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ORIGINAL ARTICLE

A feasibility study using simulation-based optimization and Taguchi experimental design method for material handling—transfer system in the automobile industry

Kemal Subulan · Mehmet Cakmakci

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Abstract Nowadays, so as to adapt to the global market, where competition is getting tougher, firms producing through the modern production approach need to bring not the only performance of the system designed both during the research and development phase and the production phase but also the performance of the product to be developed as well as the process to be improved to the highest level. The Taguchi method is an experimental design technique seeking to minimize the effect of uncontrollable factors, using orthogonal arrays. It can also be designed as a set of plans showing the way data are collected through experiments. Experiments are carried out using factors defined at different levels and a solution model generated in ARENA 3.0 program using SIMAN, which is a simulation language. Many experimental investigations reveal that the speed and capacity of automated-guided vehicle, the capacities of local depots, and the mean time between shipping from the main depot are the major influential parameters that affect the performance criteria of the storage system. For the evaluation of experiment results and effects of related factors, variance analysis and signal/noise ratio are used and the experiments are carried out in MINITAB15 according to Taguchi L16 scheme. The purpose of this study is to prove that experimental design is an utilizable method not only for product development and process improvement but it can also be used effectively in the design of material handling–transfer systems and performance optimization of automation technologies, which are to be integrated to the firms.

Keywords Taguchi experimental design · Material handling and transfer systems · Performance optimization · Process improvement

K. Subulan · M. Cakmakci (✉)
Engineering Faculty Industrial Engineering Department,
Dokuz Eylül University,
Buca 35160 Izmir, Turkey
e-mail: mehmet.cakmakci@deu.edu.tr

1 Introduction

In order to improve the process in production and optimize the results obtained from production, it is required to increase the production performance. To present the conditions for which the optimum results are obtained in the design phase, primarily, properties determining the performance level are specified and factors affecting these properties are examined. Following that, experiments are carried out in order to determine the effects of these factors on properties setting the performance and find the optimum combination (by also observing the uncontrolled factors) [1].

Considering the basic production resources, the application of experiment design techniques becomes extremely efficient for carrying out these experiments with the highest efficiency pursuing the economical and time constraints as well as interpreting the results accurately (so as to determine the relationship between controllable–uncontrollable factors and outputs and to realize the optimization). Besides, it has a supportive and directive role on all other methods applied to increase quality and efficiency.

With the material handling–transfer equipment, performance increase is achieved in storage systems with automation. Thus, long-term execution of material handling–transfer equipment within the system affects the performance with respect to various storage system criteria hence the performance increases in this respect (increasing the amount of utilization rate of material handling–transfer equipment and the minimization of average number of products awaiting to be carried by the material handling–transfer equipment and the average latency time) cost reduction and optimum storage management [2].

The purpose of this study is to prove that the experimental design is a method that can be used effectively in not only product development and process improvement studies but also in the designing of material handling–transfer systems

