

Modeling and simulation of retrieving process

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ABSTRACT

This paper presents a model of PDC, developed in Arena® 5.0, which aims at providing information about the total time of the retrieving process as the system is working under unexpected situations. This time is influenced by several variables such as shelves dimensions, routing velocity and mass of the parts. Elaborated solutions are presented to model those variables emphasizing the route, which is considered as the main factor that influences the process time. The results obtained in simulations make understandable the dynamic system and are also capable of supporting managers in decisions such as estimating the required number of employees responsible to order consolidation. It is also possible to establish relationship among pattern flow and random movement for several sizes of companies.

Key-Words: Retrieving Items. Discrete-Event Simulation. Management.

1. INTRODUCTION

A PDC (Parts Distribution Center) is responsible for activities from receiving parts provided by suppliers to ordering and delivering consolidation to customers. According to Junior (2000), customers demand exerts high pressure on activities of PDC.

The way of how companies react to those pressures defines performance goals. To remain competitive, companies must reach those goals constantly (Shih et al., 2004). For instance, the time period from the moment in which a customer requires a product until receives it is named fastness, see Slack et al. (1999). For those reasons it is important for a PDC to be prepared for demand variations.

If the demand were constant and with a few number of items, the experience of managers would be sufficient for taking decisions, but this does not happen in most cases. Even so managers are important in PDC systems related to activities coordination for the well functioning of these systems (Van den Berg, 1996; Makris and Giakoumakis, 2003).

A retrieving process, according to Hall (1993), is defined as a stage in which items are removed from shelves, but previously orders need to be converted in Collecting Lists (CL), where code and quantity of each item are registered, and ordered in the sequence of retrieving.

The main issue exposed in the literature is related to the cost of this process. Coyle et al. (1996) affirm that the cost of retrieving process is around 50 to 70% of PDC total cost. Companies should search for minimization of retrieving time because it is similar to reducing cost (Frazelle, 1989; Ratliff and Rosenthal, 1983).

Several authors searched new methods to realize routing in aisles. Caron et al. (2000) proposed routing in different configurations. Caron et al. (1998) compared different strategies of routing in aisles based on items allocation COI. COI (Cube-per-Order Index) is defined as the space occupied in shelves divided by the demand frequency. In fact, the use of COI increases significantly the performance of retrieving process (Kallyna and Lynn, 1976).

Rana (1990) proposed an algorithm for narrow aisles to obtain an estimate of the number of trips for parts collection. Moreover, it was possible to know how were the trolleys route and also the number of collected boxes by trip. Jarvis and McDowell (1991) developed an analytical model to obtain routing values for several allocating policies.

Several routing policies in aisles can be seen in Ratliff and Rosenthal (1983); and Hall (1993). The latter presented, for instance, the results of distances for different aisle widths and routing strategies. Those results were obtained since the number of collecting places had been defined. Moreover, it made comparative analyses among those results to verify which one was the best strategy to be adopted when the number of collecting places was known.

Main papers work with variables such as allocation policy of items in shelves and layout. However, proposals presented in those papers adopt simplifications which provide results different from real systems. For instance, the simulation model proposed by Caron et al. (2000) provides routing values if it was previously estimated the average number of items in each aisle. In practical situations, it is important to evaluate with more accuracy the items positions for better distance estimation. Authors such as Goetschalckx and Ratliff (1988) presented proposals for routing in aisles for a specific shelves position. The routing was obtained connecting collecting places. Nevertheless, collecting places were also previously chosen randomly. The ideal situation should be the own order to establish the item position.

Ezziane (2000) considered important the use of computational programs in companies to make and maintain them competitive in the market. Currently, several PDC use computational programs to support employees in activities such as organization of CL in the sequence which minimize employees routing. Commonly those programs only provide information when a real order comes to the system, making companies vulnerable for unexpected situations. An effective management may be accomplished only if the company has previously information permitting to visualize and prevent futures problems. It is important a tool capable of making tests and providing information to support decisions.

Computational simulation tools have as one of their main important features the construction of models which represent real systems. Banks et al. (1984) affirm simulation permits to comprehend the whole system and to realize several iterations. This way, the simulation presents itself as one important tool to be explored in a PDC, since it can deal with several variables simultaneously (Marín et al., 1998).

Simulation is classified in continuous and discrete. Taha (1988) and Banks et al. (1984) affirmed that discrete simulation evaluates the system behavior under events occurrences during different period (discretely) while the continuous simulation analyses the behavior during all period (continuously). Normally, continuous simulation uses equations while models of discrete simulation use statistical distribution for variables. This is much simple to manipulate data and, in most cases, represents exactly real systems.

Our goal is to present a discrete simulation model developed in ARENA® 5.0 to simulate the items retrieving process of a PDC including several variables related to this task. The goals of this model are to determine the average total time needed by employees to collect parts of an order, permitting to analyze systematically the influences of the following variables to the retrieving time: Quantity of items, number of employees, routing

velocity and trolley load capacity; and to establish relationship among pattern flow and random movement with size of companies.

2. DESCRIPTION OF PDC

The company, where this research was conducted, is a digging machinery and tractor assembly located in São Paulo State which is responsible for supplying reposition parts. Among several sectors there is one PDC responsible for parts with up to 20kg (around 30055 different items). Its dimensions are shown in Figure 1.

