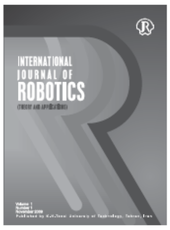

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Conflict free Path Planning for Multiple Autonomous Guided Vehicle

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ABSTRACT

In automated guided vehicle (AGV) systems, the begin-end combinations are usually connected using a fixed layout, which is not the optimal path. The capability of these configurations is limited and often the conflict of multiple AGVs. By appearing more flexible layouts and advanced technology, the positioning and dispatching of AGVs increased. In this paper, a simulation model being applicable for strategic level is designed that compares systems with and without conflict free design. Specifically, the avoidance of conflicts is substantial. Optimization process for different layouts and configuration of AGVs are worked out using statistical methods for design parameters. The outputs imply the effectiveness of the proposed approach for industrial cases. After simulation experiments for design evaluation, an optimization is fulfilled for effective implementation. This way the optimal values of critical factors and design parameters are obtained to be used in scenario evaluation for multiple AGV system.

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1. Introduction

system. To design an AGV system, both physical elements such as the vehicles and the facility layout as well as the operational control of the equipment have to be developed [1, 2]. This operational procedure design includes the definition of procedures for dispatching, scheduling and routing. Routing is to determine routes for a set of AGVs to fulfill their related transportation tasks. In current systems, AGVs use a pre-specified sequence plan, fixed paths that are combined to obtain routes [3].

Configuration of the guide path for an AGV system involves issues as the location of pickup and delivery points, the path layout and the path types. The distribution of the pickup and delivery points over the infrastructure is very significant as they influence the traffic intensity on that infrastructure [4]. The design of guide path layout is based on the objective functions to be fulfilled. Different objectives can be found in the literature such as minimizing total route costs, minimizing travel distance or minimizing travel time. A typical AGV consists of the frame, batteries, electrical system, drive unit, steering, precision stop unit, on-board controller, communication unit, safety system, and work platform. AGV systems are generally used for distribution of materials in warehouse environments, and movement of material to and from production areas and storage areas in manufacturing environments [5].

Typical objectives in design of AGV systems include 1) evaluation of the feasibility of an AGV system, 2) evaluation of the dispatching rules, 3) elimination of traffic problems, 4) maximizing the reliability, 5) maximizing the vehicle utilization, 6) minimizing the inventory level, 6) minimizing the transportation costs, and 7) maximizing the space utilization. Tools used in AGV system design can be classified in two main categories: analytical tools and simulation-based tools [6]. Analytical tools are mathematical techniques such as queuing theory, integer programming, heuristic algorithm, and Markov Chains. A number of analytical approaches to the design of AGV systems have been proposed in the literature [7]. Fazlollahtabar and Saidi-Mehrabad [8] discussed literature related to different methodologies to optimize AGV systems for the two significant problems of scheduling and routing at manufacturing, distribution, transshipment and transportation systems. They categorized the methodologies into mathematical methods (exact and heuristics), simulation studies, metaheuristic techniques and artificial intelligent based approaches.

Antakly et al. [9] dealt with the conflict avoidance problem of an AGV system, in a Flexible Manufacturing System. Regarding the complexity of this kind of problems, it has generated many works to find an optimal strategy for scheduling and routing AGVs. Valmiki et al. [10] presented an estimation of fleet size of Automated Guided Vehicle (AGV). Determination of AGV fleet size plays a decisive role on the performance of job shop environment. Simulation methods were studied in detail for the estimation of AGV fleet size in a Flexible Manufacturing System. The presented methods were based on either minimization of total travel time or overall cost. Khodayari et al. [11] presented stability algorithm has been generalized to prevent collision between members of the swarm as well as avoid collision with obstacles and two repulsive operators have been designed to guaranty the safety of the swarm members along the path. Mirzaei et al. [12] implemented a probabilistic and timed supervisory control theory (ptSCT) on ARGoS platform in swarm robotic. The proposed approach automatically calculated ptSCT, and then generated the equivalent controlling software codes. The generated controlling software can be used for both simulation and running on real robots without any changes. Shi et al. [13] proposed an obstacle avoidance path planning method for the dual-arm robot based on the goal probability bias and cost function in a rapidly exploring random tree algorithm (GA_RRT). The random tree grows to the goal point with a certain probability. At the same time, the cost function was calculated when the random state was generated. Targeting some problems of the RRT_Connect path planning algorithm, such as average search and low efficiency, proposes an improved RRT_Connect algorithm that may optimize the searched nodes and parts of planned paths [14].

