TQM BASED PRODUCT DEVELOPMENT FOR COMPONENT HANDLING IN SMES: A CASE STUDY

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Abstract:
Small and Medium enterprises (SMEs) are adopting new techniques with the advent of Industry 4.0. The companies' including SMEs manufacturing quality-oriented products as per customer requirements arevastlybenefited owing to the amalgamation of Industry 4.0 with quality management. Methodic material handling has great relevance and effective utilization of material handling devices can be ensured with the implementation of automation technologies. The product quality of handling device employed can be enhanced by adopting Total Quality Management (TQM) approach thereby affirming the concept of Automated Guided Vehicle (AGV) for SMEs. The paper highlights on data collected for currently employed material handling devices at SMEs and problems associated being analyzed using TQM tools and techniques.An attempt to eliminate causes led to proposing an AGV to handle multiple components in SMEs with associated features for reducing operator fatigue and handling times. The results of the survey, significance of TQM tools and techniques application for adoption of various features of AGV and material handling times are also presented in the paper.

Keywords*:Automated Guided Vehicle, Kano model, Material handling, Quality Control Tools, Total Quality Management*

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1. Introduction:

Quality can be viewed through varied perspectives which are currently customer oriented but the necessity of digitalization and competitiveness requires quality to be inclusive of multiple quality management concepts to serve wide-ranging customer requirements. Quality management has emerged from the manufacturing industry that is undergoing changes inthe last few years in terms of customer preferences and functions.[1]One of the major activities in manufacturing is material handling which accounts for about 80 % of production time and 15-75 % of production cost. The businesses are thus compelled to investigate and implement apt material handling systems with an element of automation in themto address these issues.[2]This need offers abundant scope for researchers to build modular handling systems for these business units. Themanufacturing and related activities can be made agile and receptive to the flexible customer requirements by integrating advancedtechnologies like cyber physical systems, machine learning, robots, sensors, etc. with Total Quality Management (TQM) outlook forthe development of novel technology products.[3]TQM tools and techniques were adopted in this product development process of building an Automated Guided Vehicle (AGV) for handling multiple sample components manufactured in SMEs. AGV is a self-driven means of transportation that facilitates the transfer of components across petite or longer locations accurately with a reduction in handling times and human fatigue. Such smart vehicles can even bestow connectivity among machines lessening their downtime with an ability to adjust production according to customer preferences and demands.[4]These varying customer demands offer abundant scope for researchers to build modular handling systems for innovative enterprises.

Six Sigma methodology accomplishes this by eliminating product defects through effective problem definition; data measurement and analysis and process control which result in higher customer satisfaction.[5] It is more often been adopted by bigger industries but can be beneficial for SMEs too. Quality control tools play a crucial role in problem identification, cause recognition and quality improvement, selection of best alternatives during product planning, etc.in industries. Despite this there are many petite manufacturing organizations not employing even the Basic Quality Control (QC) tools for above activities. Another imperative factor for satisfying customersis obtaining a clear picture of customer requirements and their priorities and incorporating them intoevery product being developed.[6]Kano model using Voice of Customer information assistsin categorizing the customer requirements as basic, competitive and innovative while building them in the product. [7][8] Hence these tools and techniques were selected for implementation in the case study of building an AGV for material handling. This paper defines a detailed framework for putting up a material handling systememploying TQM tools and techniques. Section 2 represents TQMtools and techniques applied for product developmentduring the case study while Section 3 includesoutcomes of tools and techniques and the handling times thus highlighting the advantages of AGV over existing material handling devices. The paper is concluded by Section 4 highlighting the interpretations of the work carried out for SMEs.

2. Materials and methods:

An industrial survey was conducted in SMEs with an objective to congregate information about the material handling devices currently deployed in these units, difficulties pertaining to them and the requirements for developing the new ones. About 60 responses were collected through a carefully designed questionnaire and detailed interaction with personnel of various job positions, work experience and departments for getting a wider perspective about handling systems. This section establishes correlation between the TQM tools and techniques to the data measured during the survey.

