ANALYSING THE VIABILITY OF MANUAL TROLLEY FLEET SUBSTITUTION OF ITEMS RETRIEVING PROCESS

Shih Yung Chin

Heráclito Lopes Jaguaribe Pontes

Arthur José Vieira Porto
Laboratório de Simulação - Escola de Engenharia de São Carlos/USP
Av. do Trabalhador São Carlense, 400, São Carlos, Brazil, CEP: 13566-590
sychin@sc.usp.br; hjpontes@sc.usp.br; ajvporto@sc.usp.br

Abstract. *This paper builds a simulation model of the retrieving process of a Parts Distribution Centre (PDC) using ARENA® 5.0. The PDC contains approximately 30000 soft parts of heavy machinery. Manual trolley fleet is used by 5 employees for the temporary deposit of the parts, which are collected manually from the shelves. Managers are analysing the viability of substituting the manual trolley fleet, since the existent ones have disadvantage comparing to the competition, in terms of retrieving process total time effectivity. Input data of decision factor named fleet to the model are organized in 2 levels, according to design of experiments* 2^k*, and the results of each test are obtained from 2 replications. Analysing statistically, managers will be able to evaluate possibilities, in comparison to the actual situation, and to conclude how viable it is to change the fleet.*

Keywords*: discrete simulation, items retrieving process, manual trolley fleet and design of experiments*

1. Introduction

The competition among companies has became very severe since the customers started to choose products and services with high level of quality, costs, among others. Customers have powers in decisions because of the large range of available products offered by companies. This way, companies must change their focus to reach the customers requirements. Each part of companies has changed aiming at market acquisition and has been forcing these areas to improve, such as searching for solutions in distribution of their products, for example. The profile of companies is dynamic and does constantly suffer internal modifications to attend the competition.

In warehousing systems, as part of several types of companies, there are different activities which are responsible for receiving orders until dispatching products to the customers. These warehousing systems also suffer competitiveness and, therefore, it is important constantly improvement (Gunasekaran *et al.*, 1999). Coyle *et al.* (1996) affirm that retrieving process is extremely critical because it demands around 60% of total warehousing process cost. For this reason, several companies have been studying new strategies to reduce the operational costs, which involve the use of computational tools, and also agreement with universities.

Kelton *et al* (1998) affirm the importance of creating and executing the simulation models to provide information before taking any mistaken decision that can result in excessive costs. In simulation, the input data organization is important to visualize and comprehend what is intended to obtain from the model. This data organization is a step part of the study in simulation and it is named design of experiments.

Commonly, the warehousing systems uses manual trolley to support employees in items collecting process. Shih *et al.* (2005) builds a simulation model of retrieving process in Arena 5.0 showing an unbalanced number of items technique of the collecting list aiming at reducing the retrieving time. Recently, managers of this company have noticed that manual trolley fleet is out of phase in terms of retrieving process total time effectivity in comparison to the competition. They are analyzing the possibility of substituting the existent ones. But it implies a considerable short term investment. In some cases managers may not be absolutely sure if changes will bring any short term benefits.

Therefore, this paper aims at using simulation tools, including statistic methods, to analyze the effectivity caused by the changes of the factor called manual trolley on retrieving time.

The well known simulation tool, ARENA® 5.0, is one of the software available in the discrete simulation laboratory (University of São Paulo – NUMA) and it works with statistical data distribution. This paper succeeds the simulation model of Shih *et al.* (2005) and consequently several parameter data of the model are remained. The initial data of each parameter were collected in different period from the company (some in a period of 1 week, the others in a 1 month period) and some of them with the different sample size (because of the unavailable data). Statistically, the use of distribution can minimize the data diversity impact. Input data of decision factor named fleet to the model are organized in 2 levels, according to design of experiments 2^k, and the results of each test are obtained from 2 replications. From the results, increasing the load vehicle may not reduce significantly the retrieving process time. Also the main impact on the total time is from the vehicle velocity, but it is not so significant.

2. Literature review

In published warehousing papers, cases focusing in certain factors of the process aiming especially to rout minimization are commonly found and it generally means cost reduction provided by the time.

