Analysis of Delivery and Assembly Operations in a Furniture Company Using Discrete Event Simulation

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Abstract

The objective of this study is to analyze and improve the delivery and assembly operations at a furniture company. In particular, operations at IKEA-Kuwait have been studied in detail and possible improvements are proposed. Unlike any other IKEA store worldwide, a delivery and assembly option is provided to customers in Kuwait. About 40% of overall sales are delivered and assembled by the Delivery and Assembly (D&A) Department of the store. Because of heavy load on this department, delivery lead time (LT) is relatively high with an average of 14 days. The store management wanted to reduce the LT by introducing some changes in their operations. After analyzing the D&A department, a simulation model was developed for the D&A operations to study the effects of possible changes in operational policies on reducing LT and improving other system performance measures. The results show that simple changes in resource levels and operational policies can significantly reduce the LT, increase number of completed deliveries, and improve other system performance measures.

Keywords
Furniture delivery, simulation, lead time, furniture assembly, delivery schedules.

1 Introduction
Product delivery is vital operations for furniture companies. After the furniture is sold to customers, the problem of delivery and assembly arises. Some furniture companies, such as IKEA, give the choice to the customer to either take the product and assemble by themselves or leave it to the company to deliver to their home and assemble it. If the delivery is left to the company, the customer expects it to be delivered as soon as possible. As a result, furniture companies usually have heavy load on their delivery department and need to plan for delivery and assembly operations and generate schedules for these operations. In many cases, delivery and assembly jobs accumulate due to delays and heavy backlog of jobs build up. The companies are then faced with the problem of eliminating this backlog.

Several investigators have looked into the delivery problem and analyzed it with respect to various performance measures. Anderson and Morrice (1999) presented a simulation model to study the dynamics in a service oriented supply chain system. Nilsson (1999) presented a simulation model for designing straw fuel delivery systems. The paper presents a dynamic simulation model for analysis of various delivery alternatives in order to improve and optimize system performance and to reduce the costs and energy needed in straw handling. Punakivi and Saranen (2001) identified and presented several success factors in e-grocery home delivery systems. Kim et al. (2003 discussed sequencing delivery and receiving operations for yard cranes in port container terminals. In port container terminals, the delay time of trucks in the receiving and delivery operations is one an important measure for the evaluation of the level of customer service. A dynamic programming model is suggested for a static sequencing problem in which all the arrivals of trucks are known in advance. For dynamic situations where new trucks arrive continuously, a learning-based method for deriving decision rules is suggested. Also, several heuristic rules are suggested. A simulation study is performed to compare the performances of the suggested approaches. Ying (2005) presented an experiment to explore the potential of simulation for improving ready mixed concrete delivery to construction sites. A computer simulation package is developed to simulate ready mixed concrete delivery operations from a concrete plant to multiple sites. Strategies which might improve delivery between plant and sites are investigated. Pundoor and Herrmann (2006) presented a hierarchical approach to supply chain simulation using the supply chain operations reference model. Tjahjono and Ladbrook (2011) presented a study on simulation modeling of tool delivery system in a machining line. Different tool crib operations and tool delivery strategies are studied. Fu and Jiang (2012) also presented a simulation study for evaluating advanced pickup and delivery systems. A variety of technology-oriented pickup and delivery distribution systems are modeled. A series of simulation experiments are performed on a set of hypothetical cases and a realistic example is conducted. Visintin, et al. (2013) applied discrete event simulation to the design of a service delivery system in the aerospace Industry and presented a detailed case study.

In this paper, we present a detailed analysis of delivery and assembly operations at IKEA and then develop a simulation model of the system in order to study effects of possible improvement scenarios in the system. In particular, the study is concentrated on the warehouse area and a simulation model is developed to investigate the effects of alternative solutions in reducing the accumulation of backlog jobs waiting for delivery. Simulation modeling resulted in solutions that proved to improve system performance. The department consists of four areas, which are Front-Desk, Back-Office, Tracking center, and Sulaibiya warehouse. The Front Desk is the most important step of the process where the customer pays the charges of delivery and/or assembly and provides all necessary information. The Back-Office prepares the daily schedules of delivery times. On the delivery day, the Tracking Center follows up with both teams and customers. The last part is the Sulaibiya warehouse, which is the place where all the sold items that will be delivered and assembled are stored.