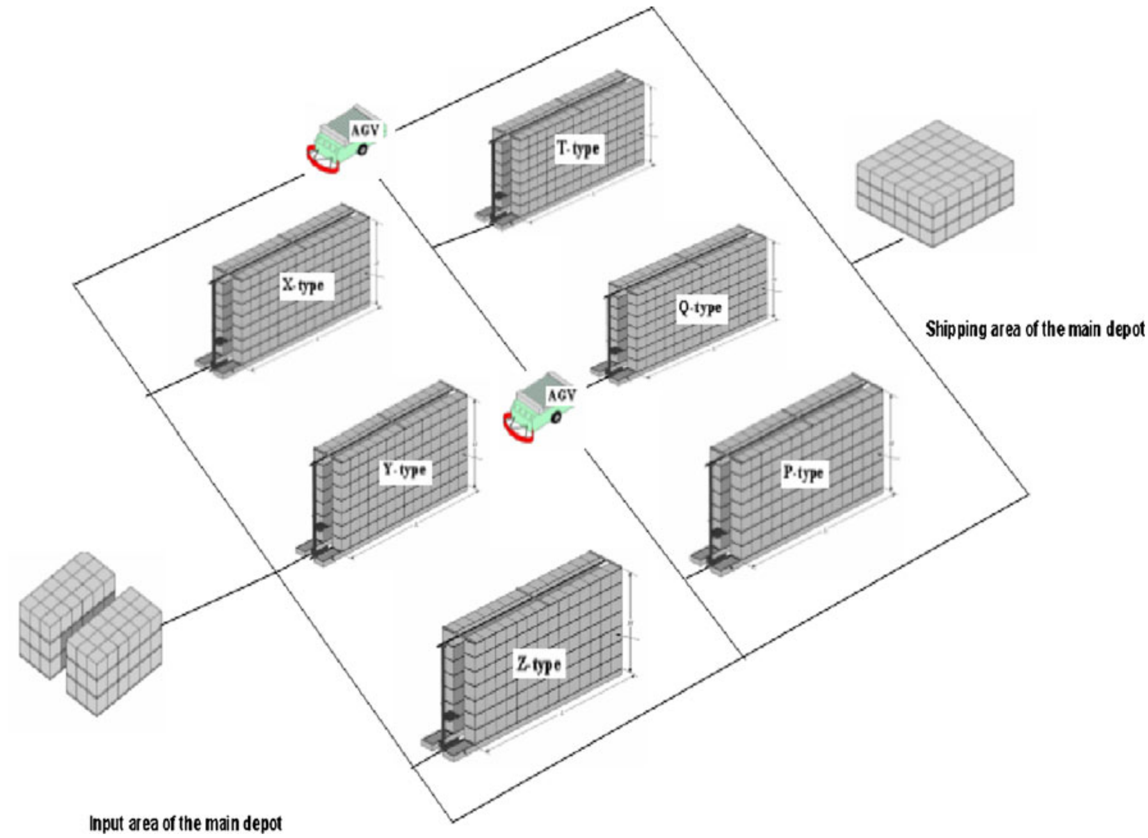


Fig. 1 The 3-D layout of storage system

and performance optimization of automation technologies, which are to be integrated into the operation.

2 Taguchi method and experimental design

Experimental design, which is used in the design phase before manufacturing in production, is not only a statistical approach but it is also a technique that can be used in research and development activities and support and complete all other quality techniques while minimizing the cost, enhancing the quality, and reinforcing the reliability of the results [1, 2]. With the application of this technique in production, several advantages are provided such as improvement of performance and quality, efficient use of the sources, acceleration of the research and development activities, making process or products less susceptible to factors, which are costly, hard to control or uncontrollable, and affect quality properties.

Taguchi method is a technique for designing and performing experiments to investigate processes where the output depends on many factors (variables, inputs) without having tediously and uneconomically run of the process using all possible combinations of values. Thanks to systematically chosen certain combinations of variables, it

Table 1 From/to chart depicting the distances between local depots and main depot inlet–outlet

From/to	Input area	*X*	*Y*	*Z*	*T*	*Q*	*P*	Shipping area
Input area	0	22.5	12.5	22.5	62.5	72.5	62.5	100
X	22.5	0	15	25	45	55	65	82.5
Y	12.5	15	0	15	55	65	55	90
Z	22.5	25	15	0	65	55	45	80
T	62.5	45	55	65	0	15	25	62.5
Q	72.5	55	65	55	15	0	15	72.5
P	62.5	65	55	45	25	15	0	62.5
Shipping area	100	82.5	90	80	62.5	72.5	62.5	0

Table 2 Loading and offloading times of AGV according to product types (in seconds)

	X	*Y*	*Z*	*T*	*Q*	*P*
Loading time	5	6	4	6	7	6
Unloading time	3	4	5	2	4	5

is possible to separate their individual effects [3, 4]. It can be also defined as a set of plans describing the data collection types with experiments. In designing an experiment, the general purpose of the problem, the input variables to be examined and their levels, the reaction of the experiment, the walkthrough of the experiment, and appropriate analysis methods should be determined.

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. In Taguchi's methodology, all factors affecting the process quality can be divided into two types: control factors and

Fig. 3 AGV-Automated guided vehicle [19]

noise factors. Control factors are those set by the manufacturer and are easily adjustable. These factors are most important in determining the quality of product characteristics [5, 6].

