Original Research

Analysis of Critical Success Factors for the Application of AGVs in the Indian Industry

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Abstract
The logistics and e-commerce industry is undergoing a massive shift towards automation and intelligent systems. E-Commerce and logistics businesses are actively deploying automated guided vehicles in warehouses to improve efficiency and save time. Warehouse operations are usually labor-intensive and require large spaces; thus manufacturers increasingly demand automation systems for storing and retrieving goods with high levels of flexibility, high reconfigurability, and, possibly, low energy consumption Automated Guided vehicles are portable robots deployed in the industry to facilitate the transport of packages on the warehouse floor. Increasing technological advancements have enabled automated guided vehicles to become more versatile in their applications. While automated guided vehicles have become more adept at their function, their market acceptance depends on various critical success factors that play an important role in their widespread adoption. In the present research work, the authors aim to determine the relative importance of various critical success factors based on collected data. Fuzzy TOPSIS methodology was used to process the data and rank the critical success factors in order of c-factor value and conclusions were drawn.

Keywords - Automated Guided Vehicles; Flexible Manufacturing Systems; Fuzzy TOPSIS; Multi Criteria Decision Making

INTRODUCTION

Industry 4.0 is facilitating the automation of conventional production and business practices, by making use of the present-day smart technology existing in the market. The advent of new technologies introduced by Industry 4.0 such as large-scale machine-to-machine communication (M2M) and internet of things (IoT) has resulted in an industry-wide shift towards automation. This has been made possible due to better communication, self-monitoring and production of smart machines that can self-diagnose issues without human intervention.
The paradigm shift within the manufacturing system imposes modifications on distribution of work between humans and machines. Jobs in engineering and management fields require demand interdisciplinary skills for effectively executing and understanding the new change [1]. An important feature of Industry 4.0 is self-reliant manufacturing techniques with the aid of smart machines capable of carrying out functions intelligently. The key focus of these machines remains safety, versatility, flexibility and cooperation. The use of robots is growing to encompass manufacturing, logistics, and workplace control. It may be expected that maximum of the firms will step by step introduce the Industry 4.0 elements and build on current system and software program solutions, therefore not endangering the stableness in their manufacturing. [2]

The efficiency of production and manufacturing processes, depends on many factors. Transportation of materials is one such factor that significantly affects the efficiency. With increasing global competition, it becomes imperative for companies to optimize the efficiency of the logistics processes. Automation of the labour-intensive warehouse operations that are usually spread over large spaces, will have manifold benefits. It will not only increase the flexibility of the systems, but also decrease the energy consumption and lead to high reconfigurability [3]. Today's industrial activities have been merged with the robotics and automation world. Automatics systems like conveyor belt systems, automated guided vehicles (AGV) on fixed tracks, automated storage and retrieval systems (AS/RS) are being deployed in the production process to facilitate the movement of goods and materials. Between all types of robot, the AGV robot has a special place between others and improvement in technology helps this design to grow and become more helpful in various applications.

The AGV robot is a programmable mobile robot integrated sensor device that can automatically perceive and move along the planned path. It finds a wide variety of applications in numerous areas ranging from e-Commerce Warehouses to advanced package management and handling systems. With an all-time high penetration of eCommerce in daily life, eCommerce businesses like Amazon, eBay amongst others leverage high accuracy and efficiency in the management, storage, handling and retrieval of packages to gain competitive advantage, making AGVs increasingly important. Advances in robotics and driverless systems technologies have led to the advent of guided vehicles, called AGVs that offer increased capability and versatility in regards to its applications. In contrast to the formerly prevalent traditional automatic systems, AGV systems offer flexible deployment and the ability to reschedule and re-route in real time, thus making them an attractive alternative. Compared to fixed conveyor belts, AGVs provide flexibility in the movement of the package while maintaining higher efficiency and accuracy, hence reducing the need for human intervention as it can retrieve and place the package to different stages.

AGVs are widely applied in various kinds of industries including manufacturing factories and repositories for material handling. After decades of development, it has a wide application due to its high efficiency, flexibility, reliability, safety and system scalability in various tasks and missions. Consequently, it has an extensive popularity in the fields of industry manufacture, such as: warehousing, logistics and factory. AGVs are serving in hospitals for medical service such as delivering food and drugs and collecting medical and biological waste and serving in airports for baggage transport. AGV is also used in some places that are dangerous for humans to reach. AGVs are used in nuclear plants for radioactive material and nuclear waste handling. They are also used in pharmaceutical industries to handle hazardous products.[4]

The wave of the fourth industrial revolution brought with it the concepts of hyper connectivity and superintelligence. These concepts, it is believed, will have a greater impact on the societies than ever witnessed by the mankind. The integration of Artificial Intelligence, Internet of things, big data, clous systems, will enable a connection between all the products and services, ultimately making the factories "smart". AGVs will further facilitate the process, by using big data processing and deep learning, to increase the efficiency of the manufacturing units.

