PERFORMANCE OF EARLIEST COMPLETION STRATEGY IN ORDER SORTATION SYSTEMS

Fahrettin Eldemir [(a)], Elif Karakaya[(b)]

[(a)]Fatih University- Department of Industrial Engineering
[(b)]TechnischeUniversität Dortmund- Chair of Factory Organization

[(a)] feldemir@fatih.edu.tr, [(b)] karakaya@lfo.tu-dortmund.de

ABSTRACT
The Order Accumulation and Sortation Systems (OASS) are becoming more important as distribution centers try to gain competitive advantages. There are certain key parameters that affect the performance of Sortation Systems. The effect of these parameters can be measured by how they are affecting throughput or average sortation time. The time required to sort mixed items depends on the sortation strategy employed in the system. A new strategy called Earliest Completion Rule has been introduced. In this study, an analytical model for calculation of average sorting time of a newly introduced sortation strategy has been developed. It has been observed that the new strategy decreases the sortation time significantly. While available analytical models assume that all orders are at the same size (quantity), in this study this assumption is relaxed. Both analytical models and simulations are employed to compare sortation strategies for different order combinations and for various design choices. AutoMod Software is used as the simulation tool.

Keywords: logistics, sortation strategies, material handling, simulation

1. INTRODUCTION

In today's competitive world, it is desirable that a distribution center runs at its optimal settings to gain a competitive advantage. More efficient distribution centers are needed to respond to increasing competition and to an increased emphasis placed on time-based service. In distribution centers, long lists of orders are put together in an intensive way. Each customer order can include various items in different quantities. In classical order picking procedure, each order is collected by an assigned picker and the products in this list might be stored at different storage addresses. Therefore, pickers may end up travelling to far distances in a warehouse in order to complete the list and searching the items all over the warehouse. This situation often causes unnecessary transportation costs and ineffective worker utilizations. To overcome shortages mentioned above, the zone picking method is widely used in warehouses. In this picking method, the items from different orders are arranged over again (batch orders) and the same product types be collected by the same workers. With this method, order pickers are assigned to a specific zone. In this way, unproductive travel time will disappear. However, although this situation saves time and speed, the items of accumulated orders are completely mixed because the items collected by different pickers arrive of the packing are at different times. While waiting for the other items from the same order they are accumulated in a place. There is no doubt that these products (items) have to be sorted according to the product type and quantity before shipping. At this point, sortation systems (these are often automated systems) are used.

The optimal condition for a given system studied would be one in which the rate of sortation (i.e., throughput rate) is maximized, thus minimizing the wave sortation time without increasing the capital and operating costs. There is a trade-off between the rate and cost. Using more resources such as labor and machines can increase the rate of sortation; however, the cost of sortation thus increases. This research focuses on maximizing the throughput rate of a given system and assumes that the other variables, such as cost and operating design parameters, are held within satisfactory limits.

There are different sortation strategies available: namely, Fixed Priority Rule, Next Available Rule, and Earliest Completion Rule. Some analytical models for these sortation strategies have been developed in earlier studies. However, the sortation models are limited to one induction lane and one sortation lane.

2. LITERATURE REVIEW

Up to this point, only a few studies have dealt with Accumulation and Sortation Order System (OASS).The first example of related to sortation strategies is developed by Bozer et al. (1988). The Fixed Priority Rule (FPR) is for lane assignment by simulating different waves of orders. Johnson (1998) developed a dynamic sortation strategy which is called Next Available Rule (NAR) and compared it with “FPR". Eldemir (2006) developed an alternative sortation strategy called Earliest Completion Rule (ECR) by using order statistics.

Closed-loop simple conveyor design researches contain a different numbers of induction lane and sortation lanes. Especially the first studies are hypothesized one induction and one sortation lane. However, later on, due to increase of orders and product variability, the conveyor design converted into many induction and sortation lanes. The following, table summarizes the literature on closed-loop conveyor system analysis according to the number of its induction and sortation lanes.

Table 1: Literature Review about Conveyor Design

Sortation Literature Summary					
Citation	Method	Problem Setting			
		One Ind.	Many Ind.	One Sort	Many Sort.
Bozer and Sharp (1985)	Simulation	√		√	
Bozer et al (1998)	Simulation	√			√
Johnson and Lofgren(1994)	Simulation	√			√
Johnson (1998)	Analytical	√			√
Meller (1997)	Analytical	√			√
Schmidt and Jackman(2000)	Analytical	√		√	
Johnson and Meller(2002)	Analytical		√		√
Russell and Meller(2003)	Descriptive		√		√
Bozer (2004)	Analytical		√		√
Eldemir (2006)	Analytical	√		√	

3. SORTATION SYSTEM DESIGN

3.1. One-One Model

In One-One Model (Figure 1), one induction lane and one sortation lane are available. Induction lane is sometimes called as "accumulation lane", as well. When the literature is evaluated thoroughly, it can be observed that this model is the first applied model to the re-circulating conveyor. For instance, Bozer and Sharp (1985) have carried out this model in order to develop sortation strategies.

