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ROBUST DESIGN OF AN FMS AND PERFORMANCE EVALUATION OF AGVS.

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ABSTRACT
Since the development of the first Automated Guided Vehicles (or AGVs in short) in the early 1950's, ra progress has been witnessed in research, design and applications of AGV systems. Although a signific amount of simulation research has been carried out for design and analysis of Flexible Manufacturing Syste (FMS), it does not provide optimal solutions. In this research, we have employed one optimum seeking meth to design and optimize a manufacturing system. This method is the Taguchi approach, which uses rob design concept to reduce the output variation. For measurement of the performance of the AGVS one crite was chosen, which was somehow neglected by earlier researchers. The results show that the average utilizat of AGVs can be maximized when this method is employed.

Keywords: AGV, FMS, Taguchi Method

1. INTRODUCTION
The Material Handling System (MHS) is the backbone of a Flexible Manufacturing System (FMS). It connects various production functions and regulates part movement. From different types of material handlers available for an FMS, the Automated Guided Vehicle System (AGVS), which comprises several microprocessor-controlled driverless vehicles, is the most adaptable and capable one. Since the development of the first automated guided vehicles (or AGVs in short) in the early 1950's, rapid progress has been witnessed in both research and applications of AGV system. AGVs are unmanned vehicles that usually run on predefined guide paths in large material warehouses to transport goods among different workstations. An AGV system is integrated mainly by AGVs, a central controller, paths, an electronic communication mechanism and routing strategies. Nowadays, AGV systems are widely used in automated material handling systems, flexible manufacturing systems and even in container terminals to transport containers [1],[2],[3],[4] & [5]. The vehicles can automatically perform loading, routing selection, and unloading. Though flexible, AGVs are highly complex and expensive. To realize the full potential, it is essential to design, plan, schedule, and control the AGV system efficiently.

Various approaches, such as mathematical programming, queuing networks, computer simulation, artificial intelligence, have been proposed for the design and control of manufacturing systems as well as AGVs. The usefulness of any of these tools depends on the nature of the problem. Typically an AGV inherits randomness from FMSs and randomness invites complexity. As complexity increases, it becomes very difficult to analytically study the system. Simulation is widely used to study the manufacturing system's performance [6], [7]. Nevertheless in and of itself, simulation is not a normative mechanism; it does not prescribe the optimum setting of system parameters [8]. In this research, we employed the Taguchi method to uncover the optimal combinations of factor levels that maximizes the average utilizations of AGVs, the utilization of which proves the goodness of the system design.

Taguchi parameter design is very useful if the problem involves uncontrollable factors, such as time between machine failures. It finds input settings insensitive to all possible combinations of the uncontrollable factors. The methodology is valuable when the decision variables are qualitative or discrete. When the input factors are quantitative and continuous, the classical RSM technique is better suited. RSM studies the local geography of the response surface near the optimal value through the response function. It combines the mathematical and statistical techniques [8]. For the AGV problem we have employed the Taguchi method. The Taguchi method is used to optimize qualitative variables. The purpose here is to present a pragmatic approach that ensures high AGV utilization in particular and enhances the overall FMS performance in general.

2. DESIGN ISSUES IN AN AGV BASED MHS

The power and smaller size of microprocessors has given guided vehicles the capability of operating autonomously, even in complex transport applications [9]. In the following, we briefly discuss the design problems that are crucial in this study.

2.1 Design Issues

(1) Number of vehicles required. Several researchers have addressed the issues of determining the AGV fleet size [10], [11] & [12]. Here the goal is to minimize the number of AGVs while satisfying the production requirements.
(2) Buffer space consideration. Buffers provide queuing spaces for in-process inventory. Large buffer sizes enhance system performance due to less blocking and locking. However it assumes higher expenses for the storage space and for the mechanism required to hold the work in process (WIP) inventory.
(3) Inter-arrival time. Large inter-arrival time leads to under-utilization of the manufacturing system and results in low utilization of AGVs. On the other hand, small inter-arrival time lengthens the waiting time for AGV service, causing long flow time, large WIP, and system congestion.
(4) Speed of AGVs. Slow AGVs increase parts waiting time, while inordinate AGV speed results in unnecessary capital expense.
(5) Number of pallets required. The total number of pallets limits the load on the shop floor simultaneously. Too few pallets cause system underutilization; whereas too many promote congestion and result in extra expense and unnecessary space waste [13]. The pallet factor has been excluded from our study since no significant effect is observed for this factor by Shang [8].