An increase in the B2C commerce activities with large number of orders placed online has had a great impact on warehousing activities. A flexible and time-efficient warehouse system is essential for smooth functioning of logistics. Automated storage/retrieval systems (AS/RSs) provide a viable solution for the same. [5,6] AGV operates all day long continuously that cannot be achieved by human workers. Therefore, the efficiency of material handling can be boosted by having the collaborating task with a number of AGV. Some of the advantages that AGVs bring to the table include increase in efficiency, worker safety and a decrease in energy cost. Apart from these advantages, AGVs they strengthen the economic, social and ecological impact. However, most supply chains in the Indian industry are still inept in these areas. Another roadblock in the implementation is the investment required for implementing the technology-based solution in manufacturing processes. Industry 4.0 technologies such as additive manufacturing, cloud computing, IoT enabled solutions, AGVs, necessitate a huge investment.

The focus on shifting towards automated techniques, capping increasing labour costs has led to the increasing popularity of AGVs in supply chains. Despite being such a promising alternative, industry wide deployment of AGVs remains an uphill task. Market acceptance of AGVs depends on a lot of secondary factors that will further facilitate the assimilation of AGVs in Warehouses and Production Lines across the industry. Lately, there has been an increasing interest in the research on the application of AGVs in the Indian context.

The objective of this study is to analyse the main critical success factors behind the implementation of AGVs based on a systematic review of the literature, surveys and discussions with industrial experts to understand the current status of AGV adoption in the industry and the key issues to efficiently use the AGVs are presented. The critical success factors are enlisted in Section 2. Further Fuzzy TOPSIS is used to rank the factor in Section 3. Conclusions and managerial implications have been discussed in Section 4.

CRITICAL SUCCESS FACTORS

Through a detailed and comprehensive literature review, and discussions with experts from various industries and backgrounds, a list of nine success factors critical to the implementation of AGVs in Indian industries were identified. Critical success factors are the attributes or the features that are required to ensure the successful implementation of a process, concept or strategy. Table I enumerates the factors identified, with a brief description of each factor.

TABLE I
CRITICAL SUCCESS FACTORS IN CONSIDERATION

	Factor	Description
S-1	Safety of the shop floor	Factors like ergonomic aspects, maximum weight of handled units, maximum allowed speed and wellbeing of shop floor staff [6]
S-2	Economic Viability and ROI	Economic Feasibility analysis and cost-benefit analysis are essential. Factors like operating costs, labour costs and other KPIs have to be taken into consideration. [7] Good payback for AGVs is under 5 years. If the ROI for AGVs is under this, there might be areas in the industry that could be substantially improved with automation [8]
S-3	Environmental Factors	Many kinds of hazardous materials are present in the industrial and general indoor environments, including toxic and harmful gases. AGVs can be implemented in such cases where the working conditions are not suitable for humans. [9]
S-4	Ability to process large amount of data	To design and test selected logistics processes, it is important to gather and analyse large amounts of data, in order to design an alternative that best fits the process. [10]
S-5	Organisational aspects	Support of the top management, required training programs, work standardization and traffic frequency. [6]
S-6	Reorganisation to make shop floors suitable for implementation	Forklifts and hand carts are the traditional material handling equipment in a warehouse. In order to successfully implement AGVs, it is important to reorganize the plant layout.
S-7	Efficient Traffic-Control	Performance and interaction of design factors like number of vehicles used in the system, location of pick up and drop points. [11] A deadlock means that several AGVs cannot move any further because each of them has to occupy the location currently occupied by another vehicle in the same set, resulting in a collapse of the entire system. [12]
S-8	Energy Consumption	In India, firms respond to increases in electricity prices by shifting to products with less electricity-intensive production processes. [13]
S-9	Repetitiveness	AGVs make the most sense in operations that deal with repetitive tasks.

