend optimally. The second line indicates the current case with its respective variability, this is due to different factors that influence how the work rate of the workers or the supply of raw materials, always must be taken care that this line is between the best case and the practical one to consider that the system of production is stable. The third line is that of the practical case and the fourth is the worst case possible.

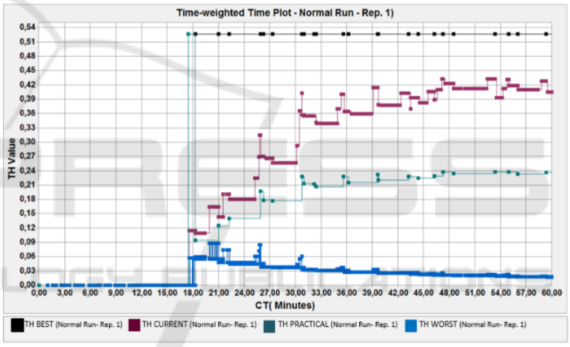


Figure 5: Behaviour TH vs. CT.

## 4 CONCLUSIONS

A simulation model was programmed using the Promodel software, considering the capacity constraints and the production parameters where the results were obtained for the four possible cases stated in Plant Physics: best case, worst case, case study and current case.

For a working day of 8 hours (480 minutes), currently 238 pairs of shoes are produced with a production rate of 0.49 pairs per minute.

Through the simulation it was determined that the production rate that maximizes the capacity of the line is 0.53 pairs per minute increasing from the current one by 8.1%, also the reduction of the cycle time For the best case to 449 minutes corresponding this value to an improvement of 6.5% with respect to the current one.

The inventory in process that must be maintained at the maximum is 32 pairs per hour, which indicates that if a greater value is conserved within the day, the company begins to generate unnecessary accumulation of the same one.

It is concluded that in order to maintain a production rate that satisfies the maximum capacity of the plant, every hour an inventory in process equivalent to 64% of the total number of units scheduled for production must be maintained.

For a manufacturing system to be optimal, the TH production rate should not change over time but remain constant, this is a clear indicator that resources are coming to the system on time and supplying it is efficient, where prevents waste generation.

The results of the model employed identify companies with an efficient management of their processes, and others that require support to analyze and respond with data and facts scientifically proven to eliminate the root causes of their problems.

## ACKNOWLEDGEMENTS

The authors thank the National Footwear Chamber of Ecuador and the Technical University of Ambato for the support provided during the execution of this work within the framework of the research project called "Operational optimization based on a lean dynamic system of alert of failures in the production processes for the footwear industry".

## REFERENCES

Anagnostou, A. & Taylor, S., 2017. A distributed simulation methodological framework for OR/MS applications. *Simulation Modelling Practice and Theory,* Volume 70, p. 101–119.

Cevikcan, E. & Kilic, H. S., 2016. Tempo rating approach using fuzzy rule based system and westinghouse method for the assessment of normal time.. *International Journal of Industrial Engineering,* 23(1), pp. 49-67.

Cocuzza, S., Fornasiero, R. & Debei, S., 2012. Novel automated production system for the footwear industry. In: Heidelberg, ed. *IFIP Advances in Information and Communication Technology (IFIPAICT).* Berlin: Springer, pp. 542-549.

Glock, . C. H., Battini, D., Grosse, E. H. & Alessandro, P., 2016. Human energy expenditure in order picking storage assignment: A bi-objective method. *Computers & Industrial Engineerin,* Volume 94, p. 147–157.

Goldratt, E. & Cox, J., 2014. *The goal: a process of ongoing improvement.* 4th ed. Great Barrington: North River Press.

Grimard, C., Marvel, J. & Standridge, C. R., 2005. Validation of the re-design of a manufacturing work cell using simulation. *In Proceedings of the 37th conference on Winter simulation* , pp. 1386-1391.

Günay, N. S., Vayvay, Ö. & Şimşit, Z., 2014. Theory of Constraints: A Literature Review. *Procedia-Social and Behavioral Sciences,* Volume 150, pp. 930-936.

Hopp, W. J. & Spearman, M. L., 2011. *Factory Physics.* Third ed. Long Grove: Waveland Press.

Johar, F., Nordin , S. Z. & Potts, C., 2016. Coordination of production scheduling and vehicle routing problem with due dates. *In advances in industrial and applied mathematics,* 1750(1), p. 030035.

Krajewski , L., Malhotra, M. & Ritzman, . L., 2016. *Operations Management: Processes and Supply Chains.* 11 ed. Edinburgh: Pearson education.

Li, B., 2010. Research on the production scheduling management system based on SOA. In: *Lecture Notes in Computer Science.* Berlin: Springer, pp. 286-294.

Li, N., Zhang, L., Zhang, M. & Zheng, L., 2005. Applied factory physics study on semiconductor assembly and test manufacturing. *In ISSM 2005, IEEE International Symposium on Semiconductor Manufacturing,* pp. 307-310.

Mahapatra, S. & Amit Sahu, 2006. Application of Theory of Constraints on Scheduling of Drum-buffer-rope System. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* pp. 15-20.

Marcelo, M. T. et al., 2016. Process improvement and utilization of machines in the production area of a shoe manufacturing company. In: *Industrial Engineering and Engineering Management (IEEM).* Bali: IEEE.

Reyes Vasquez, J. P., Aldas Salazar, D. S., Morales Perrazo, L. A. & García Carrillo , M. G., 2016. Evaluation of the capacity for assembly in the footwear. *Ingeniería Industrial,* 37(1), pp. 14-23 .

Reyes, J., Alvarez, K. & Vasquez, R., 2016. Dynamic buffer management for raw material supply in the footwear industry. *Journal of Industrial and Intelligent Information,* 4(1), pp. 1-8.

Standridge, C. R., 2004. How factory physics helps simulation. pp. 1103-1108.

Zangiacomi, A., Zhijian, L., Sacco, M. & Boër, C., 2007. Process planning and scheduling for mass customised shoe manufacturing. *International Journal of Computer Integrated Manufacturing,* 17(7), pp. 613-621.

Zhang, J. & Wang, X., 2016. Multi-agent-based hierarchical collaborative scheduling in re-entrant manufacturing systems. *International Journal of Production Research,* pp. 1-17.