3. PARAMETRIC DESIGN – THE TAGUCHI APPROACH

The philosophy and experimental design principles developed by Taguchi (1986)[14] are applied in this section. Taguchi proposed a three-step approach to product and process design. They are system design, parameter design and tolerance design. In system design, the engineer uses scientific and engineering principles, such as identifying raw materials and components, and analyzing processing sequences, to determine the basic configuration. Following system design is parameter design, which identifies settings that minimize or reduce the performance variation in the product or process. The third phase, tolerance design, is a method for determining tolerances that minimize the sum of product manufacturing and warranty cost. Taguchi comments that many companies spend a lot of effort on system design, yet concurrent cost reduction and quality achievement is more likely realized through careful parameter design. Motivated by his thought we concentrate on parameter design. With parameter design, the significant factors that affect FMS's capability and AGVs utilization were identified, and the best combinations of controllable factors are obtained.

Experiments are essential in Taguchi's parameter design. An ideal experimental design is the one that yields the maximum amount of information with the minimum number of trials. For that Taguchi provided tabulation of orthogonal arrays and made available a set of linear graphs and triangular tables, which help save time and increase the accuracy in assigning proper columns for interaction effects. The orthogonal array is a fractional factorial experiment where the main effects and low-order interactions can be studied easily by running a fraction of the full factorial experiment. In orthogonal arrays, each row represents a combination of factor levels to be run in an experiment. The matrix that designates the settings of the controllable factors for each run is called an inner array. The matrix that designates the settings of the uncontrollable factors is called an outer array. From the linear graph of an orthogonal array, the column representing the interaction between main effects can be determined. These procedures are readily usable even by those without a theoretical background of the array's origin [8]. In the following we employ the orthogonal arrays to study those factors considered to have impacts on utilization of each AGV.

3.1 Orthogonal Inner and Outer Array

Based on the discussion, so far, we have selected four controllable factors and two uncontrollable factors that affect the AGV utilization in particular and overall system performance, in general. The controllable factors are: number of AGVs (AGV); buffer size for each individual machine (BUFR); mean job inter-arrival time (INTV); and AGV speed (SPEED). Mean time between failure (MTBF) and mean time to repair (MTTR) are treated as uncontrollable factors (noise factors). Table 1 shows the associated levels for each factor. The INTV, MTBF and MTTR are all exponentially distributed with mean shown in the Table 1. For the sake of convenience, each factor is assigned a letter ranging from A to F. Each of the controllable factors was to be tested at three levels. The noise factors are uncontrollable during normal operations, but they are varied over two levels here for the purpose of tests. The purpose is to obtain a robust MHS design that will be insensitive to the noise factors during actual operation [15].

We chose an L_9 (3^4) orthogonal inner array since it is useful for 4 factors. For the two noise factors (MTBF and MTTR, each at two levels), an L_4 design is appropriate. The outer array creates noise so the FMS parameters that are least sensitive to machine breakdown and repairs can be found. The L_9 (3^4) orthogonal array has 4 columns and 9 rows. Each controllable factor can be assigned to a column and can be studied by running the 9 different factor combinations. The numbers in each row represent the levels of each controllable factor. The factors A, B, C and D are arbitrarily assigned to columns 1, 2, 3 and 4 respectively. The final design is shown in Table 2.