METHODOLOGY

Fuzzy TOPSIS is used for ranking the CSFs for the application of AGV's in the Indian Industry. The technique has been previously used in reverse supply chains for analyzing the disposition strategies and prioritizing strategic factors [14-15]. Fuzzy TOPSIS has also been employed to evaluate "third party logistics" and make decisions related to supplier selection [16-18]. After collecting the data in linguistic terms, it is first converted to a fuzzy scale. This conversion factor essentially differentiates the technique from the Fuzzy TOPSIS methodology. The step wise procedure for the methodology is described below:

I. Collection of data & conversion to fuzzy numbers:

The first step is to collect the data through surveys in the form of linguistic terms. The respondents are given the options on a 5-point scale with increasing importance as we move from 1 to 5 [16]. After collecting the data in linguistic terms, the data is converted into fuzzy numbers.

II. Creation of fuzzy decision matrix:

The data collected in step 1 is used to make a fuzzy decision matrix. The fuzzy decision matrix is further converted into triangular fuzzy numbers.

$$D = \begin{bmatrix} Y_{11} & Y_{12} & \dots & Y_{1j} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & \dots & Y_{2j} & \dots & Y_{21} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ Y_{i1} & Y_{i2} & \dots & Y_{ij} & \dots & Y_{in} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ Y_{m1} & Y_{m2} & \dots & Y_{mj} & \dots & Y_{mn} \end{bmatrix}$$

Where, $Y_{ij} = (d_{ij}, e_{ij}, f_{ij})$ is a triangular fuzzy number for the linguistic term allocated by i^{th} respondent to the j^{th} factor. i = 1, 2, ..., m is the number of people surveyed, and j = 1, 2, …, n is the number of strategic factors. The table below shows the scale in terms of triangular fuzzy numbers used for each linguistic term.

TABLE II
SCALE FOR LINGUISTIC TERMS

Linguistic Terms	Fuzzy Numbers
Very low	(0.0, 0.1, 0.3)
Low	(0.1, 0.3, 0.5)
Medium	(0.3, 0.5, 0.7)
High	(0.5,0.7,0.9)
Very Hight	(0.7, 0.9, 1)

III. Conversion into fuzzy un-weighted matrix

A fuzzy decision matrix is converted into a fuzzy un-weighted matrix (W’) using the following relationship [1].

$$W' = [r_{ij}]_{m\times n;} = \left(\frac{d_{ij}}{c_{j*}^{*}}, \frac{e_{ij}}{c_j^*}, \frac{f_{ij}}{c_j^*}\right) \; and \; W' = [r_{ij}]_{m\times n;} = \left(\frac{d_j^-}{d_{ij}}, \frac{d_j^-}{e_{ij}}, \frac{d_j^-}{f_{ij}}\right) \quad (1)$$

For benefit criteria, $c_{j*}^{*} = \max_i c$ *and* for cost criteria, $d_j^- = \min_i d_{ij}$

IV. Step 4

The weighted normalized decision matrix is obtained using the equation below [1].

$$V = W'*W \quad (2)$$

Where, W is the weight of vector criteria and $V = [v_{ij}]_{m\times n;}$

i = 1,2, …, m; j = 1, 2, …, n

V. Step 5:

Calculate fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS): The following expression yields the FPIS (A*) and FNIS (A-)

$$A^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \dots \tilde{v}_n^+) = \max\{v_{ij3}\} \quad (3)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots \tilde{v}_n^-) = \min\{v_{ij3}\} \quad (4)$$

VI. Step 6:

Calculate Euclidean distance from A+ and A-: The Euclidean distance expression for the calculation is given as:

$$d_i^-(\tilde{v}_{ij}, \tilde{v}_j^-) = \sqrt{\frac{1}{3}\left[(a_{ij} - a_j^-)^2 + (b_{ij} - b_j^-)^2 + (c_{ij} - c_j^-)^2\right]} \quad (5)$$

for the distance from the negative ideal solution, and

$$d_i^+(\tilde{v}_{ij}, \tilde{v}_j^+) = \sqrt{\frac{1}{3}\left[(a_j^+ - a_{ij})^2 + (b_j^+ - b_{ij})^2 + (c_j^+ - c_{ij})^2\right]} \quad (6)$$

for the distance from the positive ideal solution.

VII. Step 7: Calculate the closeness co-efficient:

The rank allotted is directly proportional to closeness co-efficient. The following expression is used to calculate closeness co-efficient:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (7)$$

VIII. Step 8:

Rank the criteria on the basis of the values obtained.

