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Development of Flexible Automation for the Car Seat Polyurethane Injection Molding Line

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ABSTRACT

Car seat polyurethane injection and molding process is a method of producing car seats to meet customer satisfaction such as car styling and comfort as well as its ergonomic functions. An on-site study was carried out at a local Small and Medium Enterprise company which located in Klang Valley, Selangor. An investigation on the existing car seat polyurethane injection process was conducted at the case study subject and the processing time data was gathered for the establishment of the important simulation modeling parameters or the benchmark key parameters. A conceptual new improved method was then developed, tested and validated for its workability and performance using QUEST discrete event simulation software. There are two major phases involved in this research work; (i) analysis and development of an improved method using work study method and (ii) modeling and simulation of that improved method using Delmia QUEST Simulation Software (DQSS). An investment analysis was done to compare the economics of the new improved method against the present method, using the payback period and the return on investment formulae. A prototype model was also developed to show the mock-up of the suggested system. This prototype model can be integrated with other features such as robot's manipulator and transfer lines to form an automated production line.

Keywords: *Work study, industrial robotics, line automation, Delmia Quest*

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Introduction

A more flexible and agile production line is the best solution to stay competitive in market turbulences so as to constantly adjust production volume of products, variants and quantities. Continuous improvement in the utilization of people, materials and machines is still the keyword in any organization who wants to stay competitive. There are many improvement methods available for manufacturing operations. Example of such methods are, Total Preventive Maintenance (TPM), Total Quality Management (TQM), Japanese approach of systematic housekeeping 5S, Continuous Improvement (Kaizen), benchmarking, Theory of Constraints (TOC), Business Process Re-engineering (BPR), and BPR including kaizen – called business process improvement (BPI) as well as Organization Development (OD). All these methods have a similar fundamental aim that is to improve manufacturing operations [2]. The development of process technology and development of new improved products is important in the process industries with the aim to be cost-competitive [3]. There are no specific rules to follow when designing and conducting case study research, though there are often similarities in approach [4]. Some of the tools and techniques offered by the work study methods; in particular, method study; can serve the organization in measuring progress in terms of reduced lead-time, lower cost, enhance quality and faster responses to delivery, which are of important factors in providing customer satisfaction [5].

Flexibility in production line is vital because product life cycles are getting shorter, lot size is getting smaller and there are many product variants in the market. Capability flexibility and capacity flexibility refers to the ability of the production line to react to the market demand changes such as product variants and ordering quantities, respectively [6]. Therefore, in meeting those challenges robotics and automation plays an important role. According to Groover et al.[7], robotics and automation are closely related technologies, automation as a technology that is concerned with use of mechanical, electronics, and computer-based systems in any operations and control of productions. In another explanation, Cohen and Apte [8] have expressed a similar view that, robotics is one of the supporting elements in production automation technologies apart from numerical control (NC), machines and automated assembly line. An automated assembly system relates to mechanization and automation of tasks in an assembly line and robots have been commonly used in the automated assembly systems [9]. Whereas, Biros [10] reviewed about the various features of using integrated robotic system in pharmaceutical company.

However, automotive industries still the major segment of industrial robotics and automation application. According to Weimer [11], in North America, automotive manufacturers were the first to apply robotics and until today they are still the major users. Kusuda [12] added to the statement by reporting, in Japan the automotive industry is still the major segment of the industrial robot application mainly in the arc welding and spot welding operation. Simulation has been used extensively in designing and analyzing manufacturing systems. Dr. William A. Gruver [13], Professor of Engineering Science and Head of IRMS (Intelligent Robotics and Manufacturing Systems) Laboratory stated that, Quest Simulation Software is not only enables them to test the validity of assumptions and evaluate the effectiveness of new algorithms, it also provides a means of combining physical and virtual systems in an operational environment.

This paper presented a study on the development and improvement of the p/u injection molding production process for the automotive car seat with the following objectives:

1. To design a new production line to improve the existing production performance.
2. To investigate the performance of the new production line through simulation.
3. To conduct an investment analysis study to compare the economics of the new improved method against the present method.