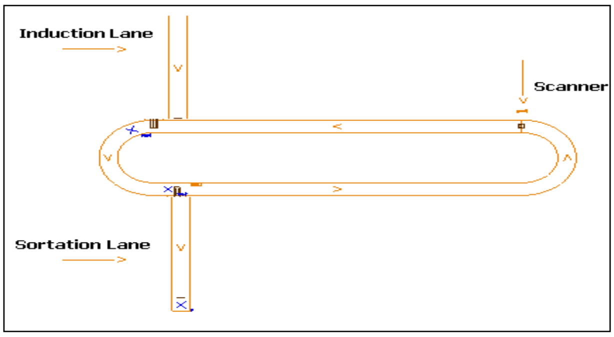

Figure 1: One - One Model Conveyor Design

3.2. One-Many Model

The One - Many Model (Figure 2) differs from the previous model since it has more than one sortation lane. When compared with others, this model is the frequently applied. For instance, Johnson and Lofgren (1994), Johnson (1998), Meller (1997) have used this model in their studies.

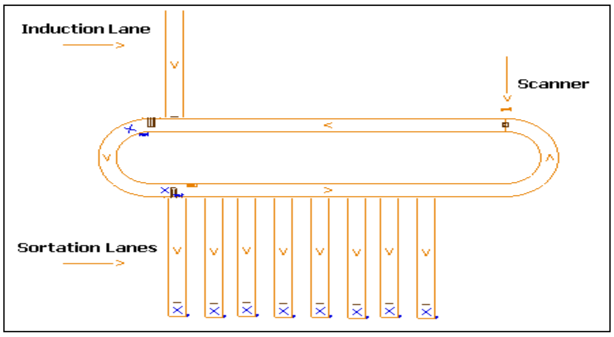

Figure 2: One - Many Model Conveyor Design

4. SORTATION STRATEGIES

Sortation strategies can be classified into two families, fixed priority rules (FPR) and dynamic assignment rules. In fixed priority rules, the orders are prioritized before sortation based on a certain rule. Dynamic assignment rules are assignment strategies that consider the item locations on the conveyor. The most common examples of this family are the next available rule (NAR) and the earliest completion rule (ECR). All parameters are determined below:

Table 2 : Notation

y	Number of items within an order
m	Number of orders within a wave
l	Length of closed-loop conveyor
v	Speed of conveyor
t	Time for an item to circulate around main sortation line
n	Number of accumulation lanes
i	Item index within an order
j	Order index within a wave
q	Number of orders sorted thus far

4.1. Fixed Priority Rule (FPR)

Sortation time evaluation by using Fixed Priority Rule is exemplified underneath. The number of accumulation lanes is accepted as one and the number of items within the order is constant.

The length of the track (closed-loop conveyor) is:

$$T = \frac{L}{v} \tag{1}$$

Assuming that the location of item i in the order j is uniformly distributed onto the conveyor, items will keep their positions on the conveyor throughout the sorting process, because the closed-loop conveyors speed is constant. Thus sorting time is found by subtraction of the last item from the first item.

The probability distribution function for the uniform distribution will be:

$$f_{l_{j1}}(l) = \left(\frac{y}{T}\right)\left(1-\frac{l}{T}\right)^{y-1} \quad 0 \le l \le T \tag{2}$$

The expected time for the first item to arrive to the sortation lane will be:

$$E(l_{j1}) = \frac{T}{y+1} \tag{3}$$

In the same way, the probability distribution function of the last order statistic will be:

$$f_{l_{j[y]}}(l) = \left(\frac{y}{T}\right)\left(\frac{l}{T}\right)^{y-1} \quad 0 \le l \le T \tag{4}$$

The expected location of the last item will be:

$$E(l_{j[y]}) = \left(\frac{y.T}{y+1}\right) \tag{5}$$

Thus, the expected time difference between the last item and first item will be:

$$E_{TS} = \frac{T(y-1)}{y+1} \tag{6}$$

Under FPR, the orders are ranked at the beginning of the sortation process. Two fixed priority rules which are commonly used in industry: namely “the smallest order first” and “the largest order first”. The expected dispersion is the same for all orders since the location of the items in each order is independent from the other items of the other orders. For this reason, the index of *[j]* is eliminated from the expression (5). The expected gap between order *[j]* and following order *[j]* is the expected difference between the position of the first box in the order *[j]* and the last box in the previous order *[j]*.

$$E_{TG} = E(l_{j1} - l_{[j-1][y]}) = \left(\frac{T}{y+1}\right) \tag{7}$$

Under FPR, the sorting time for all orders within the specific wave will be the sum of all gaps and spreads as follows:

$$T_{FPR} = \frac{m.T.y}{y+1} \tag{8}$$

4.2. Next Available Rule (NAR)

In the Next Available Rule, once sortation of an order is finished, the next order is selected dynamically. Sortation lane selects the first item (box) that arrives and the items belong to same order as the next for the sortation process. Those boxes will be sent to shipping next. The expected sorting time for each of them depends on the number of orders which left to be sorted.