2.1. Six Sigma

Material handling activity in manufacturing contends as one of the reasons for productivity enhancement and thus requires continuous improvement. Six sigma results in cost savings by creating quality products through reducing process defects and variations and hence is preferred while developing or modifying systems or products. It has two methodologies based on the focus for improvement viz. DMAIC (Define-Measure-Analyze-Improve-Control) and DMADV (Define-Measure-Analyze-Design-Verify). DMADV is preferred for new product development while DMAICmethodology was selected for this case studyas an existing business process or handling device performing inefficiently was undergoing improvisation.[9]

Define stage includes specifically defining the problem and opportunities for improvement including focus, scope and goal of the project. With subsequent interaction with the industry experts, the problem here was defined as the "Development of an automated and modular handling system for multiple components in manufacturing industries that would reduce operator fatigue, job damage and handling time and cost". The Measurestage is meant for measuring the problem specification through data collection and thus institutes the process performance baselines. This data is compared with post project results to verify the effectiveness of the improvements made. Analyze step used to identify the causes of problems and prioritize the root causes signifies the importance of probablereasons.

Improve stage includes proposing, comparing and implementing solutions for each of the prioritized problems and testing these alternatives on prototypes and final deployment of solutions on large scale. Various quality management concepts like QC tools,the Kano model and Poka Yoke were used during these stages and are discussed in upcoming relevant sections. The final Control stage includes assessment of the target achieved, process monitoring and control and incorporating a corrective action in case of sudden arise of problems with successive documentation of the same.

2.2. Quality Control Tools:

After precisely defining the material handling problem in industries, measure and analyze stages of Six Sigma were functioned using various QC tools. They can be applied at any stage of developing the productand even during post sales service and marketing.[10]These tools assist in measuring and analyzing quality problems, suggesting and testing alternatives and process implementation and control. The tools should be carefully chosen and tools used in combination offer utmost benefits rather than using them individually.The data collected in the survey was presented using Check sheets, Histogram and Pareto diagram. Check sheets provided data collection in a simple way but this data needed a meaningful classification which can be done through Pareto diagram and Histogram. Histogram displays variations in data collected better than tabular format while Pareto diagram classifying the parameters in vital few and useful many is one of the most potent decision tools.[11]Table 1 illustrates the check sheet for existing material handling devices in the industries surveyed while table 2 shows the check sheet for problems faced with these handling devices.

Table 1: Check sheet for existing material handling devices in industries surveyed

Sr. No.	Material Handling Device Types	Responses	Frequency
1	Forklift	||||| ||||| ||||| ||||| ||||| |||||	30
2	Conveyor	||||| ||||| ||||| |||	18
3	Pallet Stacker	||||| |||||		11
4	Gantry / Overhead Cranes	||||| ||||| ||||| ||||| ||	22
5	AGV	||||	4
6	Others	||||| ||||| ||||| |||||		21

In the Pareto diagram, data is represented in descending order of frequency with vital parameters on the left and thus the key types of devices used and major problems related to them were identified which assisted in problem definition in the improvement process. Figure 1 shows the Pareto diagram for existing material handling devices and figure 2 illustrates the Pareto diagram containing problems encountered with these systems. The X-axis represented the parameters while Y-axis represented the frequency of these parameters in all these figures.

Table 2: Check sheet for problems with existing handling systems

Sr. No.	Problems with Existing Material Handling Systems	Responses	Frequency
1	Shortage in supply of material	IIIII IIII	9
2	High Cost	IIIII IIIII I	11
3	Operator fatigue	IIIII IIIII IIIII IIIII IIIII IIIII II	32
4	More Time Consumption	IIIII IIIII IIIII IIIII I	21
5	Accidents	IIIII IIIII IIIII IIIII II	18
6	Poor monitoring and control over system	IIIII III	8
7	Damage to jobs during handling	IIIII IIIII IIIII IIIII III	23
8	Mixing of various jobs makes their sorting difficult	IIIII IIIII I	11
9	Others	IIIII IIIII I	11