The Polyurethane Car Seat Layout

Figure 1 shows the present layout of the car seat p/u injection molding process from two different angles and the p/u car seat products. The layout area is twenty meters in length by thirteen meters wide. It can be observed that from both pictures of (a) and (b), the polyurethane injection machine is placed at the middle of the line and semi-circled by the car seat moulds to form a 'U' or 'C' shape layout arrangement. The polyurethane injection machine is set on two straight parallel line platforms allowing the machine to move back and forth during the dispensing task. The polyurethane injection machine is also equipped with a jointed arm to hold the dispensing nozzle. This jointed arm can be rotated alongside the semi-circle mould layout, which allows the operator to attend to the designated moulds.

All the moulds arrangement as can be viewed from both pictures (a) and (b) are not fixed or anchored permanently on its floor base. The mould position is interchangeable depending on the production planning requirement and schedule. These two pictures indicate that the present condition of the car seat polyurethane injection and moulding line in this company is manually intensive. At the same time the pictures also verify that the present layout setup is only for one car seat model.

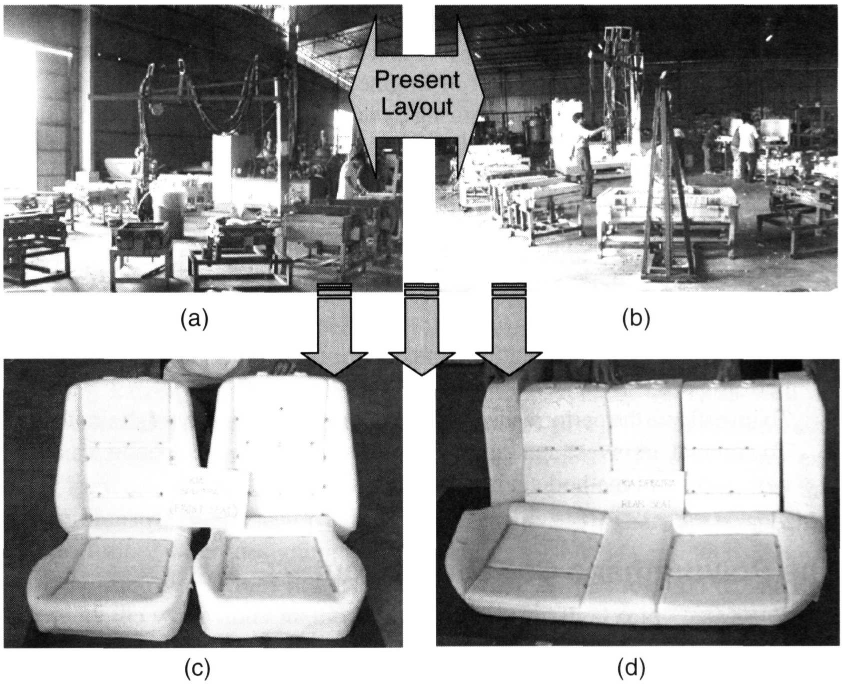

Figure 1: The Present Plant Layout (a & b) and the Car Seat Products (c & d) Produced by the Company

The Present Polyurethane Injection Process Flow

Figure 2 is a sequential picture of the present car seat polyurethane injection and moulding process flow which highlights the sequence of the present process.

The Present Scenario

Table 1 shows a total industrial demand for the polyurethane car seat of 823,500 units per year. The company was awarded 40% from the total industrial demand, amounting to 329,400 units per year. This 40% allocated quantity or 1098 units daily are shared by three different models, namely, Spectra, Sonata and Elantra. With the present production setup, the company is capable of producing only one model, which is Spectra with a daily requirement of 252 units or 23% of the awarded daily quantity. The production shortfall of 846 units per day or 73% of the awarded daily quantity were subcontracted to other supplier to fulfill the industrial demand. Due to some quality problems encountered by the subcontract