2 Analysis of the Delivery System at IKEA

Delivery and assembly (D&A) operations at IKEA have been studied and analyzed in detail for possible improvements. D&A department consists of several sections. The system is studied from the arrival of orders, which come into the warehouse located at Sulaibiya, to the delivery of furniture to the customer house. In order to model the system for analysis, a detailed description of actual system operations are presented. Once a customer makes a delivery and assembly order at the Front-Desk, s/he is given a date for delivery and assembly. The orders are then moved to the storage in Sulaibiya on the same day. Two days before the delivery date, the Back-Office schedules the delivery of orders by assigning to specific teams based on job size, area, capacity, and skills of the team. The workers in Sulaibiya load the trucks the night before the day of delivery based on the schedule given to them by the Back-Office. On the day of delivery, every team leaves to the customers' houses scheduled for that day, with an average of five jobs. A large percentage of the jobs are completed on the same day. However, several other reasons cause the orders to be returned to the backlog in the warehouse. Figure 1 shows percentages of D&A jobs that are completed in addition to the jobs that are postponed due to several reasons, delayed, sales error, quality problems and missing items.

IKEA presently has 38 drivers and 75 carpenters. They have a total of 33 teams that work six days a week with one shift starting from 7 A.M until 3:30 P.M. As per ministry guidelines, the maximum number of employees per truck is three. Each team consists of one driver, one carpenter, and an assistant. At some times, this number is exceeded. For the big projects that IKEA handles, the number of carpenters may increase more than two depending on the job. Some truck drivers take vacations, and then his team members will be distributed to other teams. Therefore, the number of trucks is more than the number of available carpenters for the majority of the time. In order to analyze the system, data for a period of 60 days was collected for the incoming orders, delivered orders, and returned orders. The delivery jobs at IKEA are classified into three different types which are Furniture (80%), Kitchen (10%), and Project (10%). IKEA has 38 trucks available, but is only using 33 trucks at the moment. The table 1 below provides a detailed description of the resources for D&A.

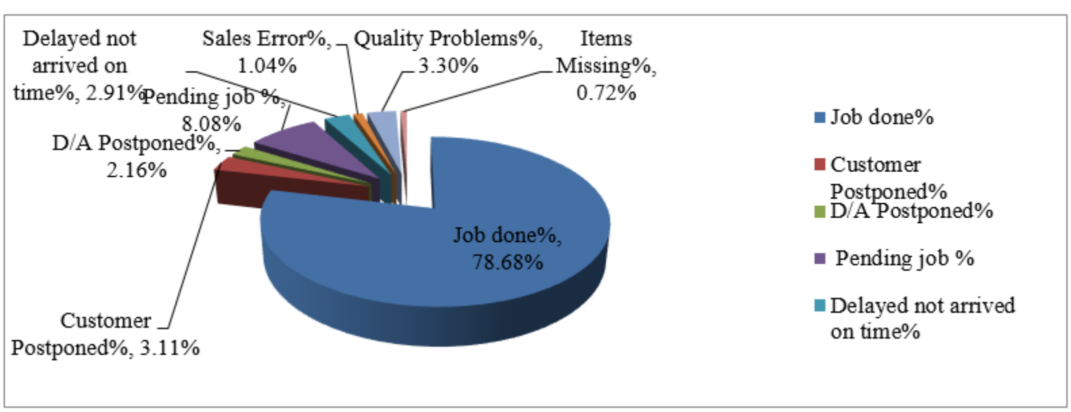


Figure 1. Status and results of D&A jobs, including completed jobs and other possibilities.

Table 1. IKEA resources utilized for D&A.

Job type	Number of Trucks in	Load / team (KD)
Furniture	25	1150
Kitchen	6	600
Project	2	1100
Total	33	2850

While analyzing the system, backlog accumulation problem in temporary storage area has been studied in detail. The effects of the inbound, outbound and return orders on the lead time and the number of completed jobs have been studied using the data collected from IKEA as well as basic process facts which are as follows:

- The orders are placed into the trucks based on the maximum load per truck.
- Trucks always leave when the capacity is greater than or equal to the load per team.
- The preferred order of the resources is furniture trucks, kitchen trucks and project trucks.
- If an order is greater than the level of productivity per truck, the order is sent with one truck and is completed on the same day.
- Every truck has 2 carpenters and 1 driver.