In this Next Available Rule, the expected sorting time for each order is depends on the number of orders which left to be sorted. Assuming that the locations of the items *(l)* in the remaining orders are independent and uniformly distributed, and q the number of orders sorted. Then the following formulation shows the probability distribution function of the first box:

$$f_{l_{j1}}(l) = \left(\frac{y(m-q)}{T}\right)\left(1-\frac{l}{T}\right)^{y(m-q)-1} \quad 0 \le l \le T \tag{9}$$

The expected value of the gap between the last item of order *[q]* and the next order is given below:

$$E_{TG}(q) = \frac{T}{y(m-q)+1} \tag{10}$$

The expected location of the last item of the order *[q+1]* is thus derived:

$$E(l_{[q+1][y]}) = T\left(1-\frac{m-q}{y(m-q)+1}\right) \tag{11}$$

Additionally, the expected time difference between the last item and first item will be:

$$E_{TS} = T\left(1-\frac{m-q+1}{y(m-q)+1}\right) \tag{12}$$

Under NAR, the sorting time for all orders within the specific wave will be as follows:

$$T_{NAR} = T.\sum_{q=0}^{m-1}\left(1 - \frac{m-q}{y(m-q)+1}\right) \tag{13}$$

4.3. Earliest Completion Rule (ECR)

In the dynamic assignment category, another sortation strategy model is the Earliest Completion Rule (ECR). When sortation of an order is finished, the next order is determined based on the location of the last items. The order with the last item being closest to the accumulation lane is selected as the next order to be sorted. Like NAR, the sortation time will depend on the number of orders which are going around on the main sortation lane. Assuming that all items are randomly and uniformly distributed on the closed-loop conveyor and the item locations are independent of each other, from order statistics, the probability density function of the last item of an order *(f_{ly})* will be the following:

$$f_{l_y}(l) = \left(\frac{y}{T}\right)\left(\frac{l}{T}\right)^{y-1} \qquad 0 \le l \le T \tag{14}$$

The cumulative distribution of l_y will be:

$$F_{l_y}(l) = \left(\frac{l}{T}\right)^{y} \qquad 0 \le l \le T \tag{15}$$

The decision time comes for the next order; there are *m-q* orders which are waiting to be sorted. Therefore, there will be *m-q* last cartons which are distributed on the closed-loop conveyor with probability density function given by (14). Among these last cartons, the one with lowest *l* value located closest distance to the accumulation lane will be selected. The probability density function of this smallest *l* value can be attained by using the first order statistics.

$$f_{l_y^{\min}}(l) = (m-q).\left[1 - F_{l_y}\right]^{m-q-1}.f_{l_y}$$

$$= (m-q).\frac{y}{T^y}.\left[1 - \left(\frac{l}{T}\right)^y\right]^{m-q-1}.l^{(y-1)}$$

$$0 \le l \le T \tag{16}$$

The expected order sorting time *[q+1]* can be found from the following statement:

$$E(l_{[q+1][y]}) = \frac{y(m-q)}{T^{y(m-q)}}.\int_{l=0}^{T}\left[l^y.(T^y - l^y)^{m-q-1}\right]dl \tag{17}$$

In Earliest Completion Rule, the total wave sortation time is given:

$$T_{ECR} = \sum_{q=0}^{m-1}\left(\frac{y(m-q)}{T^{y(m-q)}}.\int_{l=0}^{T}\left[l^y.(T^y - l^y)^{m-q-1}\right]dl\right) \tag{18}$$

5. EXPERIMENTATION

5.1 One-One Model

5.1.1 Analytical Model

An empirical method is used to compare ECR, FPR and NAR. In developing the analytical models, several assumptions are made to facilitate the analysis. To illustrate the expressions for the three sorting strategies, the time to traverse the re-circulating conveyor is T = 100 seconds, and there are m = 10 orders in each wave with y = 5 boxes per order. For analytical model experimentations, MAPPLE software is used.