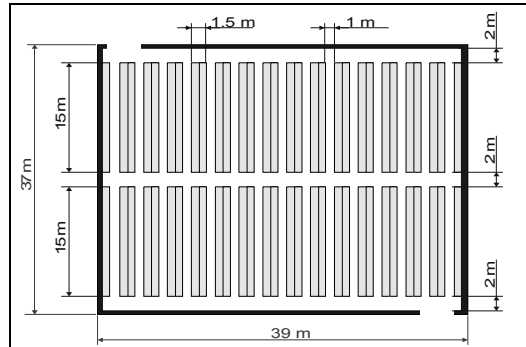


Figure 1. Dimensions of PDC.

There is an important area tied to collecting parts activity and that should be considered in modeling. It is the packing area located at the superior left side of Figure 1. Employees leave this area to execute the collecting parts and return to it later. All of 30055 items are distributed in 30 shelves, whose distribution is based on ABC criteria. Table 1 shows the number of items by type.

Table 1. Real distribution of items.

Type	Number of items	Percentage
A	1522	5.06%
B	3120	10.38%
C	25413	84.56%
Total	30055	100.00%

Reposition of parts to shelves and receiving orders are realized during the morning shift. At the end of this period a list is generated where is registered the requested code and quantity of each item. This list is ordered by code so as to establish the collecting route. In the evening shift (four hours of work) this list is divided in CL and distributed to employees.

There are several manual trolleys in the packing area used by employees in collecting activity. The maximum acceptable load of these trolleys is 120kg. The route begins in packing area to shelves and when the maximum load is reached, employees return to the same area to unload parts. In the afternoon shift, parts are dispatched to customers.

As illustrated in Figure 1, this PDC is composed by 15 vertical and three horizontal aisles. The name subaisle is given for vertical aisle of each shelf and is 15m of long. There are 10 sections (collecting points) in each subaisle. Each section is composed by two subsections, one in left and the other in right side of subaisle. Subsections are divided in drawers for storing parts.

Figure 2 illustrates pattern flow of employees routing in aisles. Numbers close to arrows represent shelves numbers. Group of shelves is named block.

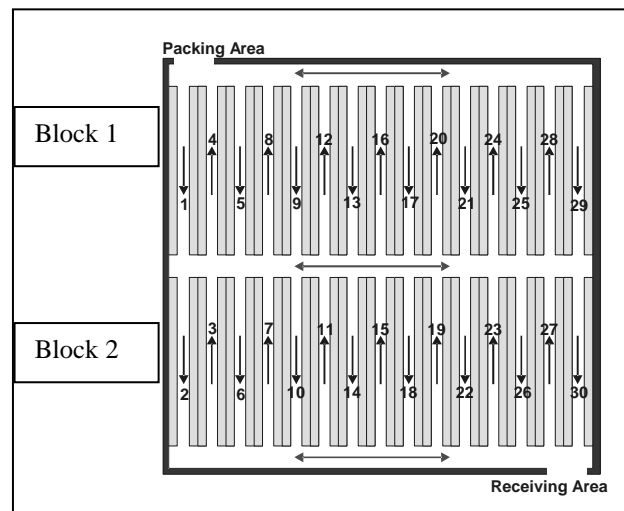


Figure 2. Flow of employees.

3. CHALLENGES

According to Frazelle (1989), the composition of retrieving time is: identification of local, identification of parts, collection and routing. The collecting time is influenced by the part weight. For routing time, it depends on the routing velocity and distance. Routing velocity depends on transported load and routed distance depends on the localization of each part.

For this PDC, there are three types of routes. The first is when employee moves from packing area to first item to be collected (when trolley is empty). The second refers to routing between collected items (same or different shelves). And the last is routing back to the packing area, which occurs after the last item is collected or when trolley capacity is reached.

Flow chart of Figure 3 illustrates steps of modeling. Step generate order creates randomly a list of items which is divided by the number of employees. Next it is calculated the time for the first employee to collect parts of his CL. This process is repeated until the time of last employee is also calculated. All processes are realized in each replication. Steps of calculation of the time spent by each employee consider the time required by the initial routing (from packing area to an item in shelf), the time required to identify the local, to identify part, to collect, to route between items and the time required by final routing (back to packing area). Note that parts weight are constantly verified, because this is the parameter that defines the moment of returning to packing area to unload parts and take another empty trolley to continue the collecting process.

4. PDC MODELING IN SIMULATION SOFTWARE ARENA® 5.0

Several variables must be modelled to permit that simulation provides the retrieving process total time closer to the real system, such as shown in following sub-topics:

4.1. ITEMS DISTRIBUTION IN SHELVES

The first part of modeling refers to layout of shelves and due to some difficulties to obtain the occupied volume it was assumed a constant density of 1000 items per shelf. Each section stores 100 items.

It is also possible to round the number of items to be stored in the same shelf (Table 2).