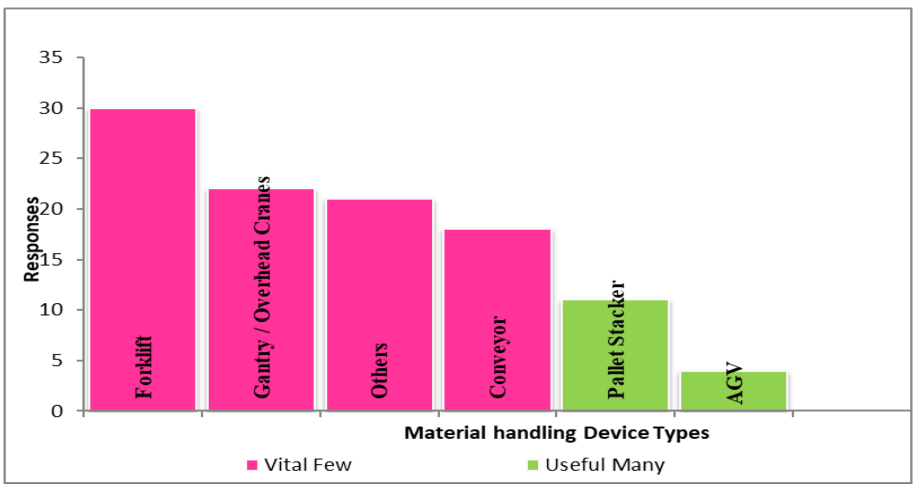

Fig.1.Pareto diagram for existing material handling systems

Figure 1 represented that 69% of existing handling systems, treated as vital few are manually operated and need intense labor involvement leading to most of the problems mentioned in Figure 2 and the use of automated devices is very limited i.e., around 4% which should be augmented. Figure 2 points out that operator fatigue, damage to jobs, higher handling times and accidents on the floor during handling comprise of about 65% of the total problems and need to be resolved on priority. Avoiding the mixing of components was another critical problem as SMEs dealt with multiple components in smaller quantities which were more likely to be mixed during manual handling.

The problem was then analyzed in detail to establish the source of the problem and Fishbone diagram being unidirectional, Relations diagram was preferred to have a multidirectional approach to achieve the root cause for inefficient material handling. Figure 2 illustrates the Relations diagram for handling problems where poor material handling is the Root Effect with maximum arrows going towards its box. Operator fatigue is the Root Cause as maximum arrows are moving out of this box and thus the tool portrays interrelation among various aspects in the multifaceted situation. This root cause is also projected in figure 3.