Table 3: Sorting Times for Numerical Examples

Sorting Sequence (Order number)	Order Sorting time (seconds)		
	FPR	NAR	ECR
1	83,33	80,39	57,26
2	83,33	80,43	58,40
3	83,33	80,49	59,70
4	83,33	80,56	61,19
5	83,33	80,65	62,94
6	83,33	80,77	65,04
7	83,33	80,95	67,64
8	83,33	81,25	71,02
9	83,33	81,82	75,76
10	83,33	83,33	83,33
Total	833,30	810,64	662,29

5.1.2 Simulation Model

A simulation method is used as well in order to compare ECR, FPR and NAR. Several assumptions are made to facilitate the simulation analysis. To illustrate the expressions for the three sorting strategies, the time to traverse the re-circulating conveyor is T = 222, 8 seconds, and there are m = 10 orders in each wave with y = 5 boxes per order. A hundred repetitions are done for each simulation experiment. Then, the mean value of these repetitions is taken.

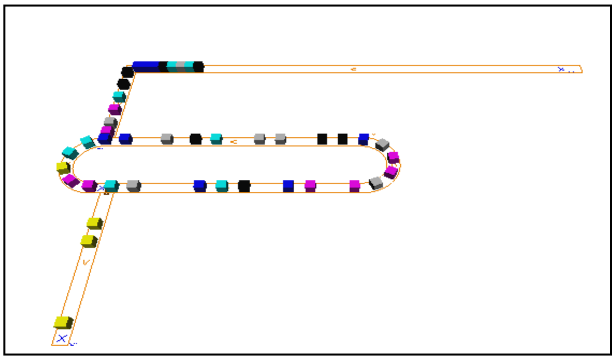

Figure 3: One-One Design Model Simulation Figure

For simulation model experimentations, AUTOMOD software is used. Figure 3 is the figure of the AutoMod software for One-One Design Model.

Table 4: Sorting Time Comparison for One-One Model by Using Simulation Model

Model	FPR	NAR	ECR
One-One Model	2.248,78	2.179,25	**1.841,70**

5.1.3 Simulation Model versus Analytic Model

Simulation model and Analytical model outputs according to different scenarios are illustrated in the following Table 5.

Table 5 : Sorting Time Comparison for One-One Model Both Simulation and Analytical Models

Orders/ Wave	Items/ Orders	Wave Sorting Time (seconds)			Wave Sorting Time (seconds)		
		Analytical Model			*Simulation Model*		
		FPR	NAR	ECR	FPR	NAR	ECR
24	1	2676	214	214	2915	442	442
12	2	1784	1478	992	2033	1724	1484
8	3	1338	1246	974	1574	1507	1268
6	4	1070	1033	878	1298	1279	1120
4	6	765	754	695	1003	991	920
3	8	595	591	563	823	829	792
2	12	412	411	403	640	643	634
1	24	214	214	214	442	442	442

As Table 5 demonstrates, the Simulation Model's results are higher than the Analytical Models in every case. The reason for this is that in the simulation model, there are some additionally spent times. The following figure points out spending time locations on the simulation system.

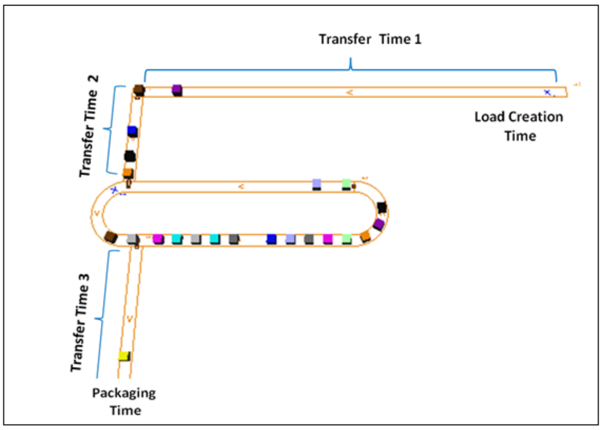

Figure 4: Extra Times Spending for Simulation

Table 6 shows averages of extra time for each spending point, which are shown in the previous figure. Besides, if subtraction is taken from simulation model to analytical model, the average difference is approximately 239 seconds. Also, the sum of the extra spending time is 234.86 second. Thus, we can say that these two numbers are too close to each other.

Table 6: Sort of Spending Time for Simulation

Spending Time	Duration
Transfer Time 1	49,5
Transfer Time 2	29,76
Transfer Time 3	35,2
Load Creation time	69,7
Packaging Time	50,7
Total Time	**234,86**

5.2 One-Many Model

5.2.1 Simulation Model

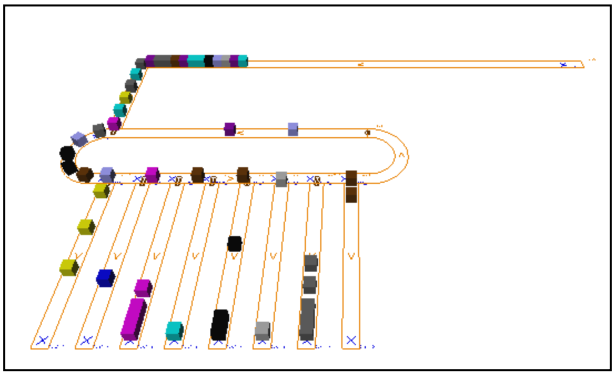

Figure 5: One - Many Design Model Simulation Figure

As can be seen clearly, the best One-Many Model is ECR model. Since the lowest value emphasizing the average of the total sorting time is given by ECR model.