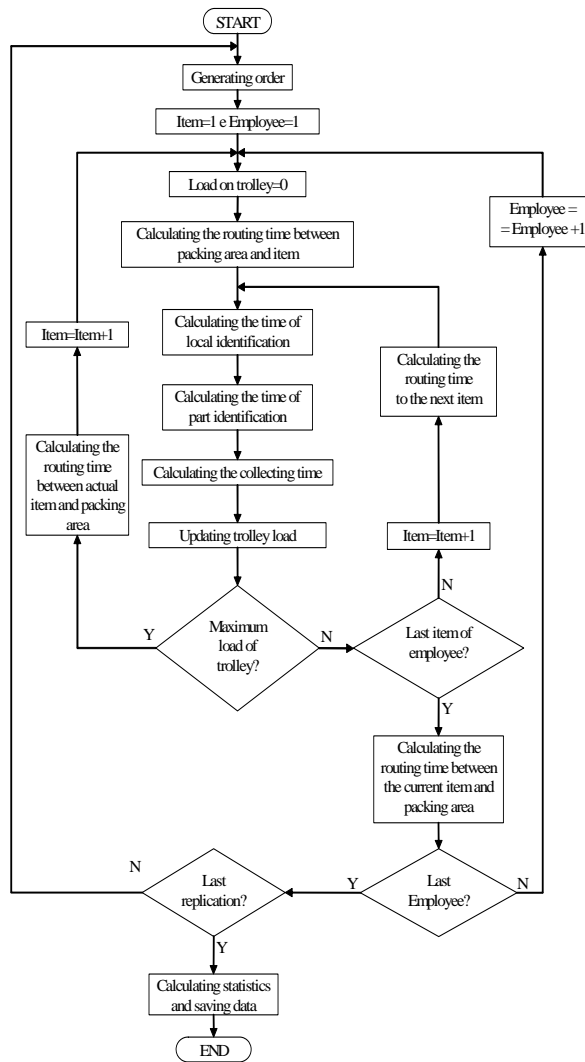


Figure 3. Flow chart of simulation model(Y=Yes; N=No).

Table 2. Rounded quantity of items.

Type	Number of items	Percentage
A	2000	6.67%
B	4000	13.33%
C	24000	80.00%
Total	30000	100.00%

4.2. GENERATING ORDER

Data of one semester period was analyzed and the number of items per order (NIO) was modeled as triangular distribution with a mean of 1700 (1).

$$NIO = \text{Integer}(\text{TriangularDistribution}(1000; 1700; 1850)) \quad (1)$$

Data also show that each order has between 30 and 40% of items type A, 20 to 30% of items type B and 30 to 50% of items type C. These data were also modeled such as represented in (2), (3) and (4).

$$\text{Items A} = \text{Integer}(\text{Uniform Distribution}(0.3; 0.4) * \text{NIO}) \quad (2)$$

$$\text{Items B} = \text{Integer}(\text{Uniform Distribution}(0.2; 0.3) * \text{NIO}) \quad (3)$$

$$\text{Items C} = \text{NIO} - \text{Items A} - \text{Items B} \quad (4)$$

Once those values are defined, the model generates random codes, not repeated codes, for each type of item according to its quantity (for type A codes range from 1 to 2000, for type B from 2001 to 6000 and type C from 6001 to 30000).

To finish order generating step it is necessary to define the parts quantity per item. Uniform distribution among 1 and 50 was adopted, but it was inadequate since in real system parts with high weight are less requested than soft parts. So it was necessary to create Table 3.

Table 3. Definition of parts quantity according to their weights.

Weight of each part	Parts quantity of item
Up to 1kg	Integer(Exponential Distribution(7))+ 1
From 1 to 5kg	Integer(Uniform Distribution(1;8))
From 5 to 10kg	Integer(Uniform Distribution(1;4))
From 10 to 20kg	Integer(Uniform Distribution(1;3))

4.3. COMPOSITION OF ITEMS RETRIEVING PROCESS TOTAL TIME

Models of four components of the time are presented in the following.

- Identification of the local: It was modeled by a triangular distribution (1.5; 2.5; 4)s.
- Identification of part: This time is represented by a triangular distribution (1; 1.5; 3)s.
- Collection: It is the time required for the employees to move their hands from shelf to trolley with collected part. The triangular distribution used is (1; 3; 4)s. For Maynard (1970), parts weight can influence on collecting time, called Factor_M. For more detail, see Shih *et al.* (2005). The collecting time is obtained multiplying time to move hands, Factor_M and quantity of collected parts.
- Routing: The employee's velocity with no load was modeled by a triangular distribution (0.75; 1; 1.2)m/s. For more detail of load influence on time, Factor_V, see Shih *et al.* (2005). Routing velocity is obtained multiplying Factor_V by unloaded velocity.

4.4. LOCATING ITEMS

Given code (from 1 to 30000) it is possible to calculate the shelf (from 1 to 30) and section of subaisle (from 1 to 10) where parts are stores using equations (5) and (6).

$$\text{Shelf} = 1 + \text{Integer}\left(\frac{(\text{Code} - 1)}{1000}\right) \quad (5)$$

$$\text{Section} = 1 + \text{Integer}\left(\frac{(\text{Code}-1)}{1000} - \text{Integer}\left(\frac{(\text{Code}-1)}{1000}\right)\right) * 10 \quad (6)$$

4.5. ROUTED DISTANCE

Due to pattern flow, it is possible to establish equations to routes, such as shown in following sub-topics.

4.5.1. Routing from Packing Area to Shelves (When Trolley Is Empty)

This routing is composed by two components. The first depends on destiny shelf and the second depends on section where the item is located. Figure 4 shows an example where item is located in a certain section of shelf 1.

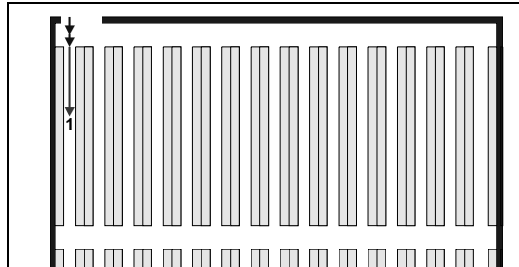


Figure 4. Routing to shelf 1.

The first component is presented by two small arrows, where each one represents 1m (due to cross-aisle measures, which are 2 meters in width). Second component, named Final Routing (FinRou), is represented by an average arrow and its length can be calculated by equation (7) and its unit is in meters [m]. The value 1.5 of this equation represents dimension of each section.

$$FinRou[m] = DestinySection * 1.5 \tag{7}$$

Figure 5 shows six routes. Bigger arrows pass through all shelf and it measures 15 meters long. Horizontal arrows measure 2.5meters (from center of an vertical aisle to another). Let us suppose that an initial item is located in the second shelf. The first routing component has four smaller and one bigger arrow, totalizing 19 meters.