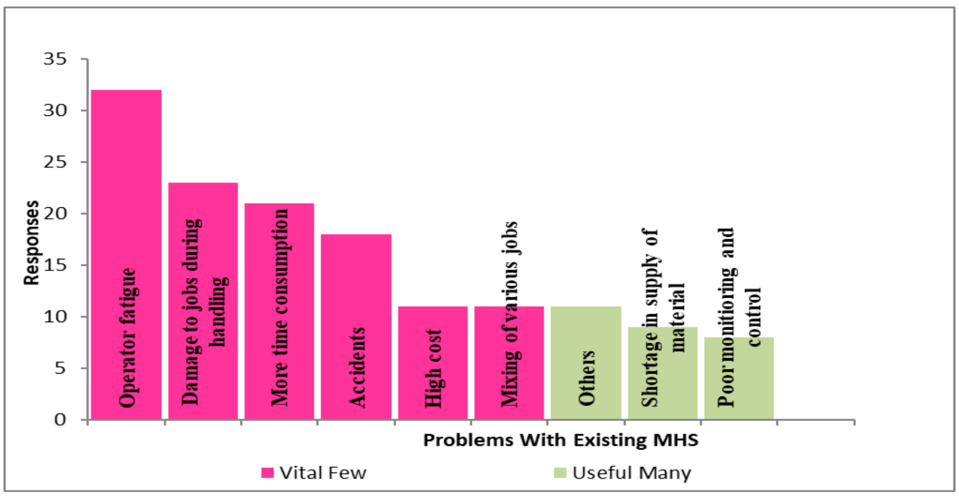

Fig. 2. Pareto diagram for problems with existing material handling systems

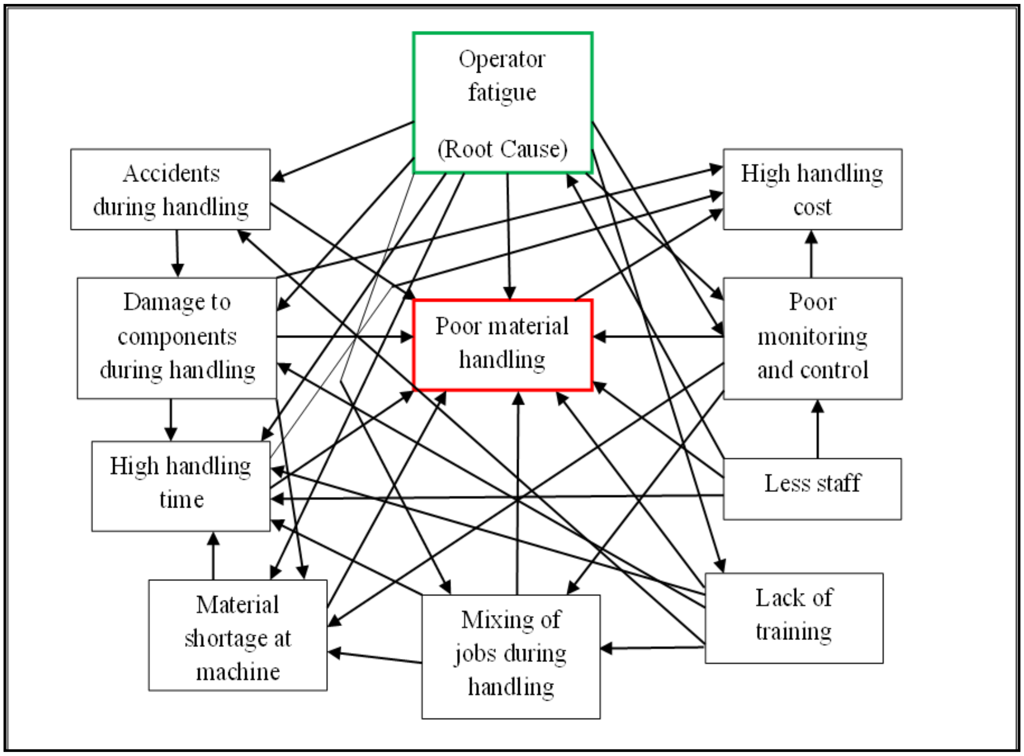

Fig. 3. Relations Diagram for Root Cause of handling problem

One of the major solutions for reducing operator fatigue during material handling is incorporating automation in handling devices thus lowering the human intervention. The initial cost for such automated devices is more but they offer higher accuracy, flexibility and safety with reduced operating costs. The histogram as shown in figure 4 signifies the automation recommendation trend and it is seen that 93% of employees interacted agreed for automation to be introduced in handling devices for in-house logistics.