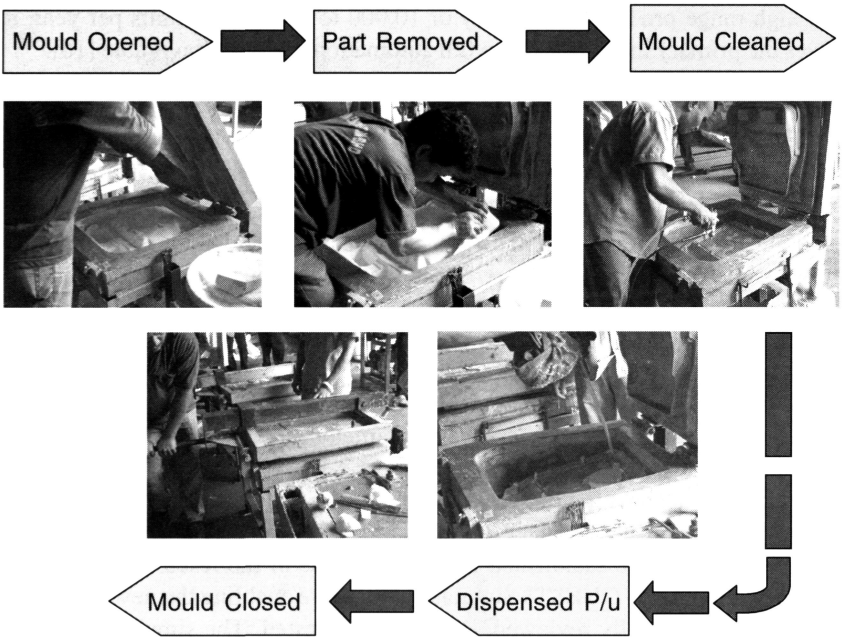

Figure 2: The Present Method (Process Flow)

Table 1: Details Industrial Demand

Requirements	Daily		Yearly	
	Units/day	Sets/day	Units/year	Sets/year
Quantity Produced	252	28	75,600	8,400
Quantity Awarded	1,098	122	329,400	36,600
Production Shortfall	846	94	253,800	28,200
Industrial Demand	2,745	305	823,500	91,500
Opportunity Loss	2,493	277	747,900	83,100

supplier, it has forced the customer to withdraw the 73% of the allocated quantity from the company temporarily until the remedial actions have been taken. With this decision the company is left with barely 9% of the total industrial demand (823,500 units per year). This problem has driven the company to look seriously into the improvement of the present production line setup with particular emphasis on the production line automation.

With the initial information that was obtained from the company, it gave the researcher a solid ground to proceed with the planned activities according to the research methodology towards the production line automation objective. Moreover, with the polyurethane car seats annually awarded quantity falling in the high range production category of 10,000 to millions of units per year, it gives the primary indication that a full automation system is favorable [16].

Research Methodology

The research methodology basically can be divided into two major phases.

The first phase began with process analysis and understanding the fundamental tasks of polyurethane injection operation on the case study subject, subsequently followed by process measurement activities. The measured data which was obtained during the process measurement activity were then synthesized and analyzed to establish benchmark key parameters. The last stage in the first phase was the development of the new improved method conceptual model based on the benchmark key parameters and information obtained throughout the on-site studies.

The second phase continued with building the simulation model of the new improved method using QUEST® simulation software. The benchmark key parameters that were established in the first phase of the research study were then entered into the QUEST® Simulation Software enabling the new improved method to be virtually reviewed, validated and tested. The simulation results were analyzed to study the performance of the new improved method. Finally, the economic assessment was done between the present method and the new improved method to review the financial viability of the new system against the present system.

The Conceptual Model

This conceptual model as shown in Figure 3 demonstrated the p/u injection machine station at one fixed position and assisted by the designated industrial robots during the p/u dispensing process. Every nine moulds of Sonata, Spectra and Elantra models will rotate and stop at its designated p/u dispensing station following their sequence of operations.