Industry 4.0 philosophy and the associated method of digital factory require a wide range of tasks and skills to be managed for their successful application and efficient operating [15]. One of the key competencies for their reliable operation is mastering computer simulation of various logistics processes that take place within the enterprise. Among the most important logistics activities in any enterprise belongs the supply process [16]. Currently, there is a major trend in the supply process to use the various automated systems, such as AGV. Neradilova and Fedorko [17] described the process of creating a simulation model of the supply process using the method of additional programming to the needs of implementing various analyses. One of the challenges in path planning for an automated vehicle is uncertainty in the operational environment of the vehicle, demanding a quick but sophisticated control of the vehicle online. To address this online path planning issue, neural networks, which can derive a heading for an operating vehicle in a given situation, have been actively studied, demonstrating their satisfactory performance [18].

The reviewed works for the simulation in the literature mostly focus on the design of an AGV based system and evaluate different implementation scenarios using different performance criteria, especially time related ones. According to the preceding research gaps, the following contributions are aimed: Design and evaluation of multiple AGV system, Evaluation of novel design for multiple AGV system, analyzing several objectives in design and implementation, Simulation and optimization for effective analysis. As a general roadmap for the current work, we pursue a problem of multiple moving agent system in which conflict is considered. This paper presents a simulation model to study the efficiency of a conflict free design concept in crossover points of a routing network of multiple AGVs.

The remainder of this paper is organized as follows. In the next section, the problem is stated and modeled with respect of conflict free design concept. In Section 3, the simulation model is developed to emphasize the concept of conflict free design for multiple AGVs. The simulation model is implemented in Section 4. Discussions and conclusions are given in the last Section.

2. Proposed problem and modelling

Consider a jobshop manufacturing system with multiple AGVs performing material handling. There are some AGVs pre-specified for material handling. The AGVs guide paths may be occupied at the time that an AGV is sent to do the material handling. Therefore, finding a free path to fulfill the function is important. The manufacturing process plan for all jobs processing time is cleared. If an AGV arrives early, it should wait until the part processing is finished. The waiting time is related to the distance the AGV moves and the due date of jobs in shops. The overall problem is to determine the manufacturing schedule and routing for AGVs to minimize the total penalized earliness/tardiness and AGVs' waiting times at the shops in jobshop configuration. In this research, a new concept of conflict-free routing and scheduling is developed. Several AGVs carry parts amongst the work stations on the guide paths to process the manufacturing plan and satisfy product demands. "Conflict free designs" are mounted as guide paths distribution centers to prohibit AGVs' conflicts during movements. The intersection of guide paths is determined as the conflict free design. In these points, an AGV is directed according to the process plan sent from the control unit and concerning work stations' demands. The advantage of the conflict free designs is that AGVs operate nonstop according to the process plan without conflicts with others reducing the amortization costs.

We assume that the location of begin and ends, the AGVs, is fixed. Three different trajectory layouts are discussed. The first AGVs routing structure is a loop. It is illustrated in Figure 1a. The average trajectory length will be the sum of the AGVs movement length. The second routing structure is the one AGV is routed along the shortest route through a mesh. This procedure is illustrated in Figure 1b. For an appropriate mesh size, the minimum distance will always be the sum of the absolute difference in the x- and in y-direction (Δx and Δy, respectively). For comparison purposes, it is assumed that the shortest path is always obtainable [19]. The third routing structure is so that cross over is considered and AGVs are guided along a straight line between beginning and end nodes; the shortest possible path (Figure 1c). When no obstacles are present, and no other AGV is hindering, there is no need for evasive action. This will result in a straight-line connection, the shortest possible path. Although it is, in fact, a fixed path layout, this simplified model is used to study the potential of free-ranging trajectories.