There are two types of orders at Sulaibiya warehouse, the initial orders in the backlog and daily incoming orders. The warehouse receives orders every day starting from 10 AM. to 10 PM. There are 3 types of jobs: Furniture, Kitchen, and Projects, and each type have a specific number of trucks. There are 25 trucks for furniture deliveries, six trucks for kitchen deliveries, and two for projects. The truck is loaded if the monetary value of total reaches the truck capacity. The minimum value for each type of job that the truck can seize are 1150 KD for furniture jobs; 600 KD for kitchen jobs; and 1100 KD for project jobs. If the total number of orders has a value less than the truck capacity, they will be batched until they reach the minimum capacity. The backlog amount in the warehouse is automatically decreased after the orders are loaded to the truck. Similarly, the total backlog value will also be reduced. The orders are separated and delivered to customers. After the orders leave the warehouse, some of the orders are returned due to the reasons mentioned previously.

3 Simulation Modeling of Delivery and Assembly System

After analyzing the temporary warehouse and backlog operations, we have decided to analyze the random flow of products into and out of the warehouse by developing a simulation model for the system. Figure 2 shows the general flow of material and related operations in the temporary warehouse. Simulation is one of the most widely used management tools in operations research. Simulation is an analysis and experimentation procedure, not an optimization tool. It is utilized to mimic the behavior of the system under various operational conditions in order to determine the factors that have significant effects on system performance. It is utilized for what-if analysis.

Simulation allows us to study the system without disturbing the real operations and without incurring huge expenses. Arena software (Kelton et al., 2004) was used to develop simulation model for the Delivery & Assembly (D&A) Operations in the temporary warehouse. Because of its large size and extensive modeling details, the simulation model is not depicted here. The process flow steps were detailed in Figure 2.

After collecting detailed data related to D&A operations, distribution of orders and various activities are determined by fitting the related data set using ARENA input analyzer. Table 2 shows distributions and related parameters for number of home delivery jobs created daily, monetary value of each order, time required for each delivery & assembly, and number of orders in the storage.

4 Validation of the Simulation Model

Simulation model is utilized to analyze the system with possible changes for improvement. However, the simulation model has to be validated first for its accuracy and appropriateness as representation of real system. Statistical model validation provides evidence whether the model is a legitimate representation of reality. The equality of the real and simulated population variances is tested first. According to result of the equality of variances test, the proper hypothesis testing for the equality of the real and simulated population mean is selected and applied. Let $\overline{X}_i$, s_i and n_i designate mean, standard deviation, and sample size of the performance measures. One of the performance measures evaluated is lead time, which is the time needed to deliver the product to customer. A 95% confidence level (α =

0.05) was assumed satisfactory when validating the lead time. Table 3 shows the results of actual and simulated lead times.