Simulation Techniques

QUEST® [13] is a flexible object based discrete-event simulation tool to efficiently model, experiment and analyze facility layout and process flow. It provides 3D digital factory layout visualization and simulation analysis of the designed production control. The new improved models of the p/u injection molding for car seat line were constructed using the QUEST® based on the conceptual model developed earlier. The p/u injection molding process parameters such as, p/u dispensing time, machine cycle time (to represent the molding time), agv speed (to represent the robot's movement), and conveyor speed were input into the

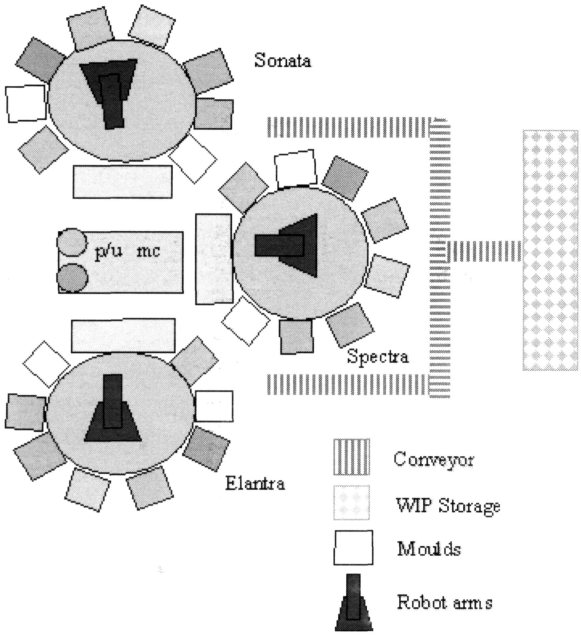

Figure 3: The Conceptual Model for the Car Seat P/U Injection Molding Line (Dial Type)

simulation model. These inputs were obtained from the data collate during the on-site studies using work measurement – time study technique.

Constructions of the New Improved Models using QUEST®

Figure 4 illustrates the single work cell of dial type model with the mould layout in a circular arrangement. It is a simulation model of dial type with a single modular work cell. The model comprises three operators attending to the nine moulds and additional of industrial robot and conveyors.

Figure 5 demonstrates the dial type simulation model with three work cells running concurrently. It is an assemblage of three single modular work cells, with the same facility and setup to run three different models concurrently. Ultimately, this three single modular work cell model will be proposed to the case study subject. However, for the new improved method validation, statistical output results of the single "C" shape model will be considered in all aspects of evaluation.

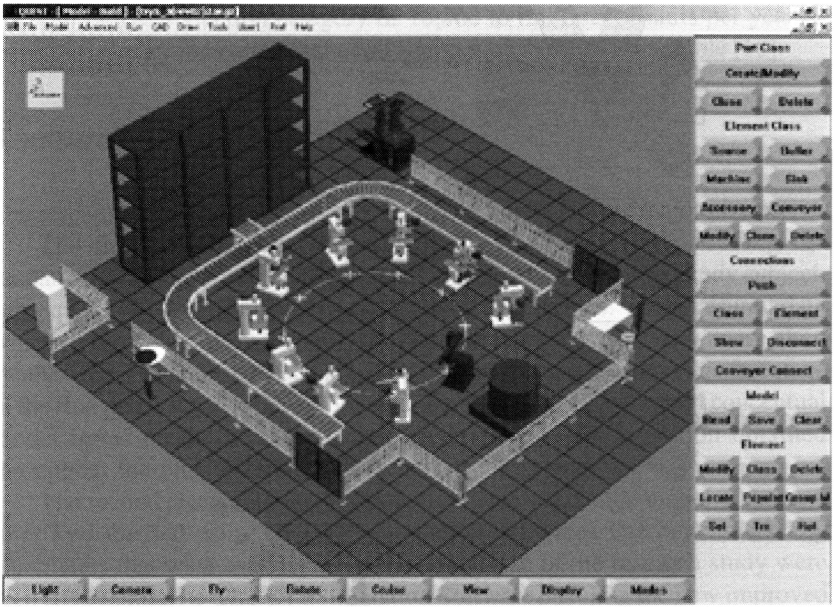

Figure 4: Simulation Model Dial Type (Single Work Cell)