Some presented techniques in those papers related to the factors, such as batching orders in Gademann *et al.* (2001), Gibson and Sharp (1992), routing policies for collecting items, Goetschalckx and Ratliff (1998) and Caron *et al.* (1998), problems in allocating items in Malmborg and Al Tassan (2000), Kallina and Lynn (1976) and also relating to the shelves layout described in Roodbergen and De koster (2001a) and Roodbergen and De koster (2001b) and among others, aiming, in all of them, mainly employees routing reduction, can be found. Owing to the complexity of the integrated activities, several papers make the use of simplifications. This way, it is rarelly commented of 2 or more factors acting simultaneously. However it is important to be similar to the real. In addict to this, managers have troubles in applying the proposed methods to obtain solutions, which may permit taking quick decisions.

The computational tool, named computer simulation, works with the models which represents the real systems. Simulation seems to present itself as one of the most important tools to be explored in papers because it can deal, easily, with several factors at the same time (Marín *et al.,* 1998).

3. Description of the parts distribution centre (PDC)

Mulcahy (1994) defines Parts Distribution Centre (PDC) as a local, where a large range of products are stored. These products can be provided by a supplier, or produced by the own company. After a certain period of time, these stored products are delivered to the customers according to the orders. Therefore, a PDC is considered as an warehouse. The next, topic 3.1, begins with the physical description of the PDC:

3.1. Layout and dimensions

The construction machinery parts company, located in Piracicaba City - São Paulo State (Brazil), has one PDC with layout and measures similar to the one illustrated in figure 1:

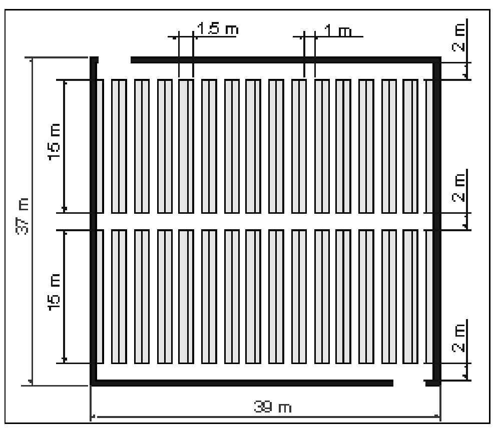

Figure 1. Layout and measures of the PDC.

Note, by figure 1, that there are 3 horizontal aisles, also called cross-aisles. Aisles is a local where employees can route to reach several locations of shelves. In summary, 15 vertical aisles compound this PDC, and in each aisle is composed by 2 shelves totalizing 30 shelves. The vertical aisle of each shelf is called subaisle. The main characteristic of this kind of shelf is that employees can collect parts from 2 sides of subaisles. Shelf is a PDC facility, composed by different layers, where different types of products are stored into it. This company has shelves with vertical shape. The measures of the shelves (length x width), cross-aisle and of the width of the subaisle are (15 x 1.5 m), 2 m and 1 m, respectively.

3.2. Sections and subsections

The name of each local of subaisle is section (or picking area) and the part of the shelf located in this picking area is called subsection. In summary, picking area is a place of aisle where employees collect a product.

There are 10 picking areas in the subaisle, it means that each subsection’s length is 1.5 m. Inside of each shelf is composed by drawers, where parts are stored.

3.3. ABC – Classification of items in the shelves

There are 30055 items distributed in 30 shelves, based on the ABC criteria. Table 1 contains current item's information by each classification. Slack *et al.* (1999) affirm that, in a PDC, there are parts more required than others. This way, they are classified as type A (as more important) until type C (less important). In addict to this, Petersen (1999) comments that more important items must be stored close to the gate.

Table 1: Current number of items.

	Actual	
Item type	Number of Items	Percentage
A	1522	5.06%
B	3120	10.38%
C	25413	84.56%

It is important to note that the number of items is different from the parts quantity. In this way, a customer may require 2 items with the quantity of 15 and 50 parts each one.

4. Activities schedule

The company works according to 3 shifts: morning, evening and afternoon. In the morning shift the computational system of the PDC located in the packing area receives orders. This system identifies the item's code and the quantity and after that, creates a picking list. As new orders arrive to the system, new codes are added to the picking list or the quantities of items are changed in case they have the same code, and automatically the codes are rearranged in crescent order. The item's codes vary from 1 to 30055. The total number of items has a high variation, floating from 1000 until 1850 items per day. In the evening shift (maximum period of 4 hours of work, this picking list is sequentially separated by the system in collecting list (CL) distributed to 5 employees. Each employee receives some CL and, after that, begins routing in aisles for collection of the parts. In the packing area, several manual trolleys are available to support employees in the collecting process. The route begins from the packing area to the shelves and when the capacity of trolleys is reached, the employee returns to the same area to unload parts. All of the collected parts are dispatched to the customers in the afternoon shift.