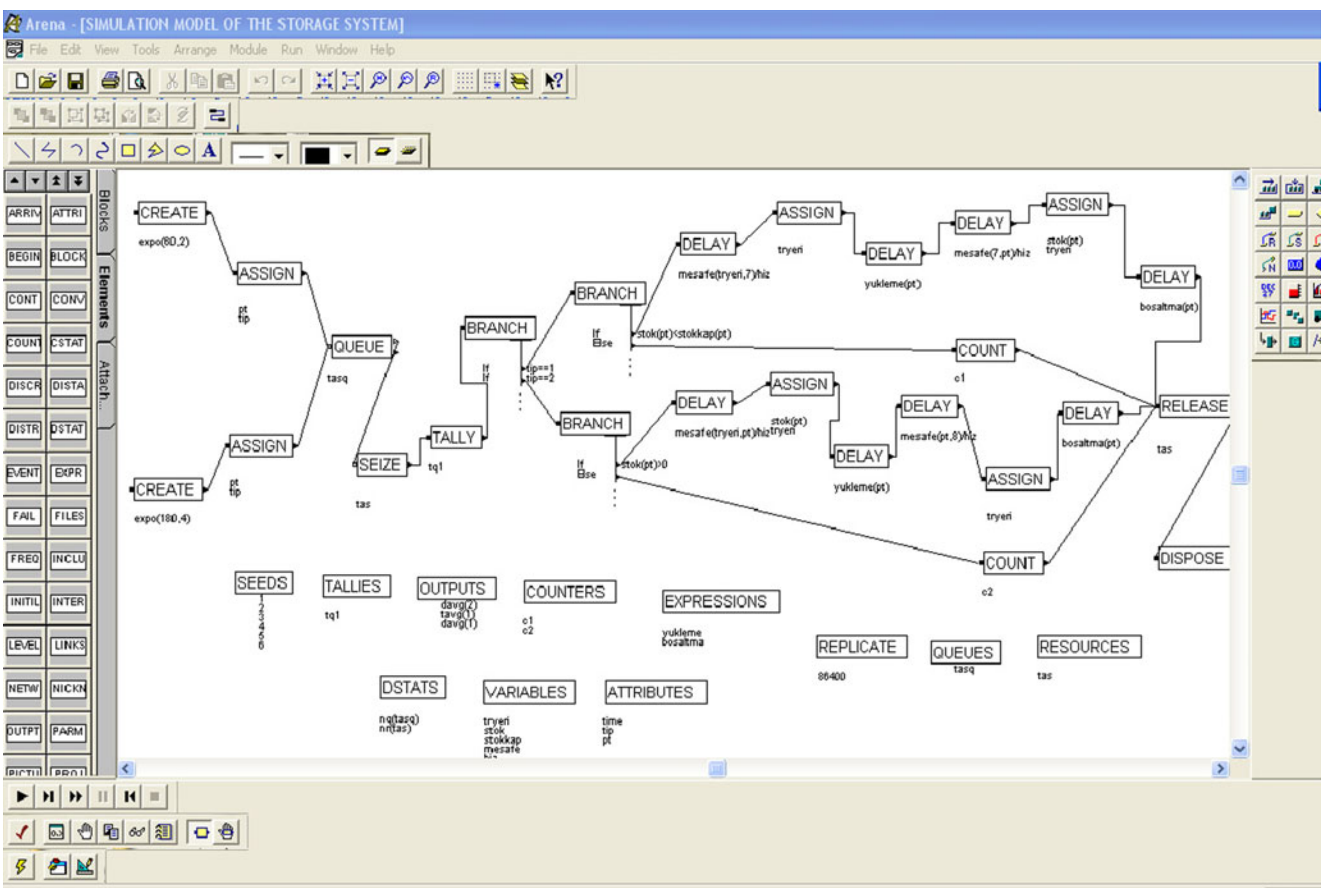


Fig. 2 Simulation model that developed for the storage system– ARENA 3.0

Table 3 Experimental factors and factor levels

Experimental control factors	*A*/speed of AGV	*B*/capacity of AGV	*C*/capacities of local depots	*D*/the mean time between shippings from the main depot (in seconds)
Level 1 (−1)	3	1	40	expo(120)
Level 2 (+1)	7	3	80	expo(180)

This technique is a technique that is used for determining the variable values affecting the process performance by systematically manipulating the controllable variables, which affect the related quality characteristics [7-9].

Genichi Taguchi came up with a solution which increases the efficiency of the evaluation and realization of experiments with the help of the approach called with his name [10]. Besides being only an experimental design technique, Taguchi method is an extremely beneficial technique for high-quality system design. On the other hand, the reduction in the number of experiments stems from ignoring the interaction between factors to some extent. The experiment results obtained through Taguchi experimental design method are converted into signal/noise (S/N) ratio for evaluation. The value of signal/noise ratio is calculated and analyzed in different ways such as low value being good or high value being good or nominal value being good, according to the targeted quality value. Whichever S/N ratio value is used in evaluation, as a result the higher S/N ratio value expresses the better experiment result. Thus, the case with the highest S/N ratio among all the factors examined within the experiment would give the best performance [11, 12]. The standard designs of Taguchi are built on this system. It is required that a model be constructed for the variation of data on the targeted value. For that purpose, loss function to calculate the deviation between the experimental and the desired value is modelled as below:

$$L(y) = k(y - T)^2 \quad (1)$$

In this function, $L(y)$ is the loss function, k is proportional constant, T is target value, and y is observed value. The data obtained through loss function, a formulation, which is expressed as S/N ratio, is developed by Taguchi. With the help of S/N ratio, which is also expressed as the variation of the process, optimum process conditions which are used for the optimization of the process are obtained. Factor levels with the highest S/N ratios are the factor combinations providing the optimum conditions [13].

$$\mathrm{S/N} = -10\log(Ly) \quad (2)$$

For S/N ratio, there are three different approaches. These are smaller is better, larger is better, and target value is better. For each approach, a different calculation scheme is developed.