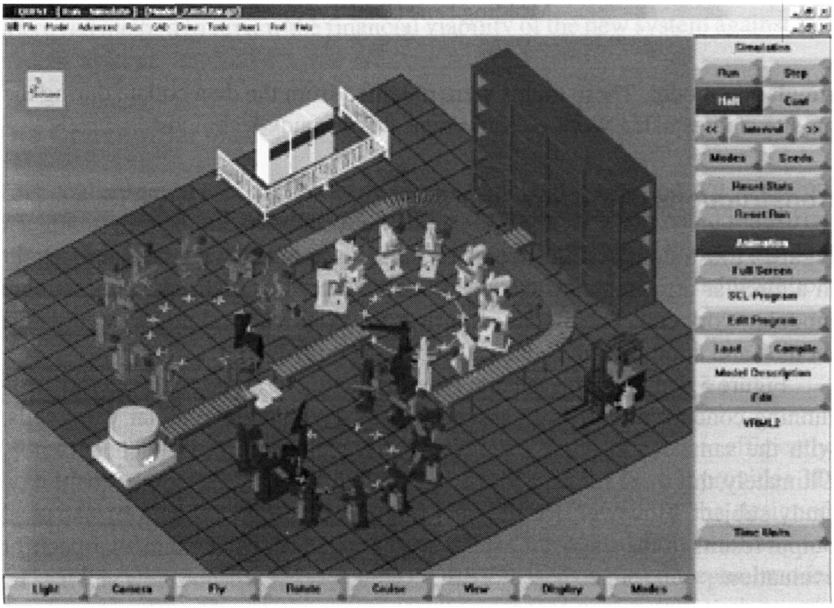

Figure 5: Simulation Model Dial Type (Three Work Cell)

The Key Input Parameters

The key input parameters for the simulation model were obtained from the on-site study that was conducted at the car seat line. The actual production output data was extracted from the production department records and the simulation input data was accomplished from the time study measured during the in-field studies. Table 2 indicates some of the key parameters of the simulation and their associated probability distributions.

Table 2: Key Input Parameters for the Simulation Model and Their Distributions

Variables	Distributions
Machine cycle time	Exponential*
Source	Poisson**
Sink	Poisson**
AGV speed	Constant
Conveyor speed	Constant

* Used to model random arrival, breakdown process, inappropriate delay times, situation where the random quantities satisfy the memory less property, e.g. Machine operational study such as machine breakdown and manpower problem.

** Used to model the number of random events occurring in an interval of time and to model random variations in batch size, e.g. Manufacturing output study such as manufacturing defects and quality control activities.

Table 3: Benchmark Parameters for the QUEST® Simulation Modeling System

Variables	Distribution (mean) - seconds	
	100% eff.	95% eff.
Source	26.39	27.7
Sink	35.21	36.97
Machine	60.9	63.95

Table 3 shows the benchmark parameters that were input during the simulation modeling. The 95% production efficiency was adopted simulating the actual production operation which is presently running at 95% efficiency.

The Prototype Model

A prototype model was developed to show the mock-up of the suggested system. This prototype model was fabricated to put forward and realized the conceptual model. Figure 6 shows the prototype model of the dial type system. This system was chosen based on its feasibility and the extra advantage of its flexibility.