5. Problematic

Currentlly, the company can collect parts in approximately 3:30 h, which is considered efficient because the maximum period is 4 h (evening). Even increasing the collecting efficiency, the company can only dispatch parts in the afternoon. The issue is the competitors can collect parts in less than 3:30 h, so it is important to search for other ways to minimize costs. Managers are analyzing the possibilities of an alteration of manual trolley fleet by another aiming the increase of their effectivity on retrieving process total time and if they decide to alter the fleet, which technology should be acquired? Basically, the main trolley characteristics are velocity and weight capacity.

The company is previewing the possibility of using electric vehicles, such as AVG (Automated Vehicle Guided), but the internal police of the company, concerning insurance issues, has established that no vehicle can exceed 1.5 m/s. In relation to the vehicle maximum load, there is the constraint from the supplier that can only provide vehicles with 200 kg of maximum capacity.

6. Modeling in simulation software Arena 5.0

6.1. Homogeneous distribution of items in the shelves

Each subsection is composed by 25 drawers and there are 2 areas to store 2 types of parts in each drawer. In this way, 50 types of parts can be found in each subsection. The mass of each part is showed in table 2, varying from 0.1 to 20 kg. The representation AINT, EXPO, UNIF, in ARENA, mean respectively integer, exponential and uniform. Also for a matter of simplification, the number of the items was rounded to permit equally distribution in the shelves, as illustrated in table 3. With the information exposed in section 6.1, it is possible to store all of 30000 items. The items distribution, according to its classification, can be seen in figure 2.

Table 2: Quantity of parts distribution in relation to mass.

Mass of Each Part	Parts Quantity of Item
Until 1 kg	AINT(EXPO(7))+1
From 1 to 5 kg	AINT(UNIF(1;8))
From 5 to 10 kg	AINT(UNIF(1;4))
From 10 to 20 kg	AINT(UNIF(1;3))

Table 3: Number of items rounded.

Adopted	
Number of Items	Percentage
2000	6.67%
4000	13.33%
24000	80.00%

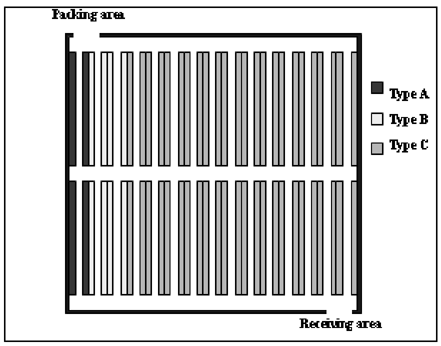

Figure 2: Shelves Distribution according to ABC Criteria.

6.2. Composition of the retrieving process total time

The retrieving process total time is composed basically by 4 components:

Time of identification of the section – This component is the time spent by the employee to identify the picking area. This time, by item, is a triangular distribution varying from 1.5, 2.5 and 4.0 s.

Time of identification of the part – Depending on the shelves' layout, it is important for employees to know in which side of the subaisle and in which drawer the part is located. This time, given in seconds, is also a triangular distribution varying among 1.0, 1.5 and 3.0 s.

Collecting time – It is the time spent by the employees to move their hands from the shelf to the trolley. Maynard (1970) affirms that the item's mass can influence the collecting time, i. e. more weight, implies more difficulty for employees and, consequently, collecting time will be increased. This issue can be defined numerically by one factor, named Factor_M, as showed in expression (1).

$$Factor\_M = 0.5 + \frac{10 * Mass\_of\_Part\,[kg]}{20} \tag{1}$$

The time spent to move their hands (holding no parts) is a triangular distribution varying from 1.0, 3.0 and 4.0 s. Therefore, the collecting time is this time multiplied by factor_M and multiplied by the quantity of collected parts.