A discrete event simulation model to compare the performance of different path planning strategies was designed, using Delphi in combination with the brain storming of several experts. This model consists of an operational environment with AGVs. Transport jobs are from different shops to others. For each AGV, a destination is drawn from a uniform distribution. AGVs travel with constant speed. Except for the destination choice, no stochastic behavior is modelled. Begin and end of the trajectories are discarded; obstacles are avoided using the proposed conflict free design model. All AGVs transportation times in the simulation are set to zero. Thus, only driving AGVs are considered. If handling times are modelled, more AGVs will be needed, although the traffic in the terminal area will be the same. For the mesh and loop strategy, only the average driven distance is used to compute a possible job performance without taking into account the effects of congestion. Hence, a linear relation between the number of AGVs and transport capacity is assumed. For the cross-strategies, the conflict free design is used to reduce the number of conflicts to zero. Thus, congestion results in non-linear behavior when a large number of AGVs is employed.

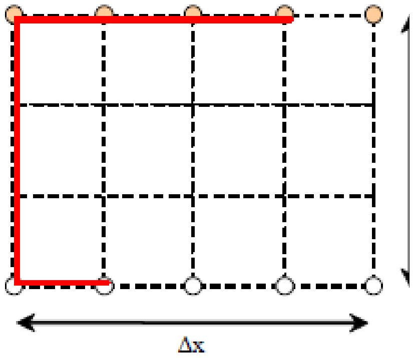

Figure 1(a). Loop routing distance

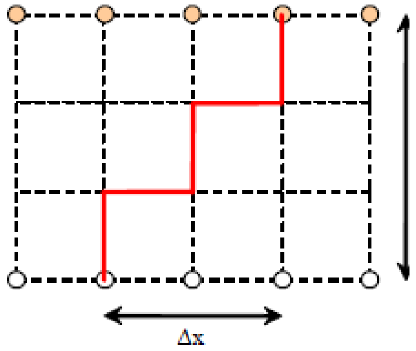

Figure 1(b). Mesh routing distance

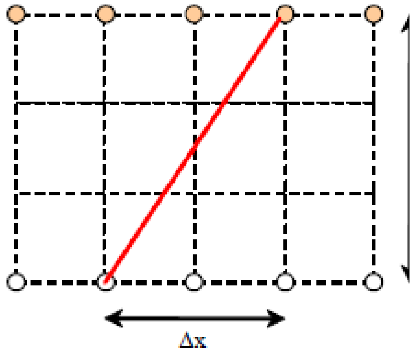

Figure 1(c). Cross-over distance

In Table 1, the results of the 'cross close' strategy, are presented. The number of AGVs differs between 1 and 50. The resulting number of executed handling tasks is almost linear with the number of AGVs below 25. In the case more than 25 AGVs are employed, the number of executed tasks decreases regarding congestion effects. In Table 2, the results of the “cross safe” strategy (having conflict free design) are shown. It is obvious that the large safety margins cause a faster and larger drop in transport capacity. In both tables, it is shown that both cross-over variants are safe, as expected. The so-called “path-conflicts” are the number of occasions that more than one AGV occupies the same path. Whether this is a problem or not depends of course on the layout of the terminal. In Table 3, the average transport distance for the three variants is shown. It is clear that the average distance for a handling task is much shorter for the cross-over variants. Hence, fewer AGVs are needed or, with the equal number of AGVs, the capacity of cross-over variants is much higher. The relation between the number of AGVs and the performance of the terminal is worked out. This performance is evaluated in the number of handling tasks completed. In the cross-over variants, the capacity will drop below the other variants when the number of AGVs is too high; the advantage of shorter distances is overwhelmed because of the density of AGVs on the terminal.

Table 1. Simulation Results of the “Cross Close” Variant

AGVs	**1**	**5**	**10**	**15**	**20**	**25**
jobs / hr	77	461	768	1011	1273	1430
path-conflicts	0	17	152	356	590	976
AGVs	**30**	**35**	**40**	**45**	**50**	
jobs / hr	1577	1715	1866	1920	2033	
path-conflicts	1491	1933	2418	2925	3569	

Table 2. Simulation Results of the “Cross Safe” Variant

AGVs	**1**	**5**	**10**	**15**	**20**	**25**
jobs / hr	77	425	633	781	883	920
path-conflicts	0	41	179	327	536	795
AGVs	**30**	**35**	**40**	**45**	**50**	
jobs / hr	972	1021	1061	1086	1129	
path-conflicts	1269	1436	1758	2138	2525	

The relation between the number of AGVs and the performance of the terminal is worked out. This performance is evaluated in the number of handling tasks completed. In the cross-over variants, the capacity will drop below the other variants when the number of AGVs is too high; the advantage of shorter distances is overwhelmed because of the density of AGVs on the terminal.