Table 7 : Sorting Time Comparison for One - Many Model by Using Simulation Model

Model	FPR	NAR	ECR
One-Many Model	690,61	678,72	**651,21**

5.3 Random and Equal Number of Items in the Order

Earlier studies assumed that the number of items in an order is the same. For example, in Johnson's article (1998) an accepted item number is y=5 for any event. In practice, it is known that it cannot be provided for every wave. The number of items varies from one order to another.

Table 8 : Sorting Time Comparison of Sorting Strategies According to Number of y

	Number of y	FPR	NAR	ECR
One-One Model	**Random**	**2142,65**	**2.116,97**	**1.818,30**
	Equal	2248,78	2.179,25	1.841,70
One-Many Model	**Random**	**668,95**	**650,04**	**636,46**
	Equal	690,61	678,72	651,21

As illustrated by the figures above, random item size provides more time saving than equal item size also this does not reflect reality.

5.4 Number of Orders versus Number of Items

Different numbers of items and order combinations are designed in order to comprehend the sortation strategies behavior for various situations. After preparing 8 combinations, for example, 24-1 means that there are 24 different orders within a wave and all orders have only one item. Table 9 represents the strategies' results:

Table 9: Total Sortation Time for Different Sortation Lanes in One - One Model

Orders/ Wave	Items/ Orders	Wave Sorting Time (seconds)		
		FPR	NAR	ECR
24	1	2.915,41	441,8	441,8
12	2	2.032,74	1.723,56	1.484,25
8	3	1.574,19	1.506,52	1.268,18
6	4	1.297,91	1.279,31	1.119,80
4	6	1.003,05	990,58	919,74
3	8	822,74	828,92	792,45
2	12	639,51	642,73	634,12
1	24	441,8	441,8	441,8

As can be seen in Figure 6, great savings can be accomplished in total sortation time for every experiment by using ECR.

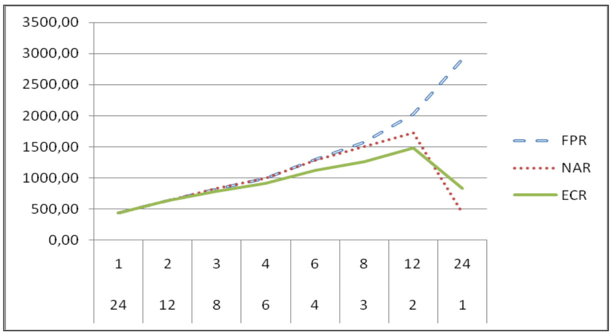

Figure 6: Total Sortation Time for Different Sortation Lanes in One - One Model

5.5 Effect of the Distance between Sortation Lanes

The following section will discuss whether distance between sortation lower is significant or not. In order to understand the effect, different model configurations are redesigned. The following two figures are about One-One Model. In the first figure, the sortation lane is located close to the induction lane to avoid a waste of time to reach the sortation lane. In the second one, the sortation lane is placed at the furthest point from the induction lane.

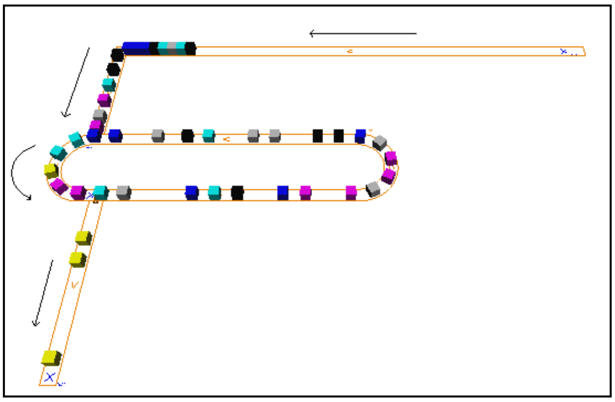

Figure 7: Close Sortation Lane for One - One Model

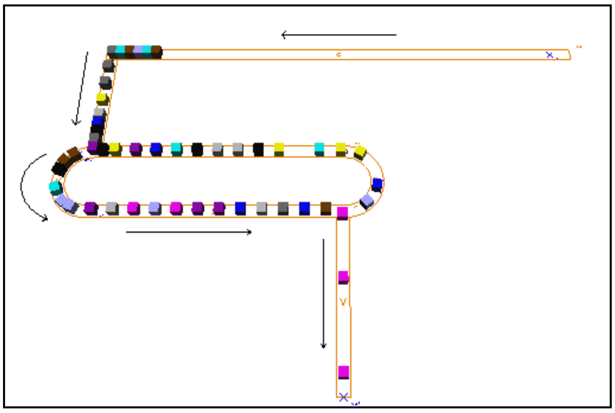

Figure 8: Remote Sortation Lane for One-One Model

Two designs are compared by sending the same number of orders and items. The results are shown in Table 10.