(a)

(b)

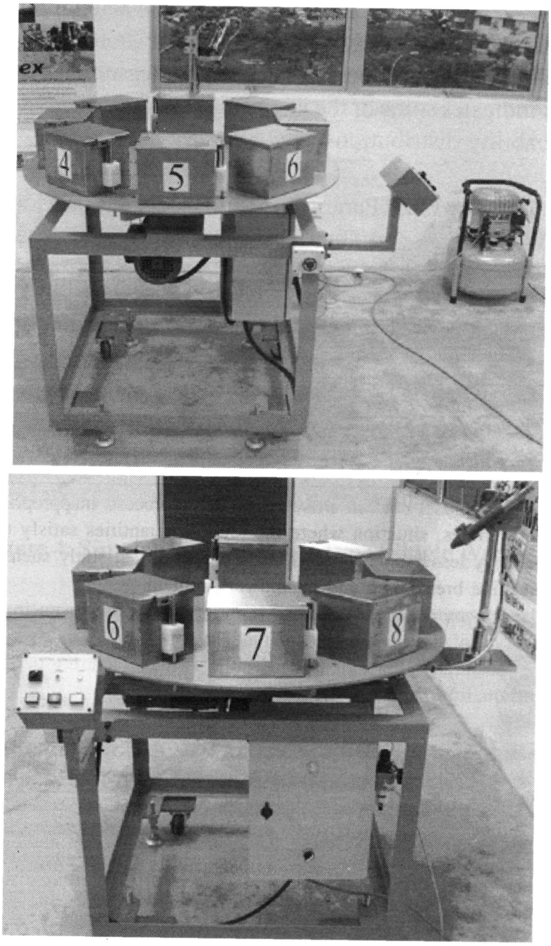

Figure 6: The Prototype Model (a) Side View (b) Front View

Results and Discussion

Delmia Quest simulation was done on a single modular work cell model to portray the new improved model based on the present setup condition. A final walk through was carried out to assess the model logic and ensure it was done correctly. Simulation was done for seven hours to imitate the actual production time in one shift operation. The production throughput of the simulated model was compared against the actual production record for data analysis purposes.

Simulation Results

The results of the study are shown in Table 4. The actual production output data was obtained from the production record of the case study location.

Table 4: Present Output versus the New Improved Method (Model) Output

Production Efficiency	Production output (parts/day)	
	Present	New Improved Model
100%	252	419
95%	239	409

At present, the daily production target is 252 parts/day or 28 units/day and, based on the production records, 5% rejection will be built in. Therefore, the production throughput is at 5% rejection or at 95% production efficiency and contributing to 239 parts/day or 26.6 units/day. The simulation results indicated that the new improved model simulation mean throughput results is 419 parts/day or 46.56 units/day at 100% production efficiency and 409 parts/day or 45.44 units/day at 95% production efficiency.

From this rationalization the 95% production efficiency will be adopted in the following calculations and all the calculation will be based on one shift production schedule.

Table 5: Layout Setup of the Present Line Setup and Quest Simulation Model

Items	Present Setup	New Improved Setup
Output/day	26.6 units/day	45.44 units/day
Working hrs/day	7 hrs	7 hrs
No. of workers	5 operators	3 operators
Line automation	nil	yes
Industrial robot	nil	yes

Table 6: Cycle Time Comparison between Present Setup and Quest Simulation Model

Line Setup	Present	New Improved Model
Cycle time at 100% efficiency	15.00 min/unit	9.02 min/unit*
Cycle time at 95% efficiency	15.81 min/unit	9.24 min/unit*

* Cycle times for the model were obtained from the Quest simulation model.

Economic Assessment

The profit per year presented in Table 7 indicated that by implementing the new system, the profit per year increases above RM2.3 million which is 65.3% more than that obtained using the present setup. The estimated profit after five years would be above RM2.4 million per year which is a 68.2% increases from the profit made using the present setup.

Table 7: Profit per Year of Present Method versus New Improved Method

Profit/year	Present Method	New Improved Method
Year 1 - 5	RM3,637,543.07	RM6,011,661.26
After year 5	RM3,637,543.07	RM6,118,161.26

Figure 7 graphically presents the trend of the profit per year of the present method against the new improved method. The graph was plotted based on the assumption made that the annual demand for the present method and the new improved method is consistent for ten years. The entire calculation was done according to the one shift operation figure.