Table 3. Average Transport Distances (m)

Layout variant	Transport distance (m)
Mesh	243.72
Loop	440.11
Cross-over	181.53

3. Simulation-based Design of the AGV System

This step's key points include the critical factors of the system, design parameters affecting the system, and the categorization of these factors. Through careful consideration of the above key points, we can design a simulation model, determine the critical factors, and design parameters that are needed for the experimental design of the model. Then, we must consider the selection of the simulation language or software and the random-number seeds for each design point, the choice of the length of simulation time to reach a steady state, and the verification and validation of the simulation model [20]. Identification of critical factors: In simulation-based design, many critical factors arise. The mutual impact of critical factors might be difficult to predict. It might be hard to decide on one factor or parameter without considering other factors and parameters [20]. Typical critical factors in the design of the multiple AGV system include: (1) minimizing the congestion; (2) maximizing the vehicle utilization; (3) maximizing the reliability; (4) elimination of traffic problems; (5) minimizing the transportation costs; (6) maximizing the space utilization; etc.

Selection of the design parameter: The design parameters for the AGV system are involved in the simulation-based design with regard to multi-factorial analysis and the optimization of critical factors. The design of experiments encompasses design parameters and operational parameters [20]. Design parameters consist of fixed and changed parameters. To separate the fixed and changed parameters, we propose sensitivity analysis. The most general and simple method for analyzing the influence of design parameters is the one parameter-at-a-time analysis using a simulation model. This analysis consists of changing only one design parameter at a time, while keeping others constant, and observing the critical factor's behavior in the simulation model; this is undertaken for all relevant design parameters. Operational parameters are factors, such as the distance between shops and movement times for AGVs, conflict free design for each AGV, which are used to run the simulation. The techniques used in system analysis can be classified into two main categories: analytical and simulation-based. Analytical techniques are mathematical models such as queuing theory, multi-object linear programming, and heuristic algorithms. In this paper, we consider systematic methods that combine simulation-based analytic and optimization techniques to increase the accuracy of the specification of the design parameters. In addition, these methods are used to extend simulation-based analytic and optimization techniques for the derivation of new and more powerful quantitative results. Therefore, the design of experiments for AGVs includes multi-factorial and regression analyses for determining the design parameters of the system while simulation is used for verifying each parameter. We contend that this method increases the confidence in the results from simulation analysis [20].

In this paper, we present the regression metamodels as objective functions and upper and lower bounds on the critical factors and the design parameters as constraints for the selection of design parameters [20]. The regression metamodel is the typical model for simulation analysis. The regression metamodel is used to determine the predictor variables and the form of the function *f(x)*. A multiple regression metamodel expresses the dependent variable *y* as a function of multiple independent or predictor variables x_i*s*. Regression equations are obtained by using the coefficients of regression analysis with identified, significant main (of the form, x_i), interaction (of the form, x_ix_j), and square (of the form, x_i^2) effects for each critical factor.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ij} x_i x_j + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \varepsilon, \quad (1)$$

for $\varepsilon \sim N(0,\sigma^2)$.

where the error terms ε are assumed to be independent and normally distributed with a mean zero and variance of σ^2, and where σ^2 remains constant.

The steps of the proposed regression metamodel are listed below:

Step (1) Formulate the objective function using the regression metamodel.

Step 1.1. Specify the design parameter's upper and lower limiting value

$$l_i \le g_i(x_j) \le U_i, \quad (2)$$

$g_i(x_j)$: The design parameter for each i and j,

U_i: The upper limiting value,

l_i: The lower limiting value.

Step 1.2. Perform the multi-factorial analysis depend on design parameter's bound.

Step 1.3. Select the statistically significant design parameters using ANOVA.

Step 1.4. Implement regression analysis for the design parameters and critical factors, and conduct the regression metamodel.

Step 1.5. Formulate the multi-objective functions using the above steps

$$Z=\left[y_1(\bar{x}),y_2(\bar{x}),...,y_n(\bar{x})\right]. \tag{3}$$

Step (2) Define the constraints.

Step 2.1. Define the constraints on design parameters and critical factors by using the upper and lower limiting values and nonnegativity conditions as follows.

$$0\le l_i\le g_i(x_j)\le U_i. \tag{4}$$

Step (3) Determine the optimal solution for multi objective model.