3.2 Statement of The Simulation Model

The statement of the problem highlights the modular features of operations of a typical FMS under consideration having AGVs. The FMS under consideration having AGVs is found to have a total of four groups of machines. Each group of machines comprises of identical machines. Out of these machines, three groups of machines are dedicated machines for three types of operations, whereas, the fourth group of machines consists of flexible machines, which can perform any of the three types of operations. All the jobs arrive at the system as items. Each item arrives at the system after certain interval of time, which has been taken as a controllable factor. The individual items join the central buffer, which is the area where new jobs wait for the AGVs and the appropriate machines. If for the subsequent operation any dedicated or flexible machine is free, the job polls for an AGV. If all the machines are busy, the job waits in the central buffer until a machine becomes free. If any one appropriate machine becomes available, the job polls for an AGV. If any AGV is free, the AGV immediately takes the job from the central buffer to the free machine and after putting the job in the machine the AGV becomes free. If no AGV is free the job waits in the central buffer. Each vehicle carries one unit load. A unit load is a collection of same parts held and transported together as a unit [16]. After the completion of any operation in any machine, the job again polls for an AGV. If any AGV is free, the AGV takes the job from the machine to the central buffer and after putting the job in the central buffer, the AGV again becomes free. If no AGV is available or free, the job remains in the machine and keeps the machine "BLOCK"ed. Local buffers are provided at each machining centre, each of which has a finite capacity. Each job is having its fixed routing sequence. The operation time of a job is dependant upon the operation number, which is being performed on the job. The three operations take 120 minutes, 40 minutes and 56 minutes respectively. After the completion of an operation, it is checked whether a dedicated machine is available for its next operation. If a dedicated machine is available the job is routed to the dedicated machine. If a dedicated machine is not available, it is checked if any flexible machine is available. If a flexible machine is available the job is routed to the flexible machine and the job polls for an AGV. The allocation of AGVs to the jobs, which are polling AGVs, is done in the same way as narrated previously. Once a machine is available, it is first checked whether a job is waiting in the central buffer. If more than one job is waiting in the central buffer, and if the available machine is a flexible one it chooses the job of which more operations have been done (i.e., the job which is waiting for the second operation will get preference over the job which is waiting for the first operation). When all the necessary operations of a job are complete, the job leaves the system after passing through a wash station. Loading and unloading time to and from an AGV is taken as a constant and the transfer time by an AGV is directly proportional to the distance traveled and inversely proportional to the speed of the AGV. Each AGV moves along a pre-determined path.

The queue discipline followed here is FIFO (First In First Out). After every 2 hours of operation 1 AGV is required for charging of batteries, which require 5 minutes.The maintenance of machines has also been modeled as uncontrollable (noise) factors.

Based on the considerations as mentioned, an analysis is to be conducted using network model to investigate the operations of the AGVs in the FMS. In order to analyze the performance characteristics of the designed AGVs in the FMS problem, the necessary performance measure, i.e., utilization of the AGVs are evaluated. Based on the evaluations of the values of the performance criteria yields, the optimized design and architecture of the AGVs in the FMS is recommended.

A simulation model for the above manufacturing environment was developed using AWESIM [17]. Due to four noise combinations and 9 controllable factorial combinations, 36 experimental conditions result. For each experimental condition the simulation is run for 5200 minutes each. The first 400 minutes of each run is truncated to eliminate initialization bias. So each run consisted of 80 hours of operation. This decision was made on the basis of data generated from pilot runs of the system. Columns 6-9 of Table 2 show the "Average Utilization of AGVs (in percentage)" under each experimental condition.

3.3 The Signal-to-Noise Ratio

An adequate performance measure should incorporate both the desirable and undesirable aspects of the output characteristics. In the Taguchi method, the term 'signal' (i.e., average value of the characteristic) represents the desirable component. The term 'noise' represents the undesirable component and is a measure of the variability of the output characteristics, which preferably should be as small as possible. Taguchi combined these two components into a signal-to-noise (S/N) ratio. The greater this value, the smaller the output variance around the target value.

Table 1: Factors and their associated levels for the simulation of AGVs in an FMS.

	CONTROLLABLE FACTORS	LEVELS		
A	No. of AGVs	5	7	9
B	Buffer size per Machine (BUFR)	12	16	20
C	Inter arrival time (INTV) (Exponentially distributed with mean value)	36min.	24min.	12min
D	AGV speed. (SPEED)	18m/min.	24m/min	30m/min
	UNCONTROLLABLE FACTORS	LEVELS		
E	Mean time between failure (MTBF) (Exponentially distributed with mean value)	60		120
F	Mean time to repair (MTTR) (Exponentially distributed with mean value)	40		70

The signal-to-noise ratio is defined as: S/N = -10Log(MSD). The mean squared deviation (MSD) is defined differently for different quality characteristics.

For bigger-the-better (BTB):

$$MSD = (1/y_1^2 + 1/y_2^2 + 1/y_3^2 + \ldots. 1/y_n^2)/n\ldots \quad (1)$$

Where
y_1 = The results of experiments in each row.
m = Target value of results
n = Number of noise combinations

Analysis of data first involves calculation of Avg. Y_U and $(S/N)_U$ ratios. In our example AGV utilization has the bigger-the-better characteristic. Hence, the given MSD formula is used for $(S/N)_U$ calculation. Avg. Y_U is the average of the four observations in each row. The last two columns of Table 2 represent "Avg. Y_U and $(S/N)_U$" respectively.