Table 4 Orthogonal array L_{16} of the experimental runs (experimental layout) and response values for the experiment

Standard run no.	Randomized	*A*	*B*	*C*	*D*	The average utilization rate of AGV(%)	The average number of waiting products for AGV	The average waiting time of products in the input area (in seconds)
1	7	1	1	1	1	91.90	25.701	1,029.9
2	3	1	1	1	2	64.87	2.4054	108.09
3	10	1	1	2	1	98.60	41.518	1,656.9
4	2	1	1	2	2	75.42	4.594	206.22
5	15	1	2	1	1	88.86	0.02662	1.0665
6	1	1	2	1	2	62.83	0.01086	0.48933
7	9	1	2	2	1	98.32	0.03409	1.3661
8	4	1	2	2	2	72.92	0.01476	0.066526
9	14	2	1	1	1	49.83	0.35922	14.396a
10	5	2	1	1	2	35.20	0.1773	7.9911
11	12	2	1	2	1	55.52	0.4393	17.613
12	8	2	1	2	2	41.22	0.22193	10.005
13	16	2	2	1	1	48.62	0.00261	0.10508
14	6	2	2	1	2	34.45	0.00107	0.004817
15	11	2	2	2	1	54.05	0.00338	0.13566
16	13	2	2	2	2	40.23	0.00144	0.06473

Table 5 S/N ratios of Taguchi experimental results

The average utilization rate of AGV(dB)	The average number of waiting products for AGV (dB)	The average waiting time of products in the input area (dB)
−0.74	−89.005	−61.025
−3.77	−8.44	−41.46
−0.12	−32.97	−64.95
−2.46	−14.2	−47.19
−1.20	31.33	−0.7
−4.05	39.1	6.035
−0.16	29.25	−2.82
−2.75	36.5	3.43
−6.06	8.84	−23.22
−9.08	14.99	−17.9
−5.12	7.098	−24.96
−7.71	13.04	−67.29
−6.27	51.36	19.25
−9.27	1.32	26.79
−5.35	49.164	17.08
−7.92	5.76	23.39

For smallest is better characteristic, function is defined as

$$Ly = (y12 + y22 + y32 + \ldots \mathrm{yn}2)/n \quad (3)$$

For target value is better characteristic, function is defined as

$$Ly = ((y1 - m)2 + (y2 - m)2 + \ldots (\mathrm{yn} - m)2)/n \quad (4)$$

For largest is better characteristic, function is defined as

$$Ly = ((1/y12) + (1/y22) + (1/y32) + \ldots (1/\mathrm{yn}2))/n \quad (5)$$

In the experimental design, orthogonality is defined as the calculability of a factor without being dependent on another factor. The effect of a factor does not have an influence on the estimation of the effect of another factor. The first rule of orthogonal series is that they are balanced experiments. In other words, they include equal number of trials for different trial conditions.

3 Definition of the problem and data

There are six different product types of ABC firm, which produces in automotive industry. There are specific locations within the main store where these products are stored. In other words, there are six different locations (local depots) for six different products (Fig. 1). All products are moved to the main depot entrance by the help of an overhead line. In the main depot, products are stored in an automation-based storage system, automated storage/retrieval systems (AS/RS) which are called local depots. For the moment, in the storage system, handling is realized using manual handling cars and forklifts. In the direction of executives' support, the feasibility studies are carried out for transition of the manual storage system to automated system.

The unit arrival percentages of six different product types to the main depot entrance from overhead lines where the final products are handled are as follows. Fifteen percent of them is X-type, 20% is Y-type, 20% is Z-type, 15% is T-type, 20% is Q-type, and 10% is P-type. Similarly, the unit outlet percentages are as follows respectively: 15% is X-type, 20% is Y-type, 20% is Z-type, 15% is T-type, 20% is Q-type, and 10% is P-type. The automation to be

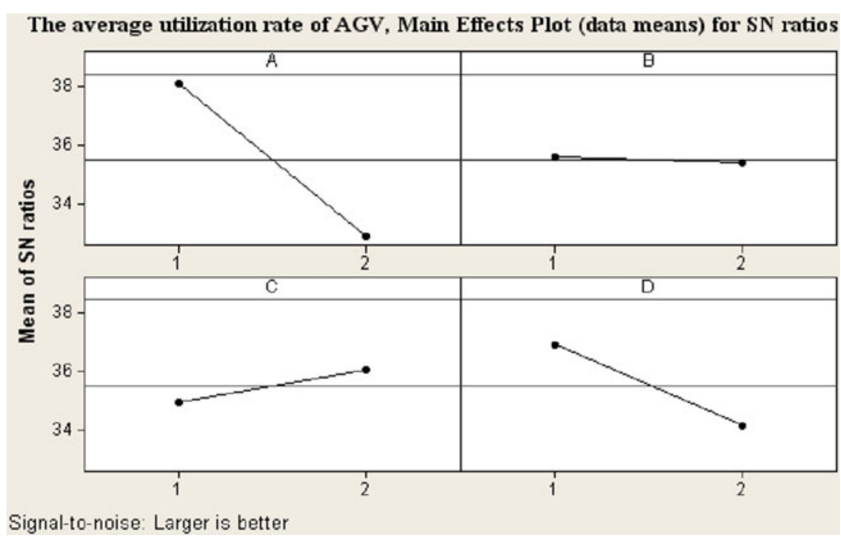


Fig. 4 The main factor effects obtained from statistical analysis for the average utilization rate of AGV