Here, the proposed model is implemented using real production data in a simulation environment. The manufacturing system consists of, eight Work Stations (WS) with input and output buffers; Automated Guided Vehicle system (AGVs) with a fixed guide path, and Incoming and outgoing routes. The operation of the system model that is simulated in this paper is based on the following assumptions. WSs, AGVs, and routes may break down; that is, they are not continuously available for processing and moving; Each WS can process only one operation at a time; Operation processing times are deterministic; The time for moving parts between system input/output buffers and MCs is negligible; Each AGV in the material handling system can carry only one part at a time; Dispatching rule for the AGV is “the closest” rule. Parts enter the system through incoming routes based upon a distribution that is approximately calculated from the procedure for processing parts, number of machines, and system specifications. The number of processing routes required for each part-type is assumed in the three steps (e.g., Part 1: WS1 - WS4 - WS6), and then, when a part enters the system, the route is assigned according to the part-type. The guide-paths in AGVs are unidirectional. If there is no other pending work for the AGV upon its completion of the current work, the AGV finds a parking area for its idle state. When the processing of each part is completed, the part will leave the system through the outgoing routes.

4. Simulation Implementation

The simulation experiment is carried out in accordance with the procedure follows here. The first test used to verify the simulation result is called chi-square goodness of fit test. Its purpose is to test for distributional adequacy. The chi-square test is used to test if a sample of data came from a population with a specific distribution. An attractive feature of the chi-square goodness-of-fit test is that it can be applied to any univariate distribution for which one can calculate the cumulative distribution function. The chi-square goodness-of-fit test is applied to binned data (i.e., data put into classes). This is actually not a restriction since for non-binned data one can simply calculate a histogram or frequency table before generating the chi-square test. However, the values of the chi-square test statistic are dependent on how the data is binned. Another disadvantage of the chi-square test is that it requires a sufficient sample size in order for the chi-square approximation to be valid. The chi-square goodness-of-fit test can also be applied to discrete distributions such as the binomial and the Poisson rather than continuous ones. The Kolmogorov-Smirnov and Anderson-Darling tests are restricted to continuous distributions.

The chi-square test is defined for the hypothesis:
H_0: The data follow a specified distribution.
H_1: The data do not follow the specified distribution.

Test Statistic: For the chi-square goodness-of-fit computation, the data are divided into k bins and the test statistic is defined as,

$$\chi^2=\sum_{i=1}^{k}\frac{(O_i-E_i)^2}{E_i}, \tag{5}$$

where O_i is the observed frequency for bin i and E_i is the expected frequency for bin i. The expected frequency is calculated by,

$$E_i=N\left(F(Y_u)-F(Y_l)\right). \tag{6}$$

where F is the cumulative Distribution function for the distribution being tested, Y_u is the upper limit for class i, Y_l is the lower limit for class i, and N is the sample size.

This test is not valid for small samples, and if some of the counts are less than five, it is required to combine some bins in the tails. The significance level is α. The test statistic follows, approximately, a chi-square distribution with (k-c) degrees of freedom where k is the number of non-empty cells and c = the number of estimated parameters (including location and scale parameters and shape parameters) for the distribution + 1. For example, for a 3-parameter Weibull distribution, *c*=4. Therefore, the hypothesis that the data are from a population with the specified distribution is rejected if,

$$\chi^2 > \chi^2_{(\alpha,k-c)}, \tag{7}$$

where $\chi^2_{(\alpha,k-c)}$ is the chi-square percent point function with *k-c* degrees of freedom and a significance level of α .

In the above formulas for the critical regions, the convention that χ^2_{α} is the upper critical value from the chi-square distribution and $\chi^2_{1-\alpha}$ is the lower critical value from the chi-square distribution. Using the computations, the H_0 hypothesis is accepted while the test statistics is larger than p-value, i.e., the data follow exponential distribution. The only problem, as described above, is the small number of samples leading to apply another test. The Kolmogorov-Smirnov test is used to decide if a sample comes from a population with a specific distribution. The Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (ECDF). Given *N* ordered data points Y_1, Y_2, ..., Y_N, the ECDF is defined as,

$$E_N = \frac{n(i)}{N}, \tag{8}$$

where *n(i)* is the number of points less than Y_i and the Y_i are ordered from smallest to largest value. This is a step function that increases by *1/N* at the value of each ordered data point. An attractive feature of this test is that the distribution of the K-S test statistic itself does not depend on the underlying cumulative distribution function being tested. Another advantage is that it is an exact test (the chi-square goodness-of-fit test depends on an adequate sample size for the approximations to be valid).