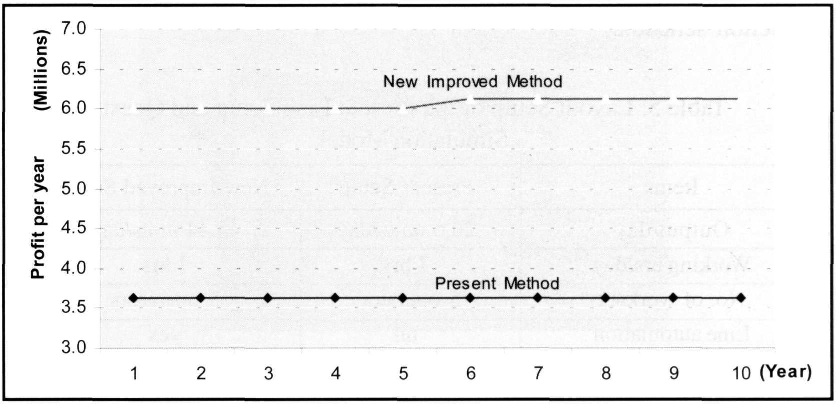

Figure 7: Profit per Year of Present Method versus New Improved Method

New Capital Investment Evaluation

For the purpose of the economic evaluation, the payback period method and return on investment methods were adopted to justify the new capital investment of the new improved method. The explanation of these two methods and the formulae used are as follows:

The Payback Period Method

This method determines the payback period is in which time the net accumulated cash flow is equal to the total capital investment cost. Assuming the annual cash flows are equal every year, therefore the payback is determined from the following formula [17]:

$$P = \frac{C}{L + V - R}$$

Where, P = the payback period in years
C = total capital investment cost, RM.
L = cost of annual labour saved, RM.
V = added value of increased output, RM.
R = annual running cost of robots (Maintenance Cost + Depreciation Cost), RM.

For the new improved method; the total capital investment cost is RM532,500.00. There is one shift operation of 2100 hours (7 hrs/shift × 25 days × 12 mths) and 2 men replaced. Labour rate is RM4.00 per hour (RM700/mth/25days/7hrs). Annual maintenance cost is RM15,000.00 and annual depreciation cost is RM106,500.00. The annual running cost of robots is RM121,500 (RM15,000.00 + RM106,500.00). Added value of increased output of the new improved method is RM2,374,118.19. Therefore the payback period is:

$$\text{Payback period} = \frac{532{,}500}{(2100 \times 2 \times 4) + 2{,}374{,}118.19 - 121{,}500}$$
$$= 0.23 \text{ year or } 2.76 \text{ months}$$

From the above calculation, it can be concluded that though the assumption of the new improved method is operating based on one working shift, the payback period is less than three months. As a consequence if the production line of the new improved method runs more than one shift, the payback period could be achieved even shorter.

Return on Investment Method

This method is to determine the annual rate of return of the investment in percentage value. The annual rate of return in percentage is obtained from this formula [17]:

$$A = \frac{V + L - D - M}{C} \times 100\%$$

Where, A = annual rate of return in percentage
C = total capital investment cost, RM.

L = cost of annual labour saved, RM.
V = added value of increased output, RM.
D = depreciation cost, RM.
M = maintenance cost, RM.

From the initial information in this research study, assumption was made that the robots and line automation is depreciated evenly over 5 years. From the cost structure the following information were gathered:

The total capital investment cost (C) = RM532,500.00
Assume yearly depreciation with straight line method for over 5 years. Therefore,

$$\text{Yearly depreciation value (D)} = \frac{\text{RM}532{,}500}{5} = \text{RM}106{,}500$$

Annual maintenance cost (M) = RM15,000
Annual labour saved (L) = RM16,800
Added value of increased output (V) = RM2,374,118.19

The annual labour saved figure is obtained from the calculation of total hours in one shift per year multiply by number of labour replaced and multiply again with the labour rate per hour (2100 hours × 2 labourers × RM4 per hour = RM16,800).