Routing time – Time spent to route in aisles is also considered one of the components of the process time. In the same way as collecting time, the trolley velocity also suffers weight influence (Maynard, 1970). As the manual trolley weight is increased, its velocity is reduced. The manual trolley's velocity (unloaded) is given by a triangular distribution, in meters per second, varying from 0.75, 1.00 and 1.20. In this way, the trolley velocity in the current situation is factor_V multiplied by the unloaded trolley velocity. The factor_V can be obtained by the equation (2).

$$Factor\_V = 0.75 + 0.25\left(\frac{120 - Weight\,[kg]}{120}\right) \tag{2}$$

6.3. Order division

Table 4 contains average item's information of daily orders in a 6 months period, in percentage.

Table 4: Average Distribution, in percentage, of daily order items

Item Type	Percentage of the Order
A	30 until 40%
B	20 until 30%
C	30 until 50%

Distributions will be used in each item type in the simulation model as showed in numbers (3) to (6).

– Variable Number of Items (VNI) = AINT(Triangular Distribution (1000, 1700, 1850)) (3)

– A Items = AINT (UNIF(0.3, 0.4)*VNI) (4)

– B Items = AINT (UNIF (0.2, 0.3)*VNI) (5)

– C Items = VNI – A Items - B Items (6)

From these information, it is possible to know which employees should run in specific parts of the shelves, because the collecting list is obtained from the division of percentage items distribution by the number of employees. In other words, it is similar to the employees distribution by the area A, B and C of PDC.

6.4. Data acquisition from the model and factorial design 2k

For the importance of analyzing the impact of the 2 control factors on the retrieving process total time, ranges of values of velocity until 1.5 m/s and maximum capacity of 200 kg on vehicle are chosen. The results of these times, including also its level values, might be compared to current data situation to verify if statistically the process has improved. The importance of this paper is to emphasize that the main goal is not search for an "optimum" vehicle, because the demand is extremely instable and as a consequence, the results would not be bruising to the reality. For these reasons, the impact of combining factor levels in the total time of the process is evaluated and therefore 2 levels are chosen.

Factor of control x_1: Vehicle velocity: Levels 1.0 and 1.5 m/s, (-1) and (+1);

Factor of control x_2: Load Capacity: Levels 150 and 200 kg, (-1) and (+1).

Shih et al. (2005) comment that retrieving process will be finished if all employees arrive in the packing area, where parts will be dispatched to customers, with their collected items. In this way, table 5 will register the time of the last employee. The time unit is in seconds. These results are obtained from 2 replications in each proposed alternative, considering that equation (2) with the value 120 (or 120 kg) will be changed according to the acceptable maximum weight of the vehicle.

Table 5: Factorial design experiments 2^2, with the results of the simulation model (in seconds).

Proposal Alternatives (Tests)	Main Effects			Interaction Effects	Replication 1	Replication 2	Average
	I	X_1	X_2	X_1X_2	Y_{i1}	Y_{i2}	$Y_{iaverage}$
1	1	-1	-1	1	12376	10400	11388
2	1	1	-1	-1	11066	9753	10410
3	1	-1	1	-1	11692	10353	11023
4	1	1	1	1	10729	10110	10420

6.5. Hypothesis testing

6.5.1. Student statistic t

It is desired to test if the effects are significantly different from zero, so the hypothesis test is:

Ho: $\mu_E=0$
H1: $\mu_E \neq 0$

I.e., the null hypothesis is that the effect (average) is zero, opposing to the alternative hypothesis, in which the effect is different from zero. The Statistic "Student t" is used in the test, according to the expression (7)

$$t=\frac{E_i-\mu_E}{S_E}=\frac{E_i}{S_E} \quad (7)$$

6.5.2. Main effects and interaction calculus

Using the equations of Montgomery (1991) to calculate the main effects E_1, E_2 and the interaction E_{12}, with k as the number of control factors, it results in:

Value of E_1:

$$\frac{(-1)*(11388)+(+1)*(10410)+(-1)*(11023)+(+1)*(10420)}{\frac{2^k}{2}} = -790.5$$

$$E_2=\frac{-355}{2}=-177.5\ ;\ E_{12}=\frac{375}{2}=187.5$$

The estimative of standard deviation, S_E, with $[2^k(n-1)]$ degrees of freedom can be obtained using the expression (8).