Despite these advantages, the K-S test has several important limitations:

1. It only applies to continuous distributions.
2. It tends to be more sensitive near the center of the distribution than at the tails.
3. Perhaps the most serious limitation is that the distribution must be fully specified. That is, if location, scale, and shape parameters are estimated from the data, the critical region of the K-S test is no longer valid. It typically must be determined by simulation.

The Kolmogorov-Smirnov test is defined by:

H_0: The data follow a specified distribution

H_1: The data do not follow the specified distribution

The Kolmogorov-Smirnov test statistic is defined as:

$$D = \max_{1 \le i \le N}\left(F(Y_i) - \frac{i-1}{N}, \frac{i}{N} - F(Y_i) \right), \tag{9}$$

where *F* is the theoretical cumulative distribution of the distribution being tested which must be a continuous distribution (i.e., no discrete distributions such as the binomial or Poisson), and it must be fully specified (i.e., the location, scale, and shape parameters cannot be estimated from the data). The significance level is α . The hypothesis regarding the distributional form is rejected if the test statistic, *D*, is greater than the critical value obtained from a standard table. There are several variations of these tables in the literature that use somewhat different scaling for the K-S test statistic and critical regions. These alternative formulations should be equivalent, but it is necessary to ensure that the test statistic is calculated in a way that is consistent with how the critical values were tabulated.

The following tactical and operational issues have to be addressed in designing the AGV system: critical factors and design parameters. In this experiment, we consider AGV conflict free. AGV conflict free is the movement of AGVs so that no conflicts occur. Table 4 presents the specification of the critical factor that is considered in this study.

Table 4. Specifications of the critical factor

Critical factor		
Notation	Remarks	Unit
y_1	AGV conflict free	%

The design parameters for the simulation design and analysis of FMS with AGVs are used for the multi factorial analysis and the simulation-based optimization. The experimental design includes six design parameters and three operational parameters. To separate the changed and fixed parameters, sensitivity analysis is used for the design parameters. Table 5 presents the value and error of the design parameters for the sensitivity analysis. The AGV Acceleration, Failure Time and AGV Velocity hardly have an effect and the other four parameters affect the critical factor. The results of sensitivity analysis as shown in Table 6 implies that number of AGV correlates with AGV conflict free negatively and other parameters are interpreted in same method. By using the sensitivity analysis result, Table 7 presents the changed and fixed parameters of the design parameters. The operational parameters are presented in Table 8.

Table 5. Value and error of the design parameters for sensitivity analysis

Design parameters		**Value**	**Error**
AGV	Number of AGVs	6 EA (each)	2 EA
	Velocity	3 m/s	1 m/s
	Acceleration	1.1 m/s^2	0.2 m/s^2
	Deceleration	1 m/s^2	0.2 m/s^2
	Processing time	12 s	3 s
	Failure time	6 s	2 s

Table 6. Sensitivity analysis of design parameters versus critical factors

	Number of AGVs	Velocity	Acceleration
AGV conflict free	-0.145	-0.068	0.008
	Deceleration	Processing time	Failure time
AGV conflict free	0.074	0.103	0.008

Table 7. Specifications of the design parameters

Design parameters			
Changed parameters		**Fixed parameters**	
Number of AGV (x_1)	[4-8] AGVs	Acceleration	1.1 m/s^2
Velocity (x_2)	[1,3,5] m/s	Failure time	6 s
Deceleration (x_3)	[0.8,1,1.2] m/s^2		
Processing time (x_4)	[11,14,17] s		

Each of the 135 (5(x_1)*3(x_2)*3(x_3)3*(x_4)) case study scenarios is simulated for fifty independent replications with a run-length of twelve hours and a warm-up length of two hour per replication in ARENA simulation software. Table 8 presents the summary results of the analysis of variance (ANOVA) testing with F and p, where significance was set at the 5% level for main (x_i), interaction (x_ix_j) and square (x_i^2) effects of the design parameter.