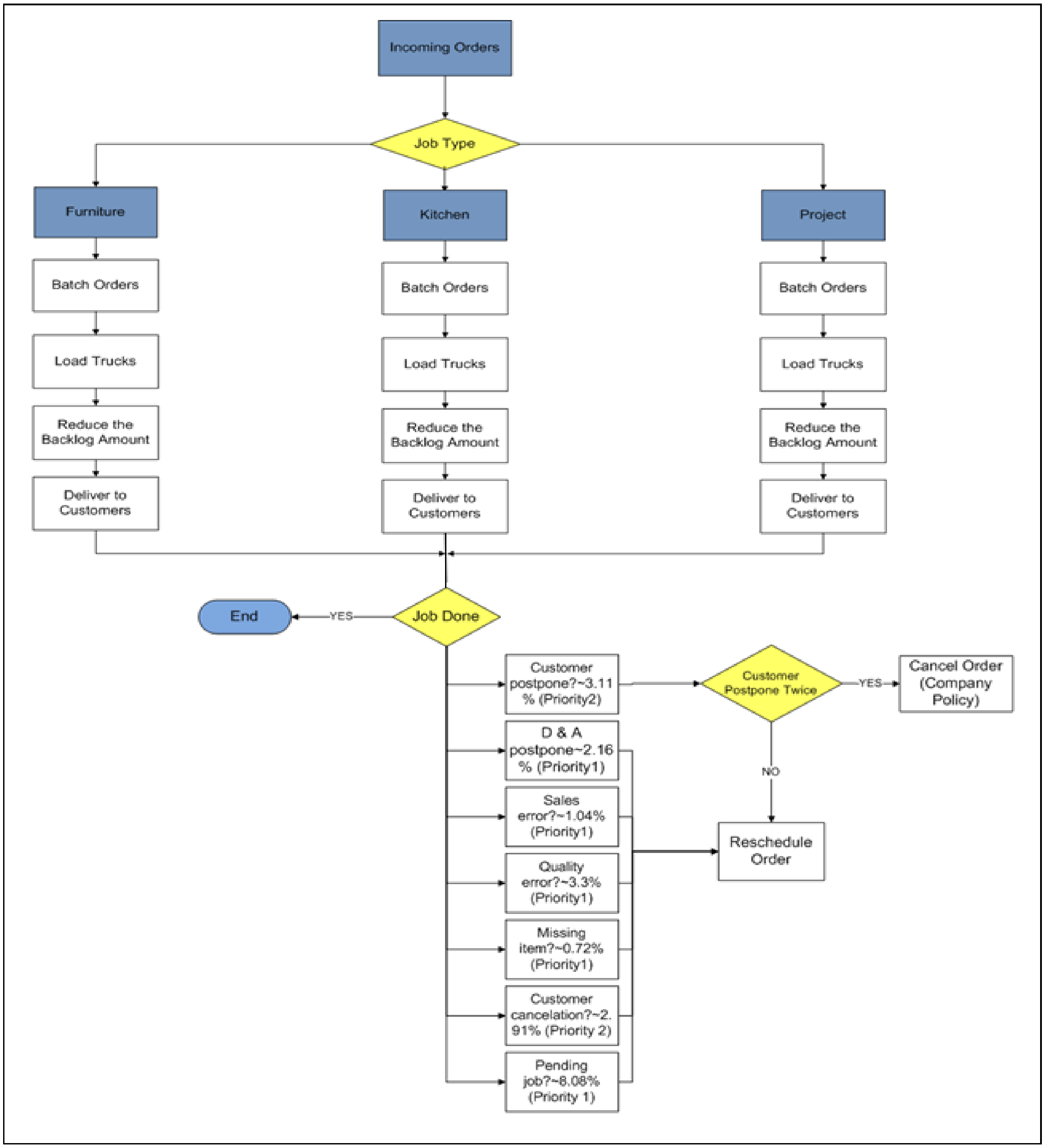


Figure 2. General flow of material and related operations in temporary warehouse.

Table 2. Distribution and related parameters for various activities in D&A

Home Delivery Jobs Created Daily	76+ERLA(37.6,2)
Monetary Value of Each Order	NORM (273,49.1)
Delivery and Assembly Time	10*BETA(0.464,0.336)
Number of Orders in the Storage	UNIF(1900,2000)

Table 3. Lead time values of the actual system and simulated model.

Lead Time (days)		
	Actual	Model
Sample Size (n)	30 months	30 replications
$\bar{X}_i$	8.766666667	8.885652778
Standard Deviation	4.553765652	0.613883014
Variance	20.73678161	0.376852355

A hypothesis test is done on the equality of variances for the simulated and actual lead times.

H_o: $\sigma_1^2 = \sigma_2^2$; **H_1:** $\sigma_1^2 \neq \sigma_2^2$

Where:

σ_1^2 = population variance of lead time in the actual system.
σ_2^2 = population variance of lead time in the model.
S_1^2 = sample variance of lead time in the actual system.
S_2^2 = sample variance of lead time in the model.

Test statistics was obtained as $\text{fo} = \frac{S_1^2}{S_2^2} = \frac{20.74}{0.377} = 55.026$

Tabulated f value was $f_{\alpha/2, n1-1, n2-1} = f_{0.025, 29, 29} = 2.101$; Rejection Criteria: $f_o > f_{\alpha/2, n1-1, n2-1}$

We can conclude that since 55.026 > 2.101, we reject H_o and conclude that there is no evidence that the variances are equal. We now proceed to the hypothesis test on the difference in means with unknown and unequal variances, since $\sigma_1^2 \neq \sigma_2^2$.