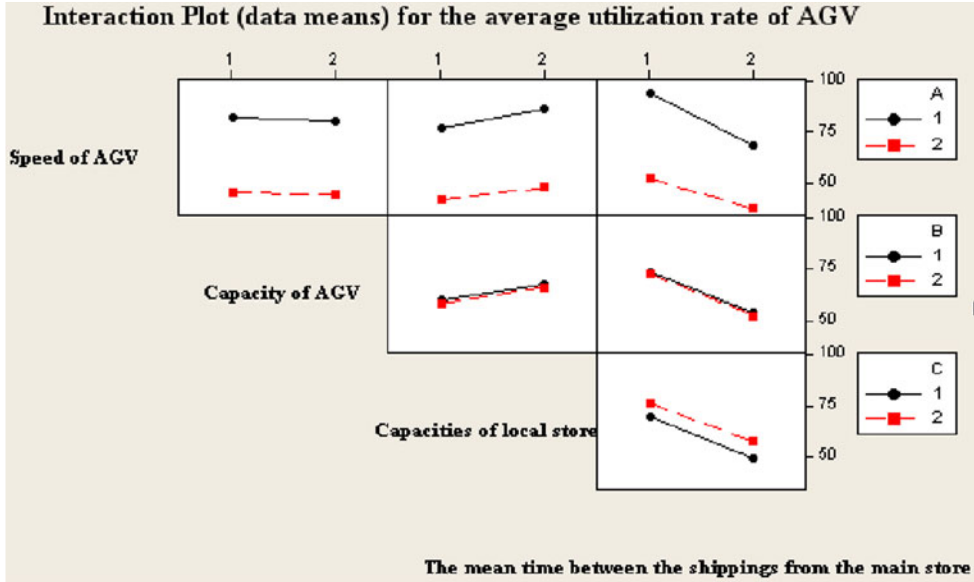


Fig. 5 Two-factor interaction effects obtained from statistical analysis for the average utilization rate of AGV

applied to the material handling–transfer system is to be designed according to the performance optimization of the automated-guided vehicle (AGV) system, which would provide the computer control of the handling operation between the locations of differently packed products. The designed AGV system is responsible for two types of handling movements.

The first one is the handling of parts, which have arrived at the main depot, to different locations; and the other one is the handling of products, which will be let out from the main depot, to the outlet of the main depot. All of these data are obtained through an input analysis carried out in the ARENA program. The number of AGVs and the number of products carried by these vehicles at a time is taken as 1. Following that, in the experimental design phase, the extent to which these values have an effect on performance criteria will be dealt with. The carrier goes to the target location following the shortest path within the main depot. This information provides us with the construction of from/to chart for the main depot whose layout is given in Fig. 1. The speed of AGV is specified