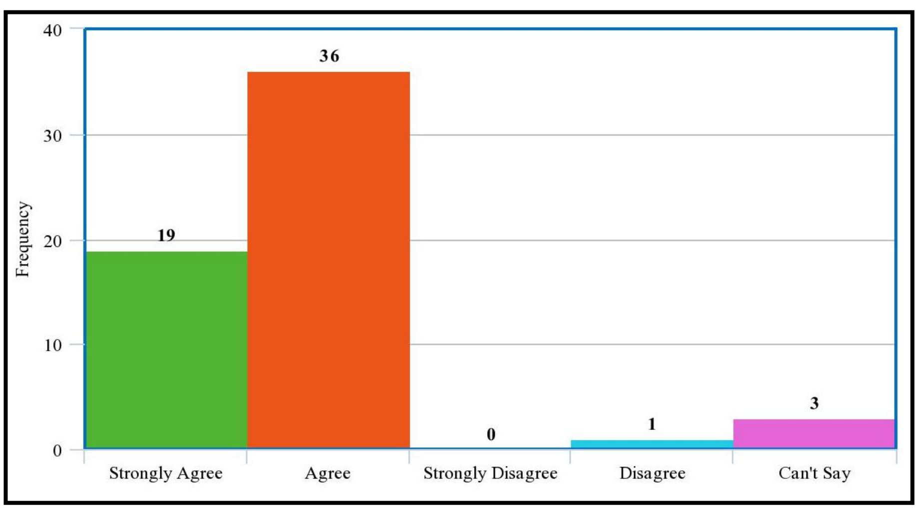

Fig.4. Histogram for automation recommendation trend

As a part of product improvement, it was decided to modify and develop a working model of a material handling device with the implementation of automation for precise motion and process control. The choice of appropriate material handling device relies on the quantity and type of material and distances through which it is to be transferred. The SMEs where the survey was conducted mainly dealt with a large variety of products in fewer quantities of products handled across sufficiently large distances thus Unit load AGV was selected as a material handling device which is depicted in Figure 5.[12]

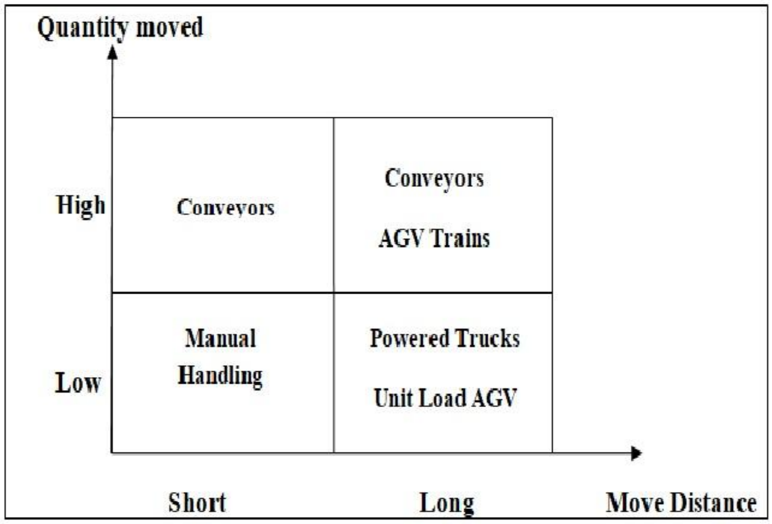

Fig. 5. Material handling device selection criteria

An AGV archetype built handled three types of components namely Nut, Spindle and Valve. It moved across 5 workstations namely Lathe, Milling, Grinding, Threading and Assembly followed by a Dispatch and the operational sequence for each component type was pre-determined. Line follower navigation method was employed for the AGV movement while it was electronically controlled for better accuracy and safety. It was meant to be a modular system which could be accommodated with minor modifications in most manufacturing industries for handling and storing multiple components produced.

Another QC tool namely flowchart provided a simple visual representation of sequential steps in a process and documented complex activities which can be tracked for superior process control thus making implementation of various tasks uncomplicated and defect free.[13] It was exercised here to demonstrate the travel sequence of AGV in terms of operational paths for any of the three components selected for concerned operators. If any of the set operational sequences is not rightly pursued or the transit of AGV is halted due to any obstacle the operator can verify with the flowchart and appropriate corrective action could be taken. This would ensure that components undergo every course of action as per the process plan which mainly reduced the errors due to incorrect handling and mixing of components too. Figure 6 illustrates the flowchart tool illustrating the operational methodology for AGV developed.

From Figure 6 it is thus evident that for manufacturing Nut, the raw material was machined on Lathe, Milling and Threading machines while Valve component was processed on Lathe and Grinding machines only which were then assembled at Assembly station and then finally dispatched. The Spindle component was generated with machining across all the five stations and in all these cases AGV handling these components was monitored referring to the flowchart and discrepancies if any were reported and rectified.