$$S_E^2=\frac{4*S_p^2}{n*m} \quad (8)$$

As all the tests' combinations are repeated the same number of times, the common unknown variance, S^2_p, is obtained by the expression (9).

$$S^2_p=\frac{S_1^2+S_2^2+S_3^2+\ldots+S_m^2}{m} \quad (9)$$

There are 4 values of sample variance and therefore the value of m is 4. To obtain values from S^2_2 to S^2_4, equations similar to S^2_1 might be used.

$$S_1^2=\frac{\left(y_{11}-y_{1average}\right)^2+\left(y_{12}-y_{1average}\right)^2}{2-1}=(12376-11388)^2+(10400-11388)^2=1952288$$

$$S_2^2=861985\ ;\ S_3^2=896461\ ;\ S_4^2=191581$$

Therefore, the value of common variance is:

$$S^2_p=\frac{3902315}{16}=243894.68$$

The value of n is 2 because of 2 replications, so the value of the standard error, S^2_E, will be 121947.34 or S_E = 349.21. The result of statistic t is:

$$t=\frac{Ei}{349.21}$$

Table 6 contains data of effects estimates with its respective values of t´s.

Table 6: Statistic t associated with its effects.

Effect	Effect Estimate	Value of Statistc t
E_1	-790.5	-2.26
E_2	-177.5	-0.51
E_{12}	187.5	0.54

6.5.3. Comparison of the t from the effects with the statistic $t_{\alpha/2,v}$

In this case, the number of degrees of freedom is 22*(2-1) = 4. For α=0.05 (5% the chance to commit the type I error), it results in:

$t_{\alpha/2,v}$= 2.776

Therefore, comparing the statistics t of the effects with $t_{0.05/2,4}$, all other effects have a t value associated in the interval [- $t_{0.05/2,4}$; $t_{0.05/2,4}$] and therefore in the region that the Ho hypothesis is accepted. It means that the impact exerted by the alternation of each control factor level is not significant in the retrieving process total time. And therefore, the manager could choose any of the proposed alternatives. But it is also important to evaluate if the chosen alternative is better than the current situation.

6.5.4. Comparison to the real situation and comments

Table 7 presents data of the real situation and the proposed alternatives to be compared. The difference of retrieving process total time (in minutes) of alternatives in relation to the current situation is presented in the last line and it is possible to visualize the impact of level combination in the retrieving process total time.

Table 7: Data Comparison: Current x Alternatives Situations.

	Current Situation	Alternatives			
		Proposal Alternative 1	Proposal Alternative 2	Proposal Alternative 3	Proposal Alternative 4
Velocity (m/s)	[Triangular(0.75, 1.00 and 1.20)] * Factor_V	1.0	1.5	1.0	1.5
Trolley Capacity (kg)	120	150	150	200	200
Process Total Time (s)	12978	11388	10410	11023	10420
Difference (min)	0	-26.5	-42.8	-32.58	-42.63

Every company aims to reach the retrieving process total time be the least possible and, by the data presented in table 7, all alternatives permit minimizing the total time of the process in relation to the current situation. The proposed alternative 2 presents more reduction of time, even if it is not so significant, and therefore it could be the first option for managers.

Fixing the velocity in 1.0 m/s and increasing the load capacity from 150 kg to 200 kg, there is a reduction of 6.08min of the total time. It is due to the fact that the increase of load on the vehicle can reduce the number of used electrical vehicles, even increasing the factor_V, and for these reason it is responsible for the reduction of the retrieving total time. Now fixing the velocity in 1.5 m/s, the load increase makes the total time increase in only 0.17 min or approximately 10 s.

The alteration of manual trolley of variable velocity by the electrical one can be one of the alternatives, because it may bring 42.8 min of total time reduction, but it also needs very high short term investments to acquire new vehicles and battery chargers, maintenance (if it is not hired from another company) and manipulation training.

7. Conclusion

This study shows the importance of using simulation and design of experiments to evaluate and compare different operational situations in manufacturing systems, especially in PDC. With this powerful computational tool, managers can visualize, from the information provided by the model, how the real system behavior will be before taking any kind of mistaken decision. It is also relevant to notice that simulation is not used to get solutions, such as search for an "optimum" vehicle configuration, but to provide information for managers as a support for decisions in dynamic systems.