We consider only the changed parameters of the design parameter, because the fixed parameters equally affect the critical factors. Objective functions are obtained by using the coefficients of regression analysis with the identified significant main, interaction and square effects for each critical factor. The result shows that all critical factor is affected by the all-design parameters including the effects of main, interaction and square. Constraints use the ranges of design parameters noted in Table 5.

Table 8. Specification of the operational parameters

Operational parameters	
Number of part-types (units)	5
Processing route for part and arrival distribution (s)	L1: WS1-WS4-WS6, Uniform (320,10)
	L2: WS1-WS2-WS6, Normal (340,10)
	L3: WS2-WS4-WS5, Triangle (420,440,460)
	L4: WS2-WS3-WS8, Normal (520,10)
	L5: WS1-WS3-WS7, Normal (600,10)
Processing time distribution for each work station	WS1: Normal (60,5); WS2: Normal (100,10) WS3: Normal (60,5); WS4: Normal (120,10) WS5: Normal (30,5); WS6: Normal (40,5) WS7: Normal (40,5); WS8: Normal (50,5)

Table 9. ANOVA for the critical factor (significant effects at the 5% level)

Critical factor	Sum of square	Degrees of freedom	Mean square
AGV conflict free	0.291	14	0.021
Critical factor	F value	$Pr>F$	R^2
AGV conflict free	95.234	0.00	0.917

5. Conclusions

The need for efficiency in the manufacturing industry has never been greater, with material, transportation and labor costs continuing to rise each year. Successful companies need to ensure that the costs associated with time, equipment and investments are being considered and optimized. At its core, manufacturing simulation is an inexpensive, risk-free way to test anything from simple revisions to complete redesigns, always with the purpose of meeting production goals at the lowest possible cost. Simulation also provides a means to test and implement principles of lean manufacturing and Six Sigma. In addition, unlike spreadsheet-based analysis and forecasting, manufacturing simulation offers a quick and efficient means to adjust parameters and re-simulate, saving valuable time and hastening results. We have presented a simulation design and analysis methodology for a multiple AGV system by introducing a new concept of conflict free design as a way of conflict avoidance. In the design steps for a real system, analysis that is based on simulation is an excellent choice, because simulation is one of the best techniques available for examining a complicated system such as those that occur in a real environment. A simulation model is developed and is employed to design an experimental scheme for multi-factorial and the regression analyses. Simulation is used to verify each parameter for simulation-based optimization. A validation test for the method is conducted. In this paper, the total numbers of simulation replications are 675 times that each of the 135 case study scenarios are simulated for fifty independent replications. However, the simulation-based analytic method is the metamodel of the simulation model, i.e., the designer develops a well-structured simulation model for real systems and the effects between the critical factors and the design parameters of this simulation model are modeled in mathematical forms by the regression model. The simulation-based optimization method is directly the metamodel of a real system. Hence, we considered that each method has advantages and disadvantages in time consumption and characteristics of a metamodel. Thus, a hybrid method is needed that combines a simulation-based analytic and optimization technique. To sum up, this method is confirmed to aid in the validation of the simulation-based design and analysis AGVs and to determine the most suitable types of design and analysis for application to material handling or manufacturing systems. Furthermore, this method produces the correct experimental results, ensures confidence in the application of the design parameters, and supports a robust design technique. For future research, the simulation-based methods of design and analysis can be expanded to incorporate other design parameters (e.g., machine breakdown, vehicle recharging) and critical factors (e.g., traffic problems, transportation cost, space utilization).

6. References

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Biography

Hamed Fazlollahtabar earned a BSc and an MSc in Industrial Engineering from **Mazandaran University of Science and Technology**, Iran, in 2008 and 2010, respectively. He received his PhD in Industrial and Systems Engineering from **Iran University of Science**. He has completed a postdoctoral research fellowship at **Sharif University of Technology**, Tehran, Iran, in the area of reliability engineering for complex systems in October 2016 to March 2017. He joined the Department of Industrial Engineering at **Damghan University**, Damghan, Iran, in June 2017 and currently is an Associate Professor of Industrial Engineering. He has been listed in top 2% scientists of the world in 2021 and 2022. He has been selected as the best researcher of all engineering disciplines in Iran 2022. He is on the editorial boards of several journals and on the technical committees of several conferences. His research interests are in robot path planning, reliability engineering, sustainable supply chain planning, and business intelligence and analytics. He has published more than 300 research papers in international books, journals, and conferences. He has also published ten books out of which seven are internationally distributed to academicians.