Table 10 : Different Distances between Sortation Lanes for One-One Model

Position of Sortation Lane	FPR	NAR	ECR
Close	2.248,78	2.179,26	1.841,71
Remote	2.248,03	2.179,14	1.841,61

As it can be understood from both tables and Figure 9, there is no significant difference in total sortation time between "Close" and "Remote" design. Thus the effect of the distance between sortation lanes in One-One Model is unimportant.

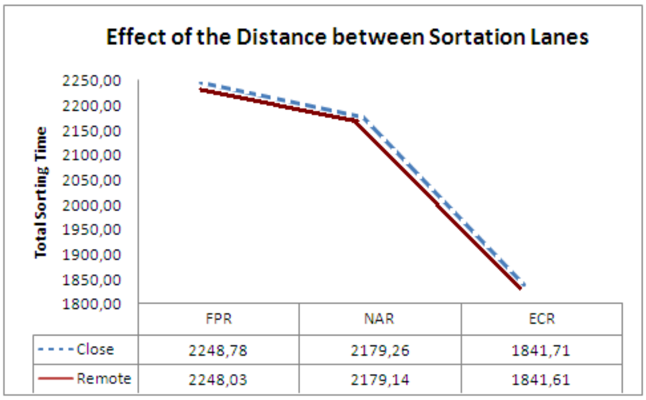

Figure 9: Effect of Distance between Sortation Lanes

The same analysis is repeated in One-Many Model. Differently from the previous figure in this figure, there are two sortation lanes. The following section will discuss whether, in this case, the distance between lane is significant or not. In order to understand the effect, two model configurations are redesigned. In the first figure, lanes are close to each other, whereas in the second figure they are located at the biggest possible distance.

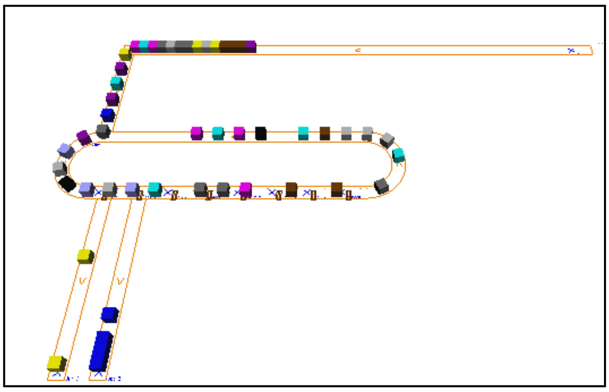

Figure 10: Close Sortation Lane for One - Many Model

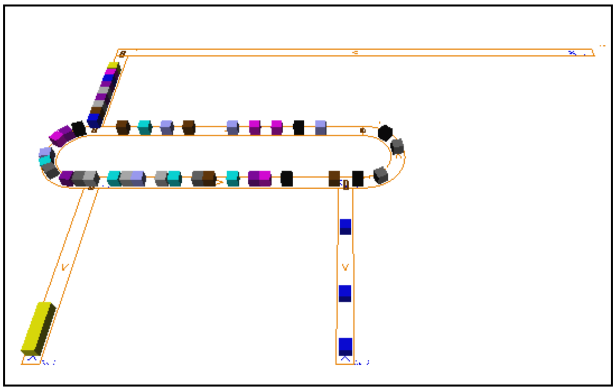

Figure 11: Remote Sortation Lane One - Many Model

The two designs are compared by sending the same number of orders and items. Results are shown in Table 11.

Table 11: Different Distance between Sortation Lanes for One - Many Model

Position of Sortation Lane	FPR	NAR	ECR
Close	1320,20	1502,12	1177,70
Remote	1375,42	1553,47	1261,14

As can be seen from in both Table 11 and Figure 12 the close sortation lane gives the best results. In fact, the difference between the two designs is not extremely big, but not insignificant either.