3.4 The Optimal Combination Of Different Factors

Though ANOVA procedures are widely used in determining which factors significantly affect the performance, Taguchi recommends analyzing the results through plots and summary measures to keep the analysis simple. It is now described below.

To find the main effects of each factor at the associated level, Taguchi calculates the average of the response variable over all replications for the given level of the factor.

Table 3 summarizes the mean response (Average Utilization of AGVs) and S/N ratios for each factor level. Since the Taguchi method emphasizes maximizing the S/N ratio, studying Table 3 leads us to choose A1, B1, C3 and D1, when we consider maximizing utilization of AGVs. Here, though the factor B has the highest utilization at level 2 (see Table 3), the difference between level 2 and 1 result are minor. For robustness sake, we have chosen B1.

Therefore, the estimated mean utilization is:

$$\text{Opt. } Y_U = \text{Avg.U} + (\text{Avg.A}_1 - \text{Avg.U}) + (\text{Avg.B}_1 - \text{Avg.U}) + (\text{Avg.C}_3 - \text{Avg.U}) + (\text{Avg.D}_1 - \text{Avg.U}) = 76.448\ldots \quad (2)$$

Where Avg.U = Overall mean utilization (of AGV) value = 48.119

Similarly, the estimated $(S/N)_U$ is 38.965.

The results of data analysis give us an idea of the behaviour of the controllable factors since there is no prior knowledge about the controllable factors. Several methods are available for optimization. The Taguchi method has the advantages of reducing the time and cost necessary for experiments and designing robustness into the process. What has been presented here is to provide a useful analysis technique for design and operational control of AGVs and machines in an FMS. It is especially valuable when qualitative control factors are involved. However despite its wide application, the Taguchi method treats factors at only a few discrete levels. There are situations in which other classical techniques are better suited, such as the experiment involving factors that vary in a continuous manner. In our study, the independent variables such as mean inter-arrival time and AGV speed are continuous. Using the Taguchi method to determine the continuous variables' optimum level is not flawless. As a future study, if the Response Surface Methodology (RSM) can be used, that can improve the results derived under the Taguchi method of finding optimum results, thereby giving the best results, instead of the local optima

Table 2: Parameter design with inner and outer arrays and experimental results for " Average utilization of AGVs (In percentage)"

INNER ARRAY					OUTER ARRAY				RESPONSE	
No.	A AGV	B BUFR	C INTV	D SPEED (m/min)	**(MTBF) E- 60** (MTTR)F -40	60 70	120 40	120 70	Avg. Y_U	$(S/N)_U$
1	5	12	36	18	70	70	64.78	64.78	67.39	36.552
2	5	16	24	24	65.88	65.88	65.92	65.92	65.9	36.378
3	5	20	12	30	55.34	55.34	55.34	55.34	55.34	34.861
4	7	12	24	30	39.9	39.9	40.17	40.17	40.035	32.049
5	7	16	12	18	60.314	60.314	60.314	60.314	60.314	35.608
6	7	20	36	24	37.97	37.97	34.671	34.671	36.321	31.176
7	9	12	12	24	37.856	37.856	37.856	37.856	37.856	31.563
8	9	16	36	30	23.633	23.633	21.611	21.611	22.622	27.065
9	9	20	24	18	47.156	47.156	47.422	47.422	47.286	33.495

Table 3: Response of each factor level (Average utilization of AGVs).

Single factor	Average Utilization of AGVs.	$(S/N)_{U.}$
FACTOR A (AGV)		
Level 1(5)	62.877	35.93
Level 2(7)	45.557	32.944
Level 3(9)	35.922	30.708
FACTOR B (BUFR)		
Level 1(12)	48.427	33.388
Level 2(16)	49.612	33.017
Level 3(20)	46.317	33.177
FACTOR C (INTV)		
Level 1(36min.)	42.111	31.598
Level 2(24min.)	51.075	33.974
Level 3(12min.)	51.17	34.011
FACTOR D(SPEED)		
Level 1(18m/min)	58.331	35.218
Level 2(24m/min)	46.692	33.039
Level 3(30m/min)	39.332	31.325

4. CONCLUSIONS

As there is no theoretical means for predicting the response (Utilization of AGVs) as mathematical functions of the factors, an empirical (simulation) approach has been adopted. In this research one method for designing and optimizing AGVs in FMS has been presented. The Taguchi method is employed to quickly identify the optimal area. One of the most important outcomes of this research is that no more experimental effort needs to be spent on not-so-important factors and the investigator can quickly concentrate on the important ones that have been identified. This thing helps in confirming our prior knowledge, if there is any, as well as extends our confidence to situations where prior knowledge does not exist. Particularly, when elimination of noise factors is neither practicable nor feasible, the Taguchi method helps reduce the noise factors rather than eliminate them. Moreover, it provides a unique way for optimization where qualitative factors are concerned.