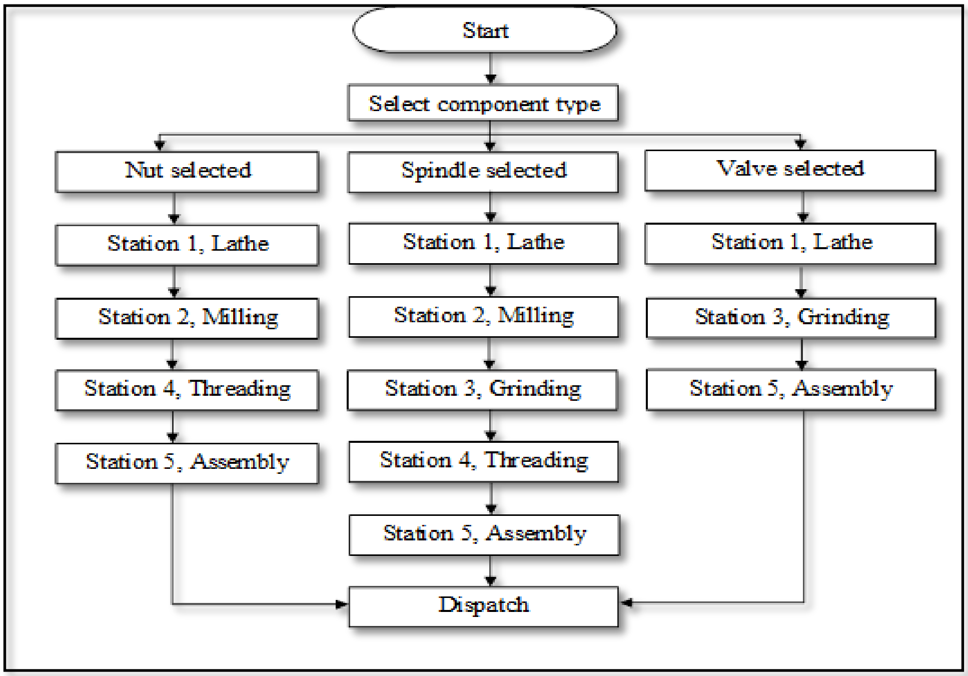

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Fig. 6.AGV operational flowchart

2.3. Kano's model:

The Kano model offers a systematic outline for prioritizing features or functionalities during product development that would attract the customers to the product and result in customer contentmentwith retention. The implementation of the Kano model following the questionnaire method to come across the consumer feedback and agreement results in classifying the product traits as distinguished by them as one dimensional, attractive and must-be requirements. The new customer centered product development can be thus accomplished in a scientific way with due consideration to customer needs with minor rework.[14] Figure 7 presents the Kano model of customer satisfaction for AGV being developed.