From the simulation, managers can affirm:

1) Increasing the load of the vehicle, in general, may not reduce expressively the retrieving total time of the process. Even if it reduces the number of trips, it is counter-balanced by the weight factor.

2) The main impact on the total time comes from the vehicle velocity, but it is not so significant.

3) Several types of operating situation, such as changing factor parameters, can be simulated as in the real situation. Managers do not need to break the functionality of the warehousing activities to make tests.

Finally, the simulation model permits to show hints aims at improving the companies performance, but the final decision depends on the internal policy of the company that is to keep or not the current manual trolley fleet.

8. Acknowledgements

The authors thank CNPq and CAPES for the financial support to the present project and Prof. José Hamilton Chaves Gorgulho Júnior (Federal University of Itajubá - Brazil) for academic contribution.

9. References

Caron, F., Marchet, G. and Perego, A., 1998, "Routing Policies and COI-Based Storage Policies in Picker-to-Part Systems", International Journal of Production Research, Vol. 36, No.3, pp.713-732.

Coyle, J. J., Bardi, E. J. and Langley, E. J., 1996, "The Management of Business Logistics", 6th edition, West Publishing, St. Paul, M. N.

Gademann, A. J. R. M., Van Den Berg, J. P. and Hoff, H. H. V. D., 2001, "An Order Batching Algorithm for Wave Picking in a Parallel-Aisle Warehouse", IIE Transactions, Vol. 33, pp. 385-398.

Gibson, D. R. and Sharp, G. P., 1992, "Order Batching Procedures", European Journal of Operational Research, Vol. 58, pp.57-67.

Goetschalckx, M. and Ratliff, H. D., 1988, "Order Picking in an Aisle", IIE Transactions, Vol. 20, No.1.

Gunasekaran, A., Mari, H. B. and Menci, F., 1999, "Improving the Effectiveness of Warehousing Operations: A Casa Study", Industrial Management & Data Systems, Vol. 99, No. 8, pp. 328-339.

Kallina, C. and Lynn, J., 1976, "Application of the Cube-per-Order Index Rule for Stock Location in a Distribution Warehouse", Interfaces, Vol. 7, No.1.

Kelton, W. D., Sadowski, R. P. and Sadowski, D. A., 1998, "Simulation with Arena", WCB/McGraw-Hill, New York.

Malmborg, C. J. and Tassan, K. A., 2000, "An Integrated Performance Model for Orderpicking Systems with Randomized Storage", Applied Mathematical Modelling, Vol. 24, pp.95-111.

Marín, R. M., Garrido, J., Trillo, J. L., Sáez, J. and Armesto, J., 1998, "Design and Simulation of an Industrial Automated Overhead Warehouse", Integrated Manufacturing Systems, Vol. 9, No. 5, pp. 308-313.

Maynard, H. B., 1970, "Manual de Engenharia de Produção: Padrões de Tempos Elementares Pré-Determinados", Editora Edgard Blücher Ltda., São Paulo.

Montgomery, D. C., 1991, "Design and Analysis of Experiments", John Wiley & Sons, New York.

Mulcahy, D. E., 1994, "Warehouse Distribution & Operations Handbook", Editora Mc Graw-Hill, New York, Cap. 1, p. 1.2.

Petersen, C. G., 1999, "The Impact of Routing and Storage Policies on Warehouse Efficiency", International Journal of Operations & Production Management, Vol. 19, No. 10, pp. 1053-1064.

Roodbergen, K. J. and De koster, R., 2001a, "Routing Methods for Warehouses with Multiple Cross Aisles", International Journal Production Research, Vol. 39, No.9, pp.1865-1883.

Roodbergen, K. J. and De koster, R., 2001b, "Routing Order Pickers in a Warehouse with a Middle Aisle", European Journal of Operational Research, Vol. 133, No.1, pp.32-43.

Shih, Y. C., Gorgulho Júnior, J. H., Nonato, S. and Porto, A. J. V., 2005, "Desbalanceamento do Número de Itens das Listas de Coleta para Reduzir o Tempo do Processo de Retirada de Itens", Revista Produto & Produção, Vol. 7, No.1, To be published.

Slack, N., Chambers, S., Harland, C., Harrison, A. and Johnston, R., 1999, "Administração da Produção", Edição Compacta, Editora Atlas, São Paulo, pp. 56-57.