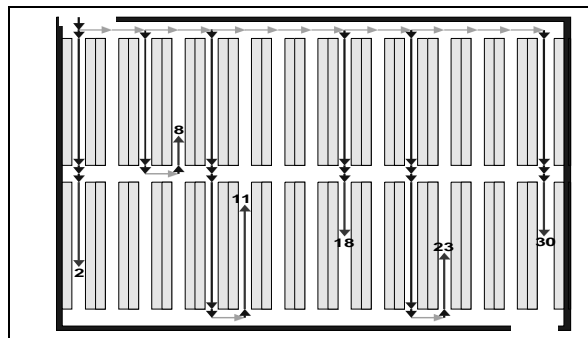


Figure 5. Examples of routes from packing area to sections.

Generically, routing values in aisles from packing area to aisles sections are shown in Table 4.

Table 4. Distances from packing area to each section (in meters).

Shelf	Distance	Shelf	Distance	Shelf	Distance
01	$2.0+FinRou$	11	$48.5+FinRou$	21	$27.0+FinRou$
02	$19.0+FinRou$	12	$31.5+FinRou$	22	$44.0+FinRou$
03	$38.5+FinRou$	13	$17.0+FinRou$	23	$63.5+FinRou$
04	$21.5+FinRou$	14	$34.0+FinRou$	24	$46.5+FinRou$
05	$7.0+FinRou$	15	$53.5+FinRou$	25	$32.0+FinRou$
06	$24.0+FinRou$	16	$36.5+FinRou$	26	$49.0+FinRou$
07	$43.5+FinRou$	17	$22.0+FinRou$	27	$68.5+FinRou$
08	$26.5+FinRou$	18	$39.0+FinRou$	28	$51.5+FinRou$
09	$12.0+FinRou$	19	$58.5+FinRou$	29	$37.0+FinRou$
10	$29.0+FinRou$	20	$41.5+FinRou$	30	$54.0+FinRou$

Analyzing data of Table 4, values added to FinRou can be decomposed such as illustrated in Table 5.

Table 5. Relationships in distances from packing area to each section (in meters).

Shelf	Distance	Relationship	Shelf	Distance	Relationship
01	2.0	$2.0 + 0 * 5$	16	36.5	$21.5 + 3 * 5$
02	19.0	$19.0 + 0 * 5$	17	22.0	$2.0 + 4 * 5$
03	38.5	$38.5 + 0 * 5$	18	39.0	$19.0 + 4 * 5$
04	21.5	$21.5 + 0 * 5$	19	58.5	$38.5 + 4 * 5$
05	7.0	$2.0 + 1 * 5$	20	41.5	$21.5 + 4 * 5$
06	24.0	$19.0 + 1 * 5$	21	27.0	$2.0 + 5 * 5$
07	43.5	$38.5 + 1 * 5$	22	44.0	$19.0 + 5 * 5$
08	26.5	$21.5 + 1 * 5$	23	63.5	$38.5 + 5 * 5$
09	12.0	$2.0 + 2 * 5$	24	46.5	$21.5 + 5 * 5$
10	29.0	$19.0 + 2 * 5$	25	32.0	$2.0 + 6 * 5$
11	48.5	$38.5 + 2 * 5$	26	49.0	$19.0 + 6 * 5$
12	31.5	$21.5 + 2 * 5$	27	68.5	$38.5 + 6 * 5$
13	17.0	$2.0 + 3 * 5$	28	51.5	$21.5 + 6 * 5$
14	34.0	$19.0 + 3 * 5$	29	37.0	$2.0 + 7 * 5$
15	53.5	$38.5 + 3 * 5$	30	54.0	$19.0 + 7 * 5$

Note there are four values constantly repeated (2; 19; 38.5 and 21.5). It is possible to create a calculation procedure which permits to obtain routing value (Figure 6).

Table 6. Relationship of distances (in meters).

Shelf	Distance	Relationship	Shelf	Distance	Relationship
01	24.0	-	16	19.5	$4.5 + 3 * 5$
02	41.0	-	17	39.0	$24.0 + 3 * 5$
03	21.5	$21.5 + 0 * 5$	18	56.0	$41.0 + 3 * 5$
04	4.5	$4.5 + 0 * 5$	19	41.5	$21.5 + 4 * 5$
05	24.0	$24.0 + 0 * 5$	20	24.5	$4.5 + 4 * 5$
06	41.0	$41.0 + 0 * 5$	21	44.0	$24.0 + 4 * 5$
07	26.5	$21.5 + 1 * 5$	22	61.0	$41.0 + 4 * 5$
08	9.5	$4.5 + 1 * 5$	23	46.5	$21.5 + 5 * 5$
09	29.0	$24.0 + 1 * 5$	24	29.5	$4.5 + 5 * 5$
10	46.0	$41.0 + 1 * 5$	25	49.0	$24.0 + 5 * 5$
11	31.5	$21.5 + 2 * 5$	26	66.0	$41.0 + 5 * 5$
12	14.5	$4.5 + 2 * 5$	27	51.5	$21.5 + 6 * 5$
13	34.0	$24.0 + 2 * 5$	28	34.5	$4.5 + 6 * 5$
14	51.0	$41.0 + 2 * 5$	29	54.0	$24.0 + 6 * 5$
15	36.5	$21.5 + 3 * 5$	30	71.0	$41.0 + 6 * 5$

Figure 9 shows procedure that permits to calculate the routed distance from the last collected part to packing area.