When only Taguchi method is used, the interaction factor cannot fully be taken into account due to the limit of linear graph in the orthogonal array. The optimization is done only over the points (3 levels in this study) considered in the design. The points chosen in the experiment may not yield the true optimum when continuous variables exist. We believe that simulation and the Taguchi method will improve the design and performance of the AGVs in the FMS environment.

5. REFERENCES

1. Qiu, L. And Hsu, W-J., 2000, “Algorithms for routing AGVs on a Mesh Topology”, *Proceedings of the 2000 European conference on 11th computing ((Euro-par 2000), 29 August – 1 September 2000, Munich, Germany*, pp.595-599.
2. Qiu, L. And Hsu, W-J., 2000, “Conflict free AGV routing in a bi-directional path layout”, *Proceedings of 5th International Conference on Computer Integrated Manufacturing, Singapore, 28-30 March 2000*,pp 392-403.
3. Qiu, L. And Hsu, W-J., 2000, “Routing AGVs by sorting”, *Proceedings of the 2000 International conference on Parallel and Distributed Processing Techniques and Applications (PDPTA’2000,) Las Vegas, Nevada, USA, 26-29 June 2000*, pp.3: 1465-1470.
4. Qiu, L. And Hsu, W-J., 2000, “Routing AGVs on a mesh like path Topology”, *Proceedings of the IEEE Intelligent Vehicles Symposium 2000, 3-5 October 2000, Dearborn, Michigan, USA,* pp.392 – 397.
5. Ye, R., Vee, V.Y., Hsu, W-J. And Shah, S.N., 2000,”Parallel simulation of AGVs in container port operations”, *Proceedings of 4th International Conference /Exhibition on High Performance Computing in Asia-Pacific Region, Beijing, China, 14-17 May 2000*, pp. 1058 – 1063.
6. Egbelu, P. J., And Tanchoco, J. M. A., 1984, “Characterization of automated guided vehicle dispatching rules”, International Journal of Production Research, pp. 22:359-374.
7. Valvanis, K. P., 1990, “On the hierarchical modeling analysis and simulation of flexible manufacturing systems with extended Petri nets”, IEEE Transactions on System, Man and Cybernetics, pp. 20:94-110.
8. Shang, J. S., 1995, “Robust design and optimization of material handling in an FMS”, International Journal of Production Research, 33:2437-2454.
9. Mahadevan, B. And Narendran, T. T., 1990, “:Design of an automated guided vehicle-based material handling system for a flexible manufacturing system”, International Journal of Production Research, 28:1611-1622.
10. Maxwell, W. L., And Muckstadt, J. A., 1982, “Design of automated guided vehicles”, IIE Transactions, 14:114-124.
11. Egbelu, P. J., 1987, “The use of non-simulation approaches in estimating vehicle requirements in an automated guided vehicle based transport system”, Material Flow, 4:359-374.
12. Sinriech, D., And Tanchoco, J. M. A., 1992, “An economic model for determining AGV fleet size”,

International Journal of Production Research, 30:1255-1268.
13. Stecke, K. E., 1985, “Design, planning, scheduling, and control problems of flexible manufacturing systems”, Annals of Operations Research, 3:3-12.
14. Taguchi, G., 1986, *Introduction to Quality Engineering-Designing Quality into Products and Processes*, Asian Productivity Organization, Tokyo.
15. Taguchi, G., Elsayed, A., And Hsiang, T., 1989, *Quality Engineering in Production Systems*, McGraw-Hill, New York.
16. Apple, J. M., 1972, *Material Handling System Design* , Wiley, New York.
17. Pritsker, A. A. B., And O’reilly, J. J., 1999, *Simulation with Visual SLAM and AweSim,* System Publishing, Indiana.

6. NOMENCLATURE

Symbol	Meaning
AGV	Automated Guided Vehicles
FMS	Flexible Manufacturing Systems
Awesim	A particular Simulation Software Package.