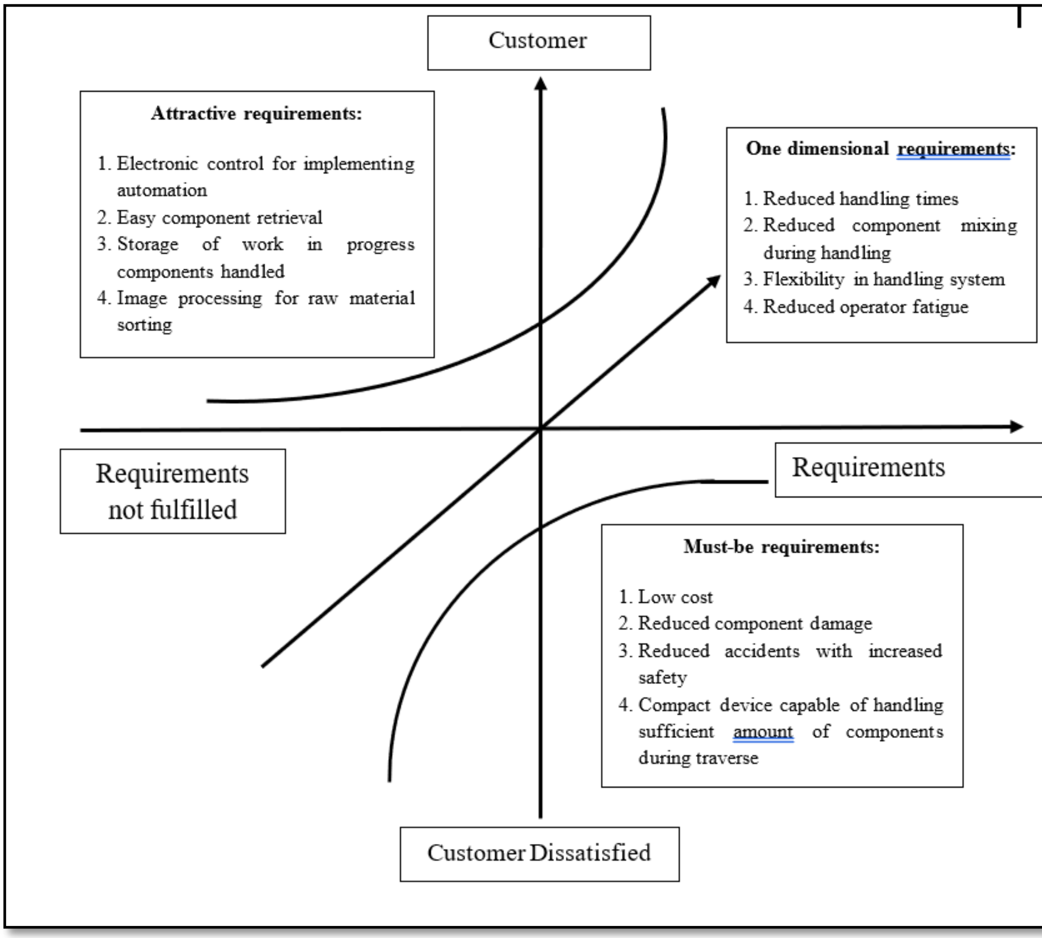

Fig. 7.Kano model of satisfaction for AGV developed

As shown above, developing a low cost and compact system offering reduced component damage and accidents was expected by the industries these being the threshold and taken for granted features and the absence of these often unspoken requirements may result in their dissatisfaction. Currently, the systems were manually operated and hence multiple errors as discussed through QC tools were encountered.

2.4. Poka Yoke:

Poka Yoke aims towards avoiding inaccuracies in lean manufacturing through deterrence, rectification and alarming operator on the occurrence of lowering the scrap and generating a defect free product. This affordable and easy to implement technique that can be prevention based or detection based involves problem identification, observation and brainstorming, selection of best idea, implementation and supervision for resolving human error related issues.[15]Mixing of components during handling was one of the major concerns for the industries and needed sorting and easy retrieval of multiple component types. The color coding technique was used for the trays for sorting components as per their dispatch quantity.The tray containing components with the highest dispatch quantity was marked orange; the medium dispatch quantity tray was marked blue while the least dispatch quantity tray was marked green.

During turns, the trays in the AGV structure containing components were moving out and there was the possibility of falling off the tray and components causing damage to them during handling. Hence a locking system was provided for each tray thus arresting its movement, especially during turns.

Another opportunity for component mixing was at the machining stations where an OK component after subsequent machining and inspection would get muddled up with rework and/or rejected components. Hence two collection bins were provided on either side of the AGV structure where the red colored bin had rejected components while rework components were accumulated in the blue bin ensuring AGV handling and storing the good quality components. Figure 8 illustrates these Poka yoke techniques adopted in AGV developed.