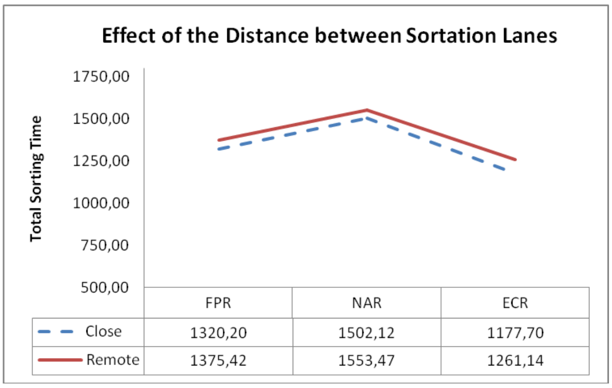

Figure 12: Effect of Distance between Sortation Lanes for One - Many Model

5.6 One –One Model versus One-Many Model

In the under mentioned situations, 12 orders that have just 2 items are sent to One - One Model, while doubled orders, in other words 24 orders that have 2 items are sent to One - Many Model which has two sortation lanes. Before the sortation, our estimation is that both outputs should be close to each other. Because the second one has double performance if it is compare to first one so twice as many order can be sorted in the same time.

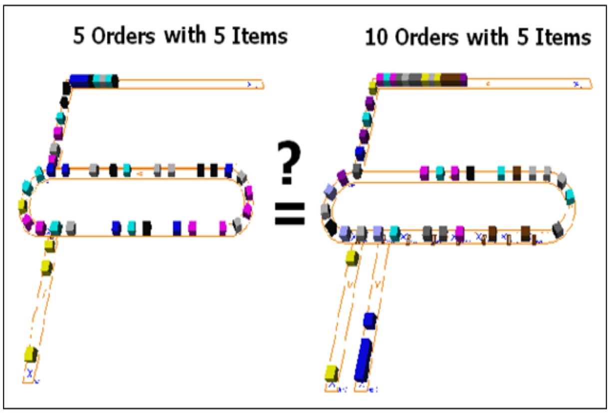

Figure 13: One – One Model versus One - Many Model

In this experimentation, number of orders m = 10 and number of items y = 5 are taken. Then, the number of orders is reduced by half. The results of this set of experiments are listed in Table 12.

Table 12: One - One Model versus One - Many Model

Model	Order	Item	FPR	NAR	ECR
One-One Model	10	5	1320,20	1502,12	1177,70
One-Model Model	5	5	1174,40	1147,94	1036,34

Distinctively, One-One Model for all strategy has less sortation time than One-Many Model. Thus, the doubling order size takes much more time even if one sortation lane to added.

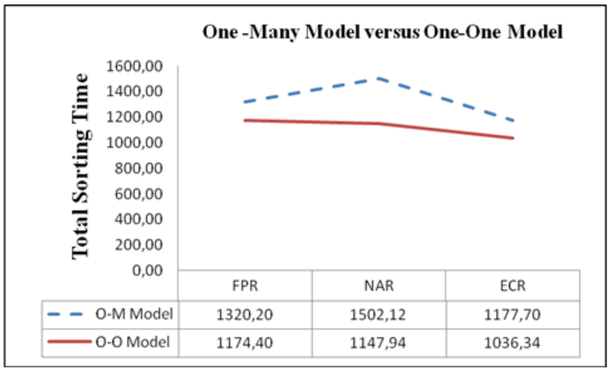

Figure 14: Effect of Distance between Sortation Lanes

6. CONCLUSION

In the course of this article, available sortation strategies have been compared and a set of modeling approaches in simulation and in analytical has been developed for the design and analysis of conveyor sortation systems. Consequently, the following conclusions can be drawn:

Based on simulation models, FPR, NAR and ECR sortation strategies have been compared. Overall outputs are represented as follows in Figure 15.

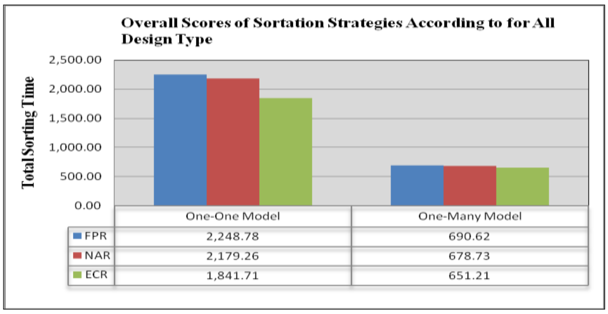

Figure 15: Effect of Distance between Sortation Lanes

Simulation models are developed for all designs, therefore, the results of simulation models are compared with analytical models and, this way, the simulation has been proved

Different scenarios are simulated by varying design and operational parameters. In contrast to the conclusions drawn by earlier studies in the field, random item size in an order supports better results. Besides, it is more appropriate for a real case.

The impact of distance between sortation lanes has been examined by designing model configurations. For One-One Model, there is no significant effect, whereas in One-Many Model the effects of distance cannot be ignored.

Design parameters and operational parameters have been compared. This study has demonstrated that adding extra sortation lane is insufficient to sort a doubled number of orders.