RESULTS & DISCUSSION

I. Data Collection

The first step in the procedure to rank the critical success factors for the application of AGVs was to collect unbiased data using a detailed questionnaire. Four experts, two from the industry and two from academia were contacted to get an unbiased view. Each of the expert rated the challenge on a five-point scale ranging from very low to very high. The data collected, using Google forms, was then imported into a spreadsheet and analysed.

II. Illustration

The step-by-step procedure as described in the previous section has been illustrated in the following section. Table II was used to convert the responses obtained into linguistic. A fuzzy decision matrix D is then obtained as shown in Table III:

TABLE III
FUZZY DECISION MATRIX

	E1	E2	E3	E4
S-1	0.7, 0.9, 1	0.5,0.7,0.9	0.3, 0.5, 0.7	0.7, 0.9, 1
S-2	0.5,0.7,0.9	0.7, 0.9, 1	0.5,0.7,0.9	0.7, 0.9, 1
S-3	0.1, 0.3, 0.5	0.0, 0.1, 0.3	0.1, 0.3, 0.5	0.3, 0.5, 0.7
S-4	0.5,0.7,0.9	0.7, 0.9, 1	0.5,0.7,0.9	0.3, 0.5, 0.7
S-5	0.3, 0.5, 0.7	0.5,0.7,0.9	0.7, 0.9, 1	0.1, 0.3, 0.5
S-6	0.5,0.7,0.9	0.0, 0.1, 0.3	0.1, 0.3, 0.5	0.3, 0.5, 0.7
S-7	0.0, 0.1, 0.3	0.0, 0.1, 0.3	0.1, 0.3, 0.5	0.1, 0.3, 0.5
S-8	0.3, 0.5, 0.7	0.1, 0.3, 0.5	0.0, 0.1, 0.3	0.0, 0.1, 0.3
S-9	0.0, 0.1, 0.3	0.0, 0.1, 0.3	0.1, 0.3, 0.5	0.3, 0.5, 0.7

The fuzzy decision matrix has been then converted into un-weighted fuzzy matrix (W') using Equation 1(Table IV).
The weighted normalized matrix has been evaluated by multiplying the un-weighed fuzzy decision matrix with the weights. Note, equal weights have been assigned to all the four experts. The distance of each of the critical success factor from positive ideal solution is evaluated using Equation 3. Similarly, the distance of each of the critical success factor from negative ideal solution is evaluated using Equation 4. Table VI and VII show the results of the calculations.
For each of the factors, distance from positive and negative ideal solution is calculated which is represented by d+ and d- (Table VI & Table VII). After calculating the relative closeness using equation 5, the factor with the largest value among the nine

factors is ranked 1 and the one with the lowest value is ranked 9th. [16] The ranking of the critical success factors is shown in table 8.

TABLE IV
UN-WEIGHTED FUZZY MATRIX R

		1			2			3			4	
S-1	0.7	0.9	1	0.5	0.7	0.9	0.3	0.5	0.7	0.7	0.9	1
S-2	0.5	0.7	0.9	0.7	0.9	1	0.5	0.7	0.9	0.7	0.9	1
S-3	0.1	0.3	0.5	0.0	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.7
S-4	0.5	0.7	0.9	0.7	0.9	1	0.5	0.7	0.9	0.3	0.5	0.7
S-5	0.3	0.5	0.7	0.5	0.7	0.9	0.7	0.9	1	0.1	0.3	0.5
S-6	0.5	0.7	0.9	0.0	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.7
S-7	0.0	0.1	0.3	0.0	0.1	0.3	0.1	0.3	0.5	0.1	0.3	0.5
S-8	0.3	0.5	0.7	0.1	0.3	0.5	0.0	0.1	0.3	0.0	0.1	0.3
S-9	0.0	0.1	0.3	0.0	0.1	0.3	0.1	0.3	0.5	0.3	0.5	0.7

TABLE V
PRODUCT OF UN-WEIGHTED FUZZY MATRIX WITH WEIGHTS

		1			2			3			4	
S-1	0.175	0.23	0.23	0.13	0.175	0.225	0	0.125	0.175	0.18	0.225	0.250
S-2	0.125	0.18	0.225	0.18	0.225	0.250	0.13	0.175	0.225	0.175	0.225	0.250
S-3	0.025	0.08	0.125	0	0.025	0.075	0.03	0.075	0.125	0.075	0.125	0.175
S-4	0.125	0.18	0.225	0.18	0.225	0.250	0.13	0.175	0.225	0.075	0.125	0.175
S-5	0.075	0.13	0.175	0.13	0.175	0.225	0.18	0.225	0.250	0.025	0.075	0.125
S-6	0.125	0.18	0.225	0	0.025	0.075	0.03	0.075	0.125	0.075	0.125	0.175
S-7	0.000	0.03	0.075	0	0.025	0.075	0.03	0.075	0.125	0.025	0.075	0.125
S-8	0.075	0.13	0.175	0.03	0.075	0.125	0	0.025	0.075	0	0.025	0.075
S-9	0.000	0.03	0.075	0	0.025	0.075	0.03	0.075	0.125	0.075	0.125	0.175