V(21.5 ; 4.5 ; 24 ; 41)	'Vector composed by four basis values
Read PO	'Information of origin shelf
Read SO	'Information of Origin Section
If PO = 1 then D= 24	'Definition of value D
If PO = 2 then D = 41	'Definition of value D
If PO >= 3 then	
A = Integer((PO -3)/4)	'Defines the value to be multiplied by 5
B = PO - 2 - 4 * A	'Defines a value of vector
D = V(B) + 5 * A	'Calculate the value for variable D
Enf if	
IniRou = (10 - SO) * 1.5	'Distance to destiny section
Distance = IniRou + D	'Calculates total distance

Figure 9. Procedures for calculating distance between a shelf and packing area.

4.5.3. Routing Among Shelves

There are two situations. First, the next item is located at the same shelf of first item and in this case the distance can be calculated by equation (9)

$$Distance[m] = (DestinySection - Section) * 1.5 \quad (9)$$

Second when the next item is located at other shelf. This situation involves three components: Routings between current item to the end of this same shelf (IniRou), from current shelf to destiny shelf and to destiny section (FinRou).

Figure 10 presents five examples, which are: from shelf 2 to shelf 4, from shelf 4 to shelf 11, and so on.

It is important to note that routing always begins from shelf with a lower number to higher one since CL are numbered by codes. Arrows of initial routes (IniRou) are calculated by equation (8) while final ones (FinRou) are calculated by equation (7). To complete this step, we need also to calculate distances between origin shelf and destiny.

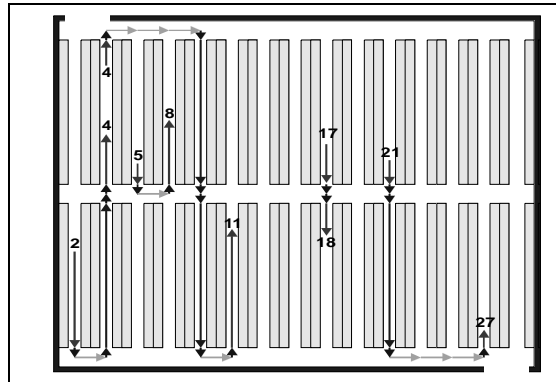


Figure 10. Some routing examples among sections of different shelves.

Routed distances between two shelves depend on definition about which one is origin or destiny shelf. For instance, consider that shelf 1 is an origin one. From this shelf, there are 29 possibilities of destiny shelves. From shelf 25, there are 5 possible destiny shelves and so on. Tables 7, 8 and 9 show routing values among shelves. Actually, all values should be in only one Table with 30 lines and 30 columns, nevertheless it could not be showed in only one page. Values showed in three Tables below have four common values. However, depending on origin shelf be even or odd, there would be four different values. There are, therefore, 8 basis numbers:

Odd origin shelf: 2; 21.5; 4.5 and 24;

Even origin shelf: 4.5; 21.5; 41 and 24.

Figure 11 shows a procedure to calculate distance among sections.

Table 7. Routed distances from origin to shelves 1 to 10.

Origin	Destiny Shelf									
	01	02	03	04	05	06	07	08	09	10
01	0	2	21.5	4.5	24	7	26.5	9.5	29	12
02	-	0	4.5	21.5	41	24	9.5	26.5	46	29
03	-	-	0	2	21.5	4.5	24	7	26.5	9.5
04	-	-	-	0	4.5	21.5	41	24	9.5	26.5
05	-	-	-	-	0	2	21.5	4.5	24	7
06	-	-	-	-	-	0	4.5	21.5	41	24
07	-	-	-	-	-	-	0	2	21.5	4.5
08	-	-	-	-	-	-	-	0	4.5	21.5
09	-	-	-	-	-	-	-	-	0	2
10	-	-	-	-	-	-	-	-	-	0

Table 8. Routed distances from destiny to shelves 11 to 20.

Origin	Destiny Shelf									
	11	12	13	14	15	16	17	18	19	20
01	31.5	14.5	34	17	36.5	19.5	39	22	41.5	24.5
02	14.5	31.5	51	34	19.5	36.5	56	39	24.5	41.5
03	29	12	31.5	14.5	34	17	36.5	19.5	39	22
04	46	29	14.5	31.5	51	34	19.5	36.5	56	39
05	26.5	9.5	29	12	31.5	14.5	34	17	36.5	19.5
06	9.5	26.5	46	29	14.5	31.5	51	34	19.5	36.5
07	24	7	26.5	9.5	29	12	31.5	14.5	34	17
08	41	24	9.5	26.5	46	29	14.5	31.5	51	34
09	21.5	4.5	24	7	26.5	9.5	29	12	31.5	14.5
10	4.5	21.5	41	24	9.5	26.5	46	29	14.5	31.5
11	0	2	21.5	4.5	24	7	26.5	9.5	29	12
12	-	0	4.5	21.5	41	24	9.5	26.5	46	29
13	-	-	0	2	21.5	4.5	24	7	26.5	9.5
14	-	-	-	0	4.5	21.5	41	24	9.5	26.5
15	-	-	-	-	0	2	21.5	4.5	24	7
16	-	-	-	-	-	0	4.5	21.5	41	24
17	-	-	-	-	-	-	0	2	21.5	4.5
18	-	-	-	-	-	-	-	0	4.5	21.5
19	-	-	-	-	-	-	-	-	0	2
20	-	-	-	-	-	-	-	-	-	0

Table 9. Routed distances from destiny to shelves 21 to 30.

