Improving Energy Efficiency for the Vehicle Assembly Industry: A Discrete Event Simulation Approach

2016 IOP Conf. Ser.: Mater. Sci. Eng. 160 012069

(http://iopscience.iop.org/1757-899X/160/1/012069)

Improving Energy Efficiency for the Vehicle Assembly Industry: A Discrete Event Simulation Approach

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Abstract. This paper presented a Discrete Event Simulation (DES) model for investigating and improving energy efficiency in vehicle assembly line. The car manufacturing industry is one of the highest energy consuming industries. Using Rockwell Arena DES package; a detailed model was constructed for an actual vehicle assembly plant. The sources of energy considered in this research are electricity and fuel; which are the two main types of energy sources used in a typical vehicle assembly plant. The model depicts the performance measurement for process-specific energy measures of painting, welding, and assembling processes. Sound energy efficiency model within this industry has two-fold advantage: reducing CO2 emission and cost reduction associated with fuel and electricity consumption. The paper starts with an overview of challenges in energy consumption within the facilities of automotive assembly line and highlights the parameters for energy efficiency. The results of the simulation model indicated improvements for energy saving objectives and reduced costs.

1. Introduction

Energy is the most essential resource for the future economy growth and prosperity with an ever increasing consumption of energy. While Global warming is considered as one of the harshest environmental problems the world has ever faced. The problem originated from the drastic increase in the emission of CO_2 (carbon dioxide) from the last several decades caused by burning fossil fuels. The energy from burning fossil fuels is crucial for manufacturing industry. As indicated in [1] the governments and manufacturing companies have placed energy efficiency in manufacturing sector on the top of agenda because of global warming, rising energy prices, and customers' increasing ecological awareness. The industrial energy consumption is estimated to increase 45% from 2012 to 2030 production [2]. Energy efficiency has achieved crucial importance in the industrial sector because of the increasing energy costs and the associated environmental impacts , as indicated in [3]. The environmental policy implications of lower energy use have led to the development of voluntary government programs for energy efficiency.

Energy efficiency and conservation is very vital in creation of environmentally friendly production facilities [1], [4], [5]. Organizations are adopting methods used for the reduction of the imbalance

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between energy supply and energy demand, with environmental sustainability for the protection of natural ecological resources. World market energy consumption was about 524 quadrillion British thermal units (Btu) in 2011. The commercial sector, industrial sector, residential sector, and transportation sector are the four major energy end-user sectors (EIA, 2015). The electric power sector also consumes energy. This paper concerns only industrial energy consumption, in particular to automobile manufacturing industry.

The research in this paper involves a case-study of a vehicle assembly plant in Malaysia. The Ministry of Energy, Green Technology and Water (KeTTHA) has reported that Malaysia managed to reduce its carbon emission intensity by 33% (Report Energy, 2014). This milestone means that the country is on track to meet its pledge of achieving a 40% cut in carbon emission intensity by the year 2020. This indicates the existence of an efficient energy consumption since the carbon emission has been reduced. However; in 2014, the final energy consumption of Malaysian manufacturing sector, was 11,679 thousand tons of oil equivalent (ktoe) which is approximately equal to 488,976,372 gigajoule (GJ). While all the resources consumed and wastes produced by manufacturing affect the environment to a greater or lesser extent, the focus of the present work is on the efficient and effective utilization of resources, and in particular energy resources. Automobile manufacturing and other manufacturing