TABLE VI

	1	2	3	4	d+
S-1	0.79	0.83	0.876	0.78	3.278
S-2	0.83	0.78	0.826	0.78	3.220
S-3	0.93	0.97	0.926	0.88	3.695
S-4	0.83	0.78	0.826	0.88	3.312
S-5	0.88	0.83	0.784	0.93	3.412
S-6	0.83	0.97	0.926	0.88	3.595
S-7	0.97	0.97	0.926	0.93	3.786
S-8	0.88	0.93	0.967	0.97	3.736
S-9	0.97	0.97	0.926	0.88	3.736

TABLE VII

	1	2	3	4	d-
S-1	0.48	0.46	0.484	0.46	1.888
S-2	0.46	0.46	0.464	0.46	1.855
S-3	0.51	0.53	0.507	0.48	2.032
S-4	0.46	0.46	0.464	0.48	1.876
S-5	0.48	0.46	0.463	0.51	1.919
S-6	0.46	0.53	0.507	0.48	1.990
S-7	0.53	0.53	0.507	0.51	2.083
S-8	0.48	0.51	0.534	0.53	2.059
S-9	0.53	0.53	0.507	0.48	2.059

TABLE VIII
FUZZY DECISION MATRIX

	d+	d-	c factor
S-1	3.278	1.888	0.365475
S-2	3.22	1.855	0.365544
S-3	3.695	2.032	0.354862
S-4	3.312	1.876	0.361564
S-5	3.412	1.919	0.359925
S-6	3.595	1.99	0.356255
S-7	3.786	2.083	0.354904
S-8	3.736	2.059	0.355341
S-9	3.736	2.059	0.355341

TABLE IX
FUZZY DECISION MATRIX

	Description	c factor
S-2	Economic Viability and ROI	0.365544
S-1	Safety of the shop floor	0.365475
S-4	Ability to process large amount of data	0.361564
S-5	Organisational aspects	0.359925
S-6	Reorganisation to make shop floors suitable for implementation	0.356255
S-8	Energy Consumption	0.355341
S-9	Repetitiveness	0.355341
S-7	Efficient Traffic-Control	0.354904
S-3	Environmental Factors	0.354862

CONCLUSION

An industry-wide shift towards automation and efficiency has sparked substantial interest in literature on Industry 4.0 technologies. In the logistics and e-commerce industry, widespread adoption of AGVS is imminent. Therefore, it becomes essential to evaluate the scope and impact of various critical success factors with regards to the market acceptance of AGVs.
The present work identifies the critical success factors for implementing AGV technologies in Indian Industries. Ranking of those factors basis their priority is done using Fuzzy TOPSIS. In the Fuzzy TOPSIS approach, it has been identified that economic viability and RoI (S-2) is ranked as the most important factor followed by the safety of the shop floor (S-1). Environmental Factors (S-3) is ranked as the least important factor. Fuzzy TOPSIS is chosen as the appropriate tool for ranking

the factors as it helps us to get rid of vagueness in human judgement. One of the limitations of Fuzzy TOPSIS is that there is a bias in the responses given by the experts. To eliminate this, each factor was explained and discussed in thorough depth with each of the expert interviewed.

Economic Viability and return on investment were ranked as the most crucial factors contributing to the adoption of AGVS, whereas, Environmental factors ranked as least important. This further implies that targeted research & development towards CSFs with higher c-value will lead to accelerated adoption of AGVs. Furthermore, it highlights that while sustainability, energy consumption and environmental impact might be important goals in the bigger picture, they rank low with regards to industry adoption. Therefore, further studies aimed at improving the environmental impact or the energy consumption of AGVs will hold better chances of adoption in the industry if they also positively address the higher-ranked CSFs.

The study done in the paper can be used as an effective roadmap for managers and manufacturers in the industry to optimise their processes by ensuring a smooth adoption of AGVs. A focus on factors that are ranked higher than the other factors can go a long way in making the adoption process easier.

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