Origin	Destiny Shelf									
	21	22	23	24	25	26	27	28	29	30
01	44	27	46.5	29.5	49	32	51.5	34.5	54	37
02	61	44	29.5	46.5	66	49	34.5	51.5	71	54
03	41.5	24.5	44	27	46.5	29.5	49	32	51.5	34.5
04	24.5	41.5	61	44	29.5	46.5	66	49	34.5	51.5
05	39	22	41.5	24.5	44	27	46.5	29.5	49	32
06	56	39	24.5	41.5	61	44	29.5	46.5	66	49
07	36.5	19.5	39	22	41.5	24.5	44	27	46.5	29.5
08	19.5	36.5	56	39	24.5	41.5	61	44	29.5	46.5
09	34	17	36.5	19.5	39	22	41.5	24.5	44	27
10	51	34	19.5	36.5	56	39	24.5	41.5	61	44
11	31.5	14.5	34	17	36.5	19.5	39	22	41.5	24.5
12	14.5	31.5	51	34	19.5	36.5	56	39	24.5	41.5
13	29	12	31.5	14.5	34	17	36.5	19.5	39	22
14	46	29	14.5	31.5	51	34	19.5	36.5	56	39
15	26.5	9.5	29	12	31.5	14.5	34	17	36.5	19.5
16	9.5	26.5	46	29	14.5	31.5	51	34	19.5	36.5
17	24	7	26.5	9.5	29	12	31.5	14.5	34	17
18	41	24	9.5	26.5	46	29	14.5	31.5	51	34
19	21.5	4.5	24	7	26.5	9.5	29	12	31.5	14.5
20	4.5	21.5	41	24	9.5	26.5	46	29	14.5	31.5
21	0	2	21.5	4.5	24	7	26.5	9.5	29	12
22	-	0	4.5	21.5	41	24	9.5	26.5	46	29
23	-	-	0	2	21.5	4.5	24	7	26.5	9.5
24	-	-	-	0	4.5	21.5	41	24	9.5	26.5
25	-	-	-	-	0	2	21.5	4.5	24	7
26	-	-	-	-	-	0	4.5	21.5	41	24
27	-	-	-	-	-	-	0	2	21.5	4.5
28	-	-	-	-	-	-	-	0	4.5	21.5

29	-	-	-	-	-	-	-	-	0	2
30	-	-	-	-	-	-	-	-	-	0

Odd(2 ; 21.5 ; 4.5 ; 24) 'Definition of odd vector
 Even(4.5 ; 21.5 ; 41 ; 24) 'Definition of even vector
 Read PO 'Information of origin shelf
 Read PD 'Information of destiny shelf
 Read SO 'Information of origin section
 Read SD 'Information of destiny section
 If PO=PD then 'If is the same shelf, then...
 Distance=(SD-SO)*1.5 'Equation (9)
 Else
 IniRou=(10-SO)*1.5 'Initial Routing
 FinRou= SD*1.5 'Final Routing
 B= Integer ((PD - PO - 1) / 4) 'Defines the value to be multiplied by 5
 A = (PD-PO) – 4 * B 'Selection of one of 4 basis value
 If (PO/2)-Integer(PO/2)=0 then 'If origin shelf is even, then...
 D=Even(A)+5* B 'Result of variable value D
 Else
 D=Odd(A)+5* B 'Result of variable value D
 Enf If
 Distance=IniRou+D+FinRou 'Total distance among items
 Enf If

Figure 11. Procedure to calculate distance among sections.

5. EXPERIMENTS

5.1. EXAMPLE 1

Let us now first show the current spent time and its components. Figure 12 presents a bar chart constructed by average values of four components of total time with five employees and for 30 replications. Average number of items per order was 1478, three of the components were almost the same (identification of the local, part and collection).

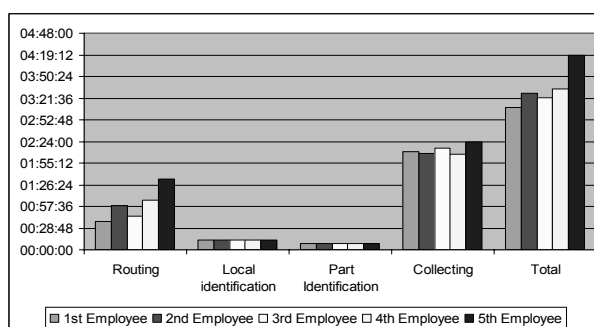


Figure 12. Composition of total time for 5 employees (in hours).

Note that 5th employee takes more than four hours to complete his task, over than evening shift. Graph shows that differences are in routing times. This is because 1st employee collects only parts located close to packing area while 5th employee collects parts of last shelves. Let us consider one replication, for instance:

For this replication, this order is 1417 items with 476 codes type A, 316 type B and 625 type C, see Table 11. Employees 1st to 4th have to collect 282 items while 5th employee, 284. "Item" column of this Table shows the first and last number of items of CL while "Code" column shows correspondent part code. Note that 5th employee takes more than four hours to complete his task, over than evening shift.

Data of Table 10 show the 1st employee works only in shelves 1 and 2 while 5th employee works in shelves 18 to 30. It can be concluded that distance among collected items type C is higher than distance between items A and B.

Table 10. Average for 30 replications.