Fig. 8. Poka Yoke techniques applied to AGV

High time consumption during handling was a critical issue due to more dependency on manual operations and obstacles in operational paths. As a part of Poka Yoke, electronic control incorporating stepper motors, Raspberry Pi and Arduino was provided for easy program based system operation and monitoring thus automating the material handling process. An ultrasonic sensor was used for obstacle detection in the AGV path which upon perceiving an obstacle would command AGV to halt until it is removed for preventing the system from damage

3. Results and Discussions:

The application of TQM tools and techniques discussed resulted in the developmentof an automated mobile vehicle as per customer requirements dealing with multiple components. The application of quality management concepts like QC tools, Kano model and Poka Yoke applied during these stages yielded following outcomes:

3.1. Sig sigma and QC Tools:

Six Sigma offered a systematic process of creating an AGV as a product primarily for SMEs indulged with diverse product handling resulting inensuringdesired quality level in thisentire process. QC tools on the other hand utilized the primary data collected through a survey taken from sixty respondents. Check sheets and Pareto diagram talked about the existing material handling systems in SMEs and impediments associated with them while root cause of these problems was accurately identified using Relations diagram. Histogram effectively presented the acceptance trend for automation in industries whereas Flow chart documented AGV travel sequence for verifying the process order during further trials resulting in minimal manufacturing defects. The visual representation based on facts and figures provided valuable inputs at various stages of AGV development in conjunction with establishing necessity for continual improvement in manufacturing ensuring accuracy, quality and safety.

3.2. Kano's model:

An electronic control for automating the system was proposed along with an image processing technique for accurate raw material inspection and sorting. AGV developed stored the work in process components in multiple trays thus saving the excess floor space used and even handling them. The color coding technique simplified the sorting and retrieval of components in the trays based on either the type of component or quantity to be dispatched. These add on features would reduce the operator fatigue delighting them over the basic features of the handling system developed. A large number of products contended on clearly defined performance attributes which in this case were reduction in handling times,components mixing and operator fatigue with subsequent flexibility in handling devices to gain versatility for handling multiple products with minor modifications as required.

3.3. Poka Yoke:

The segregation of components in the trays and their retrieval was simplified and performed accurately with no errors that further reduced downtime and reworkas observed during trials.The defective work in process components being sorted out in rework or reject side bins ensured only acceptable components to be dispatched to the end user. During the trials, it was also evident that accidents were eliminated due to the use of sensors and safety for both humans and machines was ensured due to the associated control mechanism.

3.4. AGV handling times:

The automation adopted as a result of TQM approachled to lowered component handling times as compared to the manual process as illustrated in Table 3which compares handling times in seconds for manual and automated modes for Nut, Spindle and Valve components.

Table 3: Handling times comparison for manual and automated modes

Component Type	Manual Handling Time (seconds) (x)	Automated Handling Time (seconds) (y)	The differencebetween Manual and Automated Handling Times	Total time saving (%) (x-y) * 100/x
Nut	54.26	45.26	9.00	16.58
Spindle	53.45	42.50	10.95	20.48
Valve	45.23	40.12	5.11	11.30

4. Conclusion:

The methodic fabrication of AGV for component handling employing TQM tools rendered an effective automated solution lowering the handling times by 16.58%, 20.48% and 11.30% for Nut, Spindle and Valve component respectively. Six sigma's DMAIC methodology yielded a coherent approach for AGV building whileanassortment of quality control tools assisted in measuring and analyzing the problems in existing material transfer devices to uncover the root cause for developing solutions. Kano model categorized the customer and their requirements for an AGV based on data collection whereas Poka yoke assisted in selection of sensors, electronic controller, collection bins and color coding technique in AGV for eliminating operational errors. The selection of tools and techniques relies on product or service selected, variety and volume of gathered data and expert team available for applying them to yield reliable outcomes.

A similar procedure can be exercised for refurnishing other industrial activities as required however its success relies very much upon resource availability, smartness and embeddability trade off and management and employee support as many SMEs don't candidly accept Industry 4.0 and related changes in the work culture. The emerging technologies of Industry 4.0 effectively combined with quality management practices thus evolved into Quality 4.0 which is beneficial for manufacturing industries including SMEs to achieve operational excellence and come up with innovative products for further customer contentment.

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