H_o: $\mu_1 - \mu_2 = 0$
H_1: $\mu_1 - \mu_2 \neq 0$

where:

μ_1 = population mean lead time in the actual system.
μ_2 = population mean lead time in the simulated model.
$\bar{x}_1$= sample mean lead time in the actual system.
$\bar{x}_2$= sample mean lead time in the simulated model.

Test statistics was obtained as $t_o = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} = \frac{8.767 - 8.886}{\sqrt{\frac{20.737}{30} + \frac{0.377}{30}}} = -0.142$

The degrees of freedom was $v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\left(\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2}\right)} = \frac{\left(\frac{8.667}{30} + \frac{8.887}{30}\right)^2}{\left(\frac{\left(\frac{8.667}{30}\right)^2}{29} + \frac{\left(\frac{8.887}{30}\right)^2}{29}\right)} = 30.054$

Tabulated t value was $t_{\alpha/2, V} = t_{0.025, 30} = 2.042$ and Rejection Criteria was $| t_o | > t_{\alpha/2, V}$

We can finally conclude that since $|-0.142| < 2.042$, we fail to reject H_o and conclude that the means are equal. In other words, the simulation model is a valid representation of the real system. Furthermore, we can conclude that the 95% confidence interval on the difference between the real and simulation population means includes zero. This indicates that the means of these two populations are statistically equal at a 95% confidence level. The confidence interval is ($-15.2665 \leq \mu_1 - \mu_2 \leq +15.0285$). The following equations were used to calculate the lower and upper bounds.

$$\text{Lower bound}: (\bar{X}_1 - \bar{X}_2) - t_{\alpha/2} * \sqrt{\frac{s_1^2}{n_1} + \frac{s_{12}^2}{n_2}} \quad (1)$$

$$\text{Upper bound}: (\bar{X}_1 - \bar{X}_2) + t_{\alpha/2} * \sqrt{\frac{s_1^2}{n_1} + \frac{s_{12}^2}{n_2}} \quad (2)$$

Another performance measure considered was the number of orders delivered. Let $\bar{X}_i$, s_i and n_i indicate mean, standard deviation and sample size of this performance measures. A 99% confidence level ($\alpha = 0.01$) was assumed satisfactory when validating the number of orders delivered. Table 4 shows number of orders delivered in the actual system and in the simulated model.

Table 4. Number of orders delivered in the actual system and the simulated model.

	Orders Delivered	
Parameters	Actual	Model
Sample Size	20 months	20 replications
$\overline{X}_i$	3672.45	3988.75
Standard Deviation	596.057	106.456
Variance	355,284.05	11,332.93

Again a hypothesis test is done on the ratio of two of variances to determine if the variances are equal.

H_o: $\sigma_1^2 = \sigma_2^2$

H_1: $\sigma_1^2 \neq \sigma_2^2$

Where:

σ_1^2 = population variance of number of orders delivered in the actual system.

σ_2^2 = population variance of number of orders delivered in the simulated model.

S_1^2 = sample variance of number of orders delivered in the actual system.

S_2^2 = sample variance of number of orders delivered in the simulated model.

Test statistic was $f_o = \frac{S_1^2}{S_2^2} = \frac{355{,}284.05}{11{,}332.93} = 31.3497$

Tabulated f value is $f_{\alpha/2,\, n1-1,\, n2-1} = f_{0.025,\, 29,\, 29} = 2.526$; Rejection Criteria: $f_o > f_{\alpha/2,\, n1-1,\, n2-1}$

Therefore, since 31.3497 > 2.526, we reject H_o and conclude that there is no evidence that the variances are equal. Next, hypothesis test is done on the difference in means using the unknown and unequal variances, since $\sigma_1^2 \neq \sigma_2^2$:

H_o: $\mu_1 - \mu_2 = 0$

H_1: $\mu_1 - \mu_2 \neq 0$

where:

μ_1 = population mean number of entities delivered in the actual system.

μ_2 = population mean number of entities delivered in the model.