Employee	Total time	Routed distance	Item	Code	Type	Shelf
1	3h8min46s	1750.00 m	1	3	A	1
			283	1148	A	2
2	3h27min45s	2822.50 m	284	1152	A	2
			566	2503	B	3
3	3h21min54s	2371.00 m	567	2504	B	3
			849	6018	C	7
4	3h34min9s	3279.00 m	850	6122	C	7
			1132	18059	C	18
5	4h18min57s	4746.50 m	1133	18060	C	18
			1417	29871	C	30

5.2. EXAMPLE 2

Let us consider an unexpected situation. Suddenly in a certain day of the week one employee is sick and he is not available to work. Is it capable for the remaining four employees to collect parts in a period of 4 hours? If it is not, what can be done with other variables to fill this gap? Figure 13 shows results of each component of the retrieving time and note that total time really is higher for most employees. What can be done in a short term just to supply the necessity of one absent employee to complete collecting in a period of four hours? Let us now suppose that routing velocity of employees is increased to 1,5m/s, it yields the following results as shown in Figure 14.

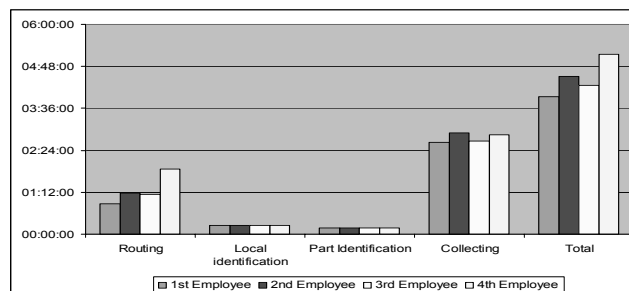


Figure 13. Total time when one employee is out.

Just with this policy, the company can reduce the retrieving time to four hours filling one employee's gap. Other variables can also be altered, such as shown in example 3.

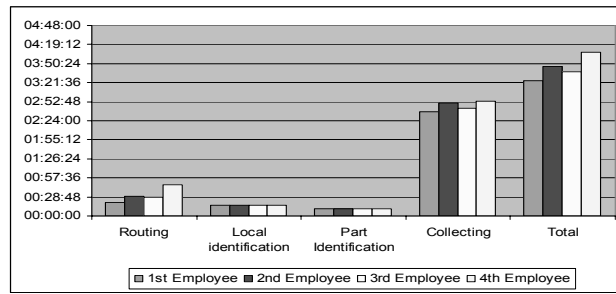


Figure 14. Total time when one employee is out (velocity of 1,5m/s).

5.3. EXAMPLE 3

Let us consider another unexpected situation. Due to some broken machines in the packing area, all of 5 men are allocated simultaneously there to accomplish customer requirements, because it becomes more urgent than collecting parts (customer satisfaction issue), and consider also women are used in retrieving process instead of men. Due to their physical endurance, they can not push trolleys with 120kg of load only 100kg or less. How many women would be necessary to finish this process in a period of four hours with 100kg of load on trolley, for example? Figure 15 shows results under those conditions. Increasing the number of employees from 5 to 6 it is possible to accomplish their tasks with load of 100kg.

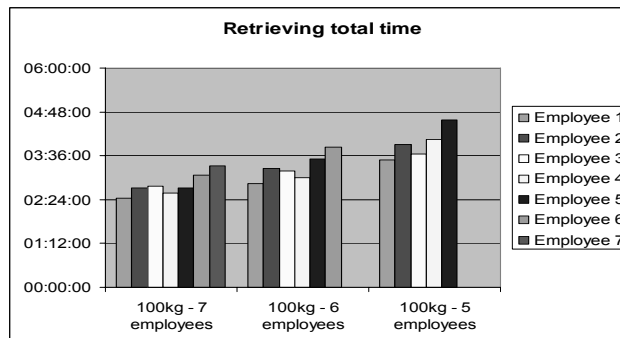


Figure 15. For 100kg of load on trolley: employees x total time.

6. TO DEFINE PATTERN FLOW OR TO USE RANDOM ROUTING?

During the modelling process, it was noticed that pattern flow adopted by the company could be increasing the routed distance. For instance, let suppose a certain part of shelf 2 must be collected. Employee must follow the flows walking to shelf 3 to return. This makes unnecessary movements.

To test the influence of flow on distance, we will implement procedures showed in this paper in Excel Worksheet, due to this software works well with if-else condition. We also intend to analyze how the size of an establishment can influence on the route, so it is analyzed blocks 1, 2 and their combination 1 & 2. First and second Tables of Table 11 shows a typical situation of establishment that works with one block. Several small establishments use only one block.

Items to be tested are chosen randomly, but this was based on flow criteria. For instance, from item 3582 of flow \uparrow , employee will collect next item of same flow direction of items code 7320 and so on. These result in 173m. As commented before, there are extra movements. If it were random, based on employees' feelings, it would result in 91,82m. It

implies consequently in larger *subaisles*, because employees can walk in the same *subaisle* at the same time and changing to a larger one becomes necessary, which means in increasing total routing.

Figures 16, 17 and 18 show that in most case flow are higher than random movement. Nevertheless sometimes it is important to establish pattern flows in cases when manual trolley offers any accident risk to employees.

When the company decides to work with only one block (even block 1 nor 2), collecting items following pattern flow or random movement is almost the same, since requested items are equally spread in shelves to respect the condition $\uparrow\downarrow$.