The added value of increased output is obtained from the gained profit difference between the new improved method and the present method. Using the formula given thus the annual rate of return is,

$$\text{Annual rate of return} = \frac{16{,}800 + 2{,}374{,}118.19 - 106{,}500 - 15{,}000 \times 10}{532{,}500}$$

$$= 426.2\%$$

The annual rate of return of 426.2% calculated above indicated that the capital investment on the new improved method will be fully recovered well within its first year of implementation. The percentage of return of more than 100% implies that the investor already passed its investment hurdle rate and enjoying the profit within the first year of investment. Therefore from this economic evaluation it can be concluded that the new capital investment of the new improved method is viable and highly recommended for the implementation at the case study subject.

Conclusion

Research indicates a huge potential improvement can be achieved in production volume, revenue and profit through systematic study that involves application of industrial robotics and line automation. The exploitation of QUEST® simulation software provides the means to explore into great detail study of the new improved model without interrupting the actual production line and virtually display the real life situation. From the simulation results, when the number of production unit per year increased, the sales opportunities that are available in the market can be secured accordingly. Simultaneously, when the production cost per unit price reduces, the profit per year also will increase significantly. For the benefit of the case study subject, the process improvement made on the p/u injection molding for the car seat line will allow the company to secure back their subcontracted model and recapture their sales revenue as well as explore other business opportunity.

Acknowledgement

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JOURNAL OF MECHANICAL ENGINEERING (JMechE)

Aims & Scope

Journal of Mechanical Engineering (formerly known as Journal of Faculty of Mechanical Engineering), is an international journal which provides a forum for researchers and academicians worldwide to publish the research findings and the educational methods they are engaged in. This Journal acts as a vital link for the mechanical engineering community for rapid dissemination of their academic pursuits as well as a showcase of the research activity of FKM for the outside world.

Contributions are invited from various disciplines that are allied to mechanical engineering. The contributions should be based on original research works. An attempt will be made to review the submitted contributions with competent internal and external reviewers as to the suitability of the paper for satisfying the objectives of the journal.

All papers submitted to JMechE are subjected to a rigorous reviewing process through a worldwide network of specialized and competent referees. To be considered for publication, each paper should have at least two positive referee's assessments.

General Instructions

Manuscripts intended for publication in the Journal FKM should be written in camera ready form with production-quality figures and done electronically in Microsoft Word 2000 (or above) and submitted along with one hard copy. Manuscripts should be typed using Times New Roman font (point 10) on one side of the paper (A4 size), single-spaced, with wide margins (1 in left and right, and 1 in on top and bottom). The manuscript should include the title of the paper; the author's name and affiliation; a short abstract of between 200 and 300 words which clearly summarises the paper; and a list of keywords. Limit your submission to a maximum of 20 typed pages.

Keywords

Keywords supplied by the author should appear on a line following the abstract. The keywords selected should be comprehensive and subject specific. Maximum of five keywords should be sufficient to cover the major subjects of a given paper. General terms should not appear as keywords, as they have little use as information retrieval tools. Please choose keywords to be as specific as possible and list the most specific first, proceeding to the most general last.

Units

All scientific and technical data presented should be stated in SI units.

Footnotes

Footnotes should be kept to an absolute minimum and <u>used only when essential</u>.

Formulae

Formulae should be typewritten using MS Word compatible Equation Editor.

Tables

Tables, should be included within the text where appropriate and must be numbered consecutively with Arabic numerals and have titles that precede the table. They should be prepared in such a manner that no break is necessary.

Figures

Authors should appreciate the importance of good-quality illustrations. All graphs and diagrams should be referred to, for example, Figure 1 in the text. All figures must be numbered consecutively with Arabic numerals. A detailed caption should be provided below each figure according to the following format:

Figure 1: (a) A simple 2-D cantilever and (b) microcantilever with a diamond probe.

Figures should be embedded within the text where appropriate. Glossy photographs when required should be scanned to a resolution suitable with the reproduction requirements (1200 dpi generally will be sufficient).

References

Use squared brackets to indicate reference citation such as [1], [3]-[5] in the main text. Include references at the end of the paper according to the citations order that appears in the paper using the following format.

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