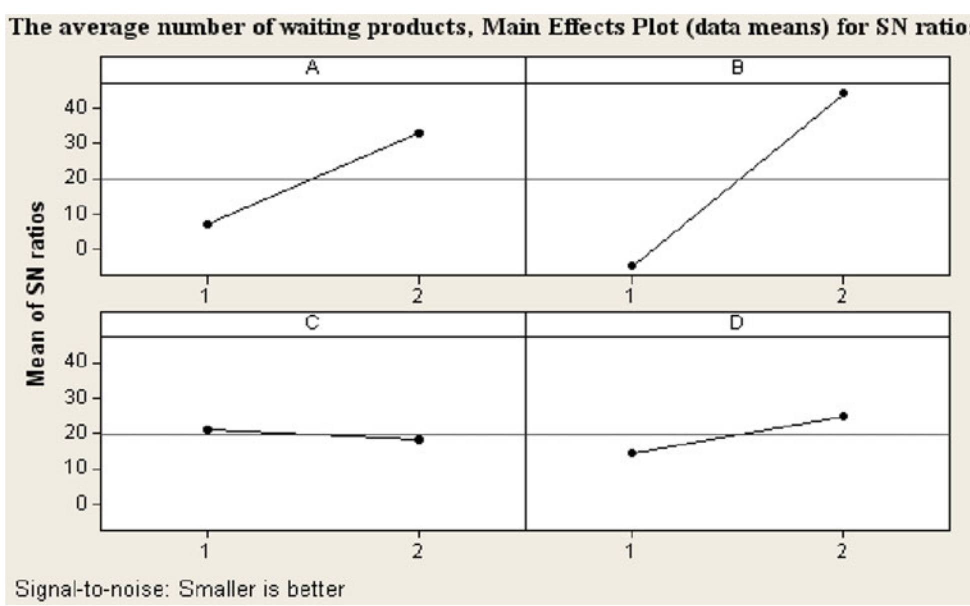
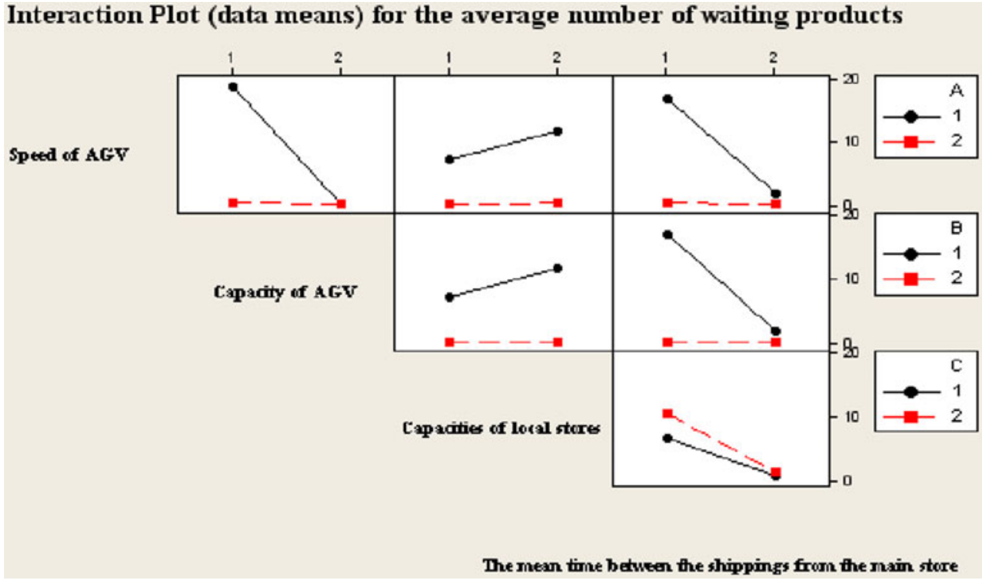


Fig. 6 The main factor effects obtained from statistical analysis for the average number of waiting products for AGV

Fig. 7 Two-factor interaction effects obtained from statistical analysis for the average number of waiting products for AGV



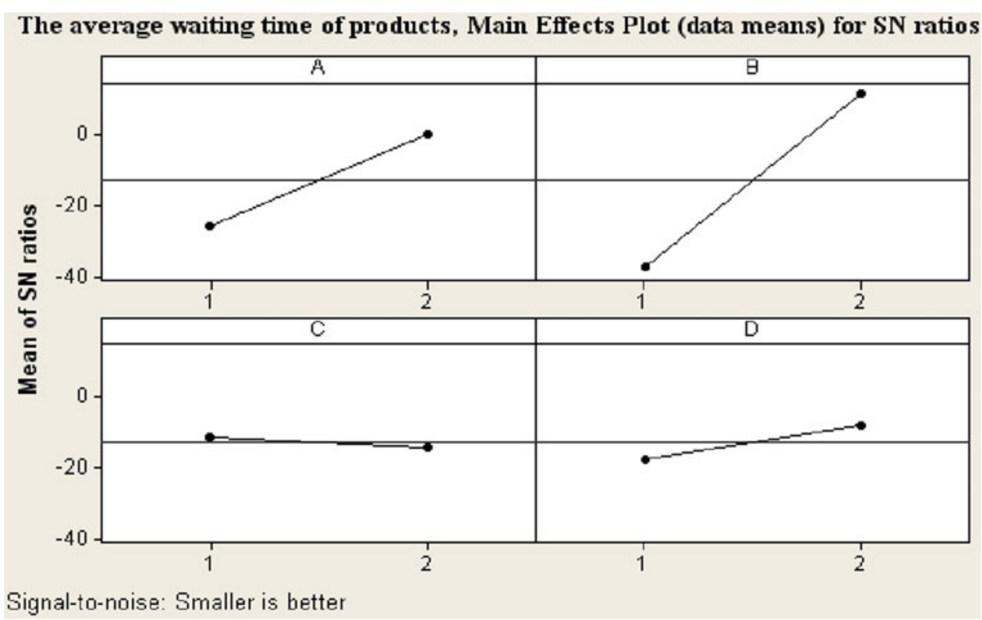
as 3 m/s. The AS/RS system, where every product is stored, has a capacity of 40 products/unit and at the starting moment it is assumed that the stock level on these system is 0.

In Table 1, distance matrix (meter) which consists of local depots, inlet, and outlets of the main depot regarding the routes that AVG should follow using the layout of main depot, and from/to chart can be seen. AGV times differ due to the weights of products being transferred. The loading and offloading of heavier products are executed slower due to product sensitivity (Table 2). For the problem described above, a simulation model, which simulates ABC firm working three shifts, is run for 24 h and the obtained performance criteria values are used as data in the experiment design.