$\overline{X}_1$ = sample mean number of entities delivered in the actual system.

$\overline{X}_2$ = sample mean number of entities delivered in the model

Test statistics was $$t_o = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} = \frac{3672.45 - 3988.75}{\sqrt{\frac{355{,}284.05}{20} + \frac{11{,}332.93421}{20}}} = -2.336$$

Degrees of freedom was $$v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\left(\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2}\right)} = \frac{\left(\frac{355{,}284.05}{20} + \frac{11{,}332.9341}{20}\right)^2}{\left(\frac{\left(\frac{355{,}284.05}{20}\right)^2}{19} + \frac{\left(\frac{11{,}332.9341}{20}\right)^2}{19}\right)} = 20.211$$

Tabulated t value was $t_{\alpha/2,V} = t_{0.005,20} =$ 2.845 and Rejection Criteria was $|t_o| > t_{\alpha/2,V}$

We can finally conclude that since $|-2.336| < 2.845$, we fail to reject H_o and that there is no evidence that the means are not equal. In other words, the simulation model is a valid representation of the real system. Furthermore, We can conclude that the 99% confidence interval on the difference between the real and simulation population means includes zero. This indicates that the means of these two populations are statistically equal at 99% confidence level. The confidence interval is (701.535 ≤ $\mu_1 - \mu_2$ ≤ +68.935). and the same equations are used to calculate the upper and lower bounds.

5 Analysis of Improvements for the Delivery and Assembly System

Several objectives are kept in mind when performing this study. The main objective is to minimize the D&A lead time. As a result of this, the number of orders delivered will be increased. This will be done primarily by reducing the number of orders in the backlog and increasing the number of resources to an ideal level. This study will be deemed feasible after performing both cost and sensitivity analysis. We conducted a survey at IKEA and included some questions to know the maximum acceptable day for delivery and assembly to compare it with the optimal number of the lead time that we got. We also asked the customers if they are willing to pay more for a faster period to see if it's a good idea to apply it in IKEA. This survey helped us calculate customers satisfaction by asking to rate the delivery and assembly department from 1 to 10. Three criteria usually will need to be specified to determine the appropriate sample size for the survey: the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured. The level of precision, sometimes called sampling error, is the range in which the true value of the population is estimated to be.

The confidence or risk level is based on ideas encompassed under the Central Limit Theorem. The key idea encompassed in the Central Limit Theorem is that when a population is repeatedly sampled, the average value of the attribute obtained by those samples is equal to the true population value. Furthermore, the values obtained by these samples are distributed normally about the true value, with some samples having a higher value and some obtaining a lower score than the true population value. The third criterion, the degree of variability in the attributes being measured, refers to the distribution of attributes in the population. The more heterogeneous a population, the larger the sample size required to obtain a given level of precision. The less variable (more homogeneous) a population, the smaller the sample size. Note that a proportion of 50% indicates a greater level of variability than either 20% or 80%. This is because 20% and 80% indicate that a large majority do not or do, respectively, have the attribute of interest. Because a proportion of 0.5 indicates the maximum variability in the population, it is often used in determining a more conservative sample size, that is, the sample size may be larger than the true variability of the population attribute were used. There are several approaches to determining the sample size, one of which is using the following formula:

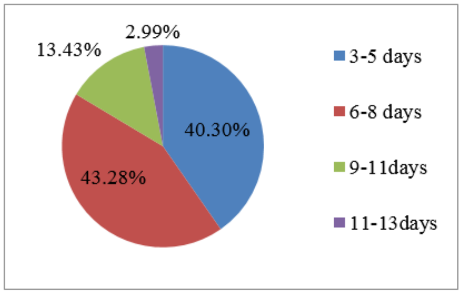
$$n_0 = \frac{Z^2 pq}{e^2} \tag{3}$$

Where n_0 is the sample size, Z^2 is the square of the standard normal distribution value with α% on the right side (1 - α equals the desired confidence level, e.g., 95%); p is the estimated proportion of an attribute that is present in the population, and q is 1-p. In our case, we assume p=0.5 (maximum variability). Furthermore, we desire a 90% confidence level and ±10% precision. The resulting sample size is given by:

$$n_o = \frac{(1.64^2)(0.50)(1-0.50)}{0.10^2} = 67.24 \tag{4}$$

We can conclude that a sample size of 67 customers can be used in this case. After conducting 67 surveys, a few results were concluded. As it can be seen in the pie chart figure 3a below, the largest percentage preferred a lead time of 6-8 days, followed by 3-5 days. We can therefore conclude that about 84 % would like the lead time to be around 3-8 days at maximum. The main reason why 0-3 days was not included in the survey is for the fact that the question asked mentioned ‘preferred maximum number of days’. Also, IKEA does not deliver in less than three days, mainly because it is close to impossible for the amount of deliveries they get daily. We have come to realize that the customer is one of the main reasons to why the D&A lead time are increasing. The second question involved asking about whether or not customers are willing to pay an extra charge for a faster delivery service. It is shown in pie chart figure 3b that 28.36% of customers are willing to pay more for a faster delivery, and 37.31% will pay depending on the charge, meaning that the majority are willing to pay extra charge for faster delivery. This shows us how customers really want a faster delivery service. This can assure IKEA that the cost of adding more resources will be met by the income from the extra charge. Therefore, we believe that the customer who postpones the delivery time on the day of the delivery must pay once again in order to reschedule the delivery. Another thing that must be done is that the delivery date must be lengthened to more than the regular duration.

The third question was on the average rating the 67 customers gave the D&A department. The average out of 10 turned out to be 6.98. We can refer to this as the customers’ satisfaction level and therefore conclude that 69.8 % of customers are currently satisfied by the D&A department. This shows us that the department needs to be improved in order for this satisfaction level to increase to the better.



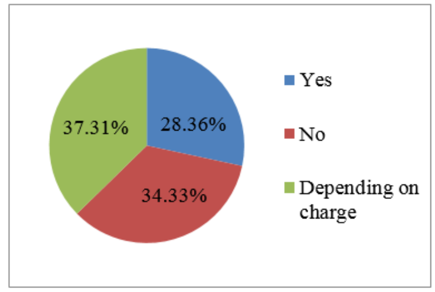


Figure 3. a) Preference of the lead time days b) Willingness to pay extra charge for fast delivery

Throughout the study, we have kept two performance measures in mind, lead time and the number of orders delivered. In order to come up with improvements during our analysis, we will be using these performance measures as indicators to whether they have improved or not. We have tried several systematic changes in the system by adding more resources and running the simulation model with these changes to see possible improvements in the system. Simulation model is replicated several time to obtain accurate results. Number of replications for the sensitivity analysis is calculated by using an initial number of replication n_{old} and the corresponding half width of confidence interval h_{old} as in the following equation:

$$n_{new} = n_{old} (h_{old}^2/h_{new}^2) \quad (5)$$

Where n is the number of replications (old and new desired value, h is the half width of lead time. In our case n_{old} = 5; h_{old} = 11.99; h_{new} = 4; thus $n_{new} = 5*(11.99^2/4^2) = 45$ replications are needed. Therefore, the new number of replications is set to be 45 with 10% warm-up period (about 4.5 days). As mentioned before, the ways to improve the performance measures are to increase some resources as changing the number of trucks, number of shifts per day, whether to include delivery on Fridays, and delivery cancelation policy. Table 5 shows the possible changes in resources and system policies.

A total of 33 trucks, one shift only, and no delivery on Fridays are the current situation. As for the cancellation policy, IKEA has the right to cancel the customer's order if the customer postponed for the second time. As a suggestion, they should reduce the cancelation policy to one time. This is only when the customer decides to postpone a delivery order on the same day of the delivery. This is where a return voucher should be immediately issued to the customer. During the analysis some assumptions were set as follows:

Table 5. Possible changes in system resources and other system activities for improvement

Variables		Current system	Other Possibilities	Number of Possibilities
X1	Furniture trucks	25	27, 29, 31, 33, 35	6
X2	Kitchen trucks	6	8	2 (6 and 8)
X3	Project trucks	2	3	2 (2 and 3)
X4	Number of shifts	1	2	2 (1 and 2)
X5	Delivery on Friday	0	1	2(0 and 1)
X6	Cancelation policy	2	1	2 (2 and 1)

- It is allowed to postpone the order one time in one case; during the calls of confirmation which takes place two days before delivery. Otherwise, if the customer postpones the same day of scheduled delivery, he/she will get a return voucher and the order will be canceled.
- They can increase total working hours by distributing the teams into shifts. Without shifts, a worker works for a long time on a job, and by the time he will get bored of his work. So this will in turn cause less productivity, lower quality and more cost (on average, they are working nine hours and a half daily, hence being paid overtime). But when the idea of shifts is introduced, each worker will be paid less, productivity will increase and the quality of assembly will be much better. Also, they will be able to cover a larger number of working hours.