Future research can be pursued in the following directions:

- Analytical models for One - Many Model is required. In this research, analytical model is applied to only One - One Model. Thus, for other models, an analytical model should be developed in order to make comparisons with the result of the simulation model.
- Order configurations can be varied. For instance, 120-1 order combination is worth examining in order to clearly contemplate the behavior of sortation strategies.
- Other operational parameters such as conveyor speed, order assignment to specific lane before sorting and wave algorithm need to be conducted to see their effects.
- Other design parameters such as type of conveyor (circular and non-circular) and length of circulation conveyor must be analyzed.
- This research aimed to provide a case study. The design parameters of this study can be applied to a real case.

REFERENCES

Bozer, Y.A., Hsieh, Y. J. 2004. Expected waiting times at loading stations in discrete-space closed-loop conveyors. *European Journal of Operational Research*, vol. 155(2), p. 516-532

Bozer, Y.A., Quiroz, M. Sharp, G.P. 1988. An evaluation of alternate control strategies and design issues for automated order accumulation and sortation system. *Material Flow,* vol. 4, p. 265-282

Demongodin, I., Prunet, F. 1993. Simulation modeling for accumulation conveyors in transient behavior. *COMPEURO 93*, Paris, France, p. 29-37

Dotoli M., Iacobellis, G., Stecco, G. and Ukovich W. 2009. Performance Analysis and Management of an Automated Distribution Center, *IEEE Industrial Electronics IECON '09*, Porto, Portugal p 4371-4376

Dotoli M., Iacobellis, G, Stecco, G., Ukovich W., 2009. Performance Analysis and Management of an Automated Distribution Center, IEEE

Gagliardi, J, Angel R, Renauld, J. 2010. A simulation modeling framework of multiple-Aisles Automated Storage and Retrieval System, CIRRELT vol. 57

Eldemir, F. and Malmborg, C.J. 2006. Earliest Completion Rule: An Alternative Order Sortation Strategy. *Progress in Material Handling Research*, 2006, 1, p. 147-155

Harit, S., Taylor G.D. 1995. Framework for the Design and Analysis of Large Scale Material Handling Systems. *Winter Simulation Conference*, Arlington, VA, USA, p. 889–894.

Jayaraman, A., R. Narayanaswamy, et al. 1997. A sortation system model. *Winter Simulation Conference*, Atlanta, GA, USA, p. 866-871

Jing, G., Kelton, W. D., Arantes, J.C. 1998. Modeling a Controlled Conveyor Network with Merging Configuration, *Proceeding of the Winter Simulation Conference*, Washington, DC, USA, p. 1041-1048

Johnson, M. E., 1998. The impact of Sorting Strategies on Automated Sortation System Performance *IIE Transactions*, vol. 30(1), p. 67-77

Johnson, M. E., Russell, M. 2002. Performance analysis of split-case sorting systems. *Manufacturing & Service Operations Management,* vol. 4(4), p. 258-274

Johnson, M. E., Lofgren, T. 1994. *Model Decomposition speeds distribution center design Interfaces*, vol. 24(5), p. 95-106

Koster, R., Le-Duc, T. and Roordbergen, K.J. 2007. Design and control of warehouse order picking: A literature review. *European Journal of Operational Research* vol.182, p. 481–501

Le-Duc, T. and de Koster, R. 2005. Determining Number of Zones in a Pick-and-pack Order picking System. *ERIM Report Series Research in Management,* Rotterdam

Maxwell, W. and Wilson, R., 1981. Deterministic models of accumulation conveyor dynamics, *International Journal of Production Research*, vol. 19(6), p. 645-655

Meller, R. D. 1997. Optimal order-to-lane assignments in an order accumulation/sortation system. *IIE Transactions* 29, p.293-301

Roodbergen, K.J. and Vis, I.F.A. 2009. A survey of literature on automated storage and retrieval system *European Journal of Operational Research*, Vol.194, p. 343-362

Russell, M. L. and Meller, R. D. 2003. Cost and throughput modeling of manual and automated order fulfillment systems. *IIE Transactions*, vol.35, p. 589-603

Schmidt, L. C. and Jackman, J., 2000. Modeling recirculating conveyors with blocking, *European Journal of Operational Research*, vol. 124, p. 422-436

Sonderman, D. 1982. An analytic model for recirculating conveyors with stochastic inputs and outputs. *Internal Journal of Production Research*, vol. 20, p. 591-605

AUTHORS BIOGRAPHIES

Fahrettin Eldemir works as Assistant Professor at the Fatih University. He received his Ph.D. in Industrial Engineering from the Rensselaer Polytechnic Institute and his MS in Industrial Engineer from the Rensselaer Polytechnic Institute. His email address is <feldemir@fatih.edu.tr >

Elif Karakaya is a Ph.D. student in Chair of Factory Organization at the Technique University Dortmund. She received her M.S. in Industrial Engineering from the Fatih University, and her B.S. in Industrial and Computer Engineering from the Kültür University. Her email address is <karakaya@lfo.tu-dortmund.de>