4 Experimental procedures and results

Simulation model developed in problem-specific ARENA 3.0 simulation program can be seen in Fig. 2. The values of variables, which are determined as controllable factors, within the model, are altered according to the determined factor levels, and the model is run. In this way, the related

Fig. 8 The main factor effects obtained from statistical analysis for the average waiting time of products in the input area



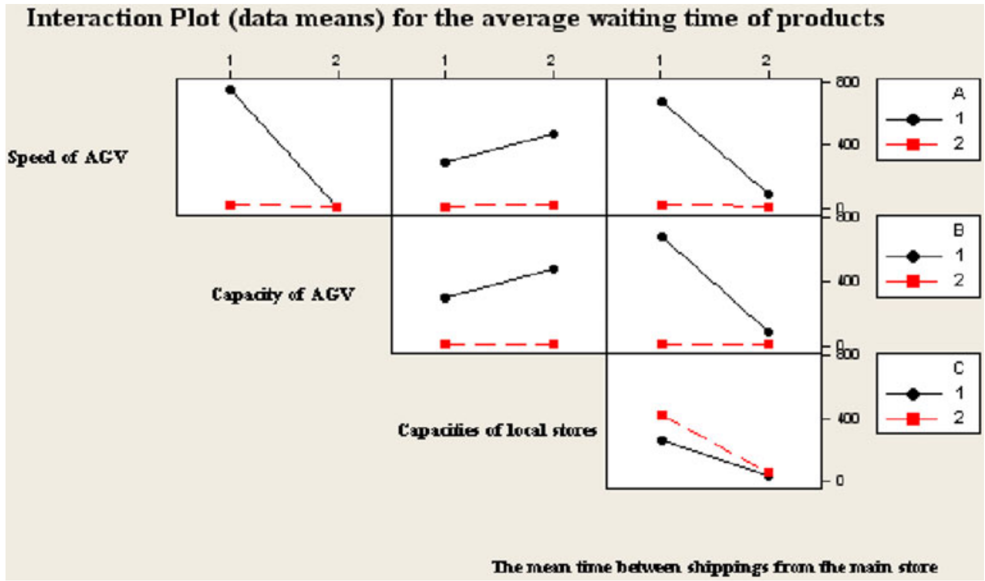


Fig. 9 Two-factor interaction effects obtained from statistical analysis for the average waiting time of products in the input area

performance criteria values are obtained as response variables within the experimental design.

Generally, the total response number is dependent on the number of factors, factor levels, number of constrained factors, and number of experiment repetitions. Especially, in multifactored experiments, the response number may be very high. This situation increases the cost as well as the time spent for experiments. For this reason, in order to reduce the number of experiments and cost, the number of responses is reduced. However, the reduction of the response number may cause insufficient data collection for the inspected event. Hence, responses should be reduced without affecting the data collection procedure.

In the consideration of all this information, in order to specify the number of repetitions, the interval estimation of the basically related performance criterion, beneficial use ratio of AGV, is performed in ARENA program by taking repetition number as 5 and following that, after the desired half-interval level is specified, the necessary observation number is determined using the following equation [14].

$$n^* = \left[n \cdot \left(h/h^*\right)^2\right] \tag{6}$$

Under these circumstances, the total observation number is specified as 20. As a result of the brainstorming sessions held and the cause–effect matrices constructed in the firm, several performance criteria such as average utilization rate of AGV (see in Fig. 3), the average number of products awaiting in the main depot' input area to be transferred to the local depots and average idle time of these parts are set as the performance criteria used for specifying the activity of the automation.

It is observed that these performance criteria are affected by AGV speed, AGV capacity, local depots' capacities, and the intervals between the product transfers at the main depot outlet (Table 3).

Before the application of the experiment, it is required that a "receipt" table should be prepared for the team who will run the experiment. The receipt table is constructed according to the factor values which should be adjusted for every observation and "+" and "−" signs of L16 design matrix [7, 8].

The experiment will be run by taking the repetition number as 20 due to the facts explained before. For the repeated experiments, response variables are assigned using the average of results and point estimation. Hence, the reliability of the results is provided statistically by repeating the experiments for 20 times and averaging the results.

In Table 4, point estimation values for the average utilization rate of AGV, average number of products awaiting for AGV handling and average idle time for the awaiting product can be seen. These values will be used in the calculation of signal/noise ratio and variation analysis operations.