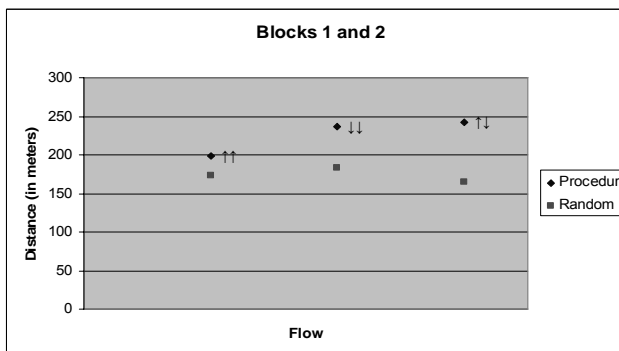
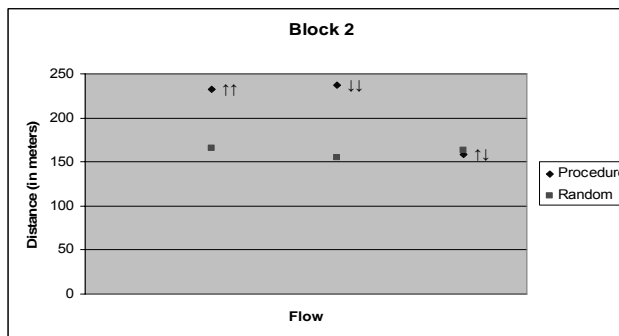
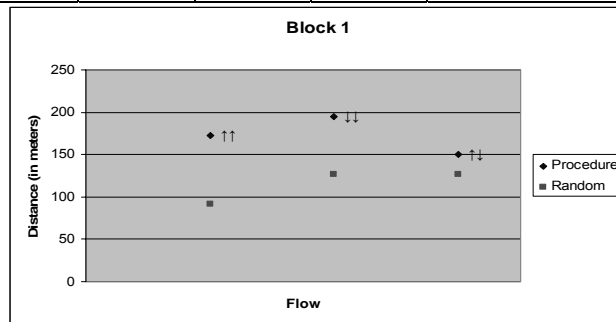
Now larger establishment (with several shelves blocks), it is recommended employees to collect parts with exit direction \uparrow to avoid opposite movements \downarrow . To do that, employees should start collecting from receiving area with manual trolley to packing area. Collecting similar or complementary parts may help to minimize routed distances, due to they are stored closer, and with loaded trolley employees follow \uparrow to packing area. Data used to the test were: Maximum weight (kg) = 200; Trolley velocity (m/s)=0,6; Parts weight (kg)=20; Time to identify the local (s) = 2,5; Time to identify the part (s) = 1,5; Collecting time (s) = 3; Quantity of parts = 4.

Table 11. Results from Excel.

Block 1				
Item / Flow				Distance (procedure)
3582 / \uparrow	7320 / \uparrow	11704 / \uparrow	15840 / \uparrow	173m
753 / \downarrow	8730 / \downarrow	16441 / \downarrow	24390 / \downarrow	194,5m
3292 / \uparrow	8400 / \downarrow	15670 / \uparrow	20680 / \downarrow	150,5m

Block 2				
Item / Flow				Distance (procedure)
5688 / \downarrow	13119 / \downarrow	17611 / \downarrow	25881 / \downarrow	232
6941 / \uparrow	14663 / \uparrow	22142 / \uparrow	26384 / \uparrow	237
1667 / \downarrow	6768 / \uparrow	17746 / \downarrow	22231 / \uparrow	159

Blocks 1 and 2				
Item / Flow				Distance (procedure)
875 /↓	5469 /↓	12277 /↓	25478 /↓	198
3151 /↑	10090 /↑	19558 /↑	26119 /↑	237
7759 /↑	17866 /↓	23227 /↑	29545 /↓	242



Figures 16, 17 and 18. Relationship between procedure and random.

7. CONCLUSIONS

The goal of this paper was to present a model of a PDC aiming at determining the average total time spent by employees to collect parts of one order. Several procedures were shown to model variables that affect this time making results closer to the reality.

Although the presented model was developed for a specific PDC, it can be used to simulate different number of items, sections, shelves (only for 3 cross-aisles). This

modification can be done altering equations 5, 6, 7, 8 and 9 and also three presented procedures.

Simulation has an important task in manufacturing systems providing information previously without changing real system. Simulation is not applied to obtain solutions, but provide information to support managers in decisions. For instance, it is possible to estimate the required number of employees that permits order consolidation in a established period of time avoiding delivering delay.

From data presented in Table 11, for instance, it is possible to conclude that dividing equally order in a similar parts (CL) will result in an unbalanced spent time for collecting consolidation. This time may become higher than 4 hours of evening shift. It is possible to search for a method that permits balancing average total time by each employee. Even with the same number of items in CL, routing will be different. New methods are proposed for future searches for dividing CL.

It is also established a relationship between pattern flow and random movement. Smaller companies can use both due to the fact that routed distances are almost the same, but under conditions of requested items equally distributed ($\uparrow\downarrow$). For bigger companies, random movement is still more effective, but if it is decided to follow a flow pattern due to safety issues, it is suggested that each employee collects similar or complementary parts avoiding \downarrow flow.

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Modelagem e simulação do processo de retirada de itens

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RESUMO

Este trabalho apresenta um modelo de CDP, desenvolvido em Arena 5.0, o qual gera informações aos decisores sobre o tempo total do processo de retirada de itens. Este tempo sofre influência de diversas variáveis tais como dimensões das prateleiras, velocidade de deslocamento e a massa das peças. São apresentadas as soluções elaboradas para modelar estas variáveis com ênfase na distância percorrida, que é o principal fator que influencia o tempo consumido nesta atividade. Os resultados obtidos nas simulações permitem compreender a dinâmica do sistema e também auxiliar os decisores, por exemplo, na definição do número de funcionários necessários.

Palavras-chave: Retirada de itens. Modelagem em simulação discreta. Gerenciamento.