- In case of two shifts, if the number of trucks are odd, the second shift will be having a greater number than the first shift. The first shift starts from 7:30 AM till 4 PM, and the second starts from 12 PM till 8:30 PM.

Considering 6 system changes (X1 ,…., X6) with their possibilities given in table 5, the total number of combinations is $6x2^5$= 192 combinations. Each combination was simulated with 45 replications and the results were compared. A specific combination was found to optimize each performance measure. The results are shown in table 6. As it can be seen from table 6, combination of changes in the system that resulted in optimum (minimum) lead time did not necessarily result in optimum (maximum) number of orders delivered. A decision has to be made between these two optimum combinations for implementation. Sensitivity analysis was carried out with respect to total costs, which included cost of trucks and the personnel for delivery, in order to decide between the two optimum combinations presented in Table 6.

Table 6. Average performance value for the actual system and the optimum combination

Performance Measure	Original Actual System	Optimal Averaged Value	Combination which resulted in optimal value
Lead time (Days)	9.3	4.025	35-8-3-1-1-1
Number of orders Delivered	3657.24	5328.18	31-8-3-1-1-1

Total costs were calculated for the combination of the minimum lead time and the combination of the maximum number of orders delivered. Sensitivity analysis was carried out by determining costs of other combinations near the optimum. It was found that the cost of combination, which resulted in maximum orders delivered, was 52.02% of the cost of combination that resulted in a lead time, which was approximately 1 day longer than the optimum lead time as depicted in table 7. Effectively, by allowing a 1-day increase in lead time, from 4.025 days to 5.1 days, the total delivery costs are reduced by 52%. Therefore, optimum combination, which results in maximum delivery has been selected as the best solution. It should be noted that when the trucks were increased in the first combination, which was based on minimum lead time, the number of orders delivered were reduced. This is due to several factors including the size of the items, which might be large. Since the change is only in the number of furniture trucks, most of the inbound orders might not be furniture orders that might be a reason why the number of orders delivered is reduced. If the company wants to stick to the range of lead time obtained from the survey, it is possible to achieve a delivery lead time of 7.36 days and number of completed deliveries of 4124 orders with a startup cost which is only of 0.07% of total delivery cost that is needed to achieve minimum lead time shown in table 7. The policy in this case would be a combination of 25 furniture trucks, eight kitchen trucks, three project trucks, one shift for the workers, not including delivery on Fridays and a customer postponing policy of one time.

Table 7. Results of sensitivity analysis with respect to delivery costs

	Based on Minimum Lead Time	Based on Maximum Orders Delivered
Combination	35-8-3-1-1-1	31-8-3-1-1-1
Lead Time (Days)	4.025	5.1
Orders Delivered	5271	5328
Total Cost (KD)	X	0.5202 X

6 Conclusion

This study presented a simulation model to investigate the effects of several possible changes in furniture delivery operating policies on two performance measures, namely the lead time and the number of deliveries completed. 192 possible operating policies were simulated and two optimum changes were found: one for the lead time and one for the number of deliveries completed. Finally, sensitivity analysis was carried out with respect to the cost of delivery to determine the best among the two optimum. It was found that the optimum corresponding to maximum deliveries completed was the best choice because, the lead time was just increased by 1 day from the optimum while the total delivery cost was reduced by more than 50%. Therefore, based on these criteria, a system with 31 furniture trucks, eight kitchen trucks, three project trucks, one shift for the workers, including the delivery on Fridays and a customer postponing policy of one time was chosen as the best operating policy. Simulation modeling of delivery and assembly operations proved to be very useful in determining the best policy to achieve certain performance measures.

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