5 Evaluation of results

5.1 Taguchi method results

In Taguchi experimental design method, the criterion used for measurement and evaluation of quality characteristics is the ratio of signal (S) to be measured to the noise factor (N). Signal value is the actual value that the system gives and desired to be measured, while noise

Table 6 ANOVA results for the average utilization rate of AGV, ANOVA results for the average number of waiting products for AGV, ANOVA results for the average waiting time of products in the input area

Source	Sum of squares	Degree of freedom	Mean square	*F* value
ANOVA results for the average utilization rate of AGV				
A: Speed of AGV	5424.32	1	5424.32	9100.6
B: Capacity of AGV	9.42	1	9.42	15.81
C: Capacities of local stores	222.9	1	222.9	373.98
D: The mean time between shippings	1571.33	1	1571.33	2636.28
A×B	0.74	1	0.74	1.24
A×C	12.04	1	12.04	20.2
A×D	124.99	1	124.99	209.7
B×C	0.2	1	0.2	0.34
B×D	0.00	1	0.00	0.01
C×D	1.66	1	1.66	2.79
Residual	2.98	5	0.60	
Total	7370.61	15		
ANOVA results for the average number of waiting products for AGV				
A: Speed of AGV	333.96	1	333.96	6.00
B: Capacity of AGV	354.58	1	354.58	6.37
C: Capacities of local stores	20.57	1	20.57	0.37
D: The mean time between shippings	229.96	1	229.96	4.13
A×B	332.54	1	332.54	5.98
A×C	20.01	1	20.01	0.36
A×D	223.89	1	223.89	4.02
B×C	20.52	1	20.52	0.37
B×D	229.37	1	229.37	4.12
C×D	11.68	1	11.68	0.21
Residual	278.14	5	55.63	
Total	2055.21	15		
ANOVA results for the average waiting time of products in the input area				
A: Speed of AGV	545508	1	545,508	6.31
B: Capacity of AGV	580324	1	580,324	6.72
C: Capacities of local stores	33387	1	33387	0.39
D: The mean time between shippings	356385	1	356,385	4.12
A×B	543117	1	543,117	6.29
A×C	32431	1	32,431	0.38
A×D	347988	1	347,988	4.03
B×C	33292	1	33,292	0.39
B×D	355538	1	355,538	4.11
C×D	17570	1	17,570	0.2
Residual	432024	5	86,405	
Total	3277562	15		

factor is the undesired factor portion within the measured signal value.

In the calculation of signal/noise ratio, the target quality value which is desired to be reached at the end of the experiment, is also important. At this point, three important categories are available [1, 15-18]:

- *Lower value is better* (target is to reach the lowest value)
- *Higher value is better* (target is to reach the highest value.)
- *Nominal value is better* (target is to reach the nominal value)

In Table 5, the signal/noise ratios, which are calculated using Eqs. 3 and 5 with the help of measured AGV utilization rate, average number of awaiting products, and average idle time values for each experiment, are

Table 7 Confirmation runs and optimal setting showing results for the performance criterion

	Optimal factor levels for the average utilization rate if AGV		Optimal factor levels for the average number of waiting products for AGV		Optimal factor levels for the average waiting times of products in the input area	
	Level	Value	Level	Value	Level	Value
Speed of AGV	1	3	2	7	2	7
Capacity of AGV	1	1	2	3	2	3
Capacities of local stores	2	80	2	80	1	40
The mean time between shippings from main store	1	Expo (120)	2	Expo (180)	2	Expo (180)
Optimal predicted S/N ratios	0.136		137.24		27.49	
Predicted values obtained from Confirmation runs	98.60%		0.00144		0.04817 s	

depicted. At the end of all these calculations, the highest signal/value ratio value refers to the best experimental results. In other words, it refers to the experimental results where AGV utilization rate is maximum, minimum number of awaiting products, and idle time of the products are minimum. For finalizing the optimization phase, variation analysis is performed using the calculated signal/noise ratios.

Later on, in order to clarify how these factors affect each performance criterion, the statistical analysis was carried out. These main-factor effects are plotted in Figs. 4, 5, and 6. Also, Figs. 7, 8, and 9 show the two-factor interaction effects.

5.2 ANOVA results

Analysis of variance (ANOVA) was conducted to identify significant factors in an automated storage system process. ANOVA can be used to divide the total variation in the data into variation resulting from main effects, interaction effects, and error (Table 6).

6 Conclusion

The main factor levels A1–B1–C2–D1 are specified as the factor levels increasing the average utilization rate of AGV, while main factor levels A2–B2–C2/1–D2 are specified as the factor levels reducing the awaiting average product number. Moreover, main factor levels A2–B2–C1–D2 are observed as the factor levels reducing the average idle time of the awaiting parts. It is obviously seen that, the main factor effects, two-factor interaction effects and the S/N ratios supported the same optimal factor levels (Table 7).

As a result of this study, it has been proven that the Taguchi experimental design is a method that can be used effectively in not only product development and process improvement studies but also in the designing of material handling–transfer systems and performance optimization of automation technologies, which are to be integrated into the operation. It can be seen that the simulation-based optimization technique can be effectively used in a feasibility study as an experimental tool with the advantages of cost reduction and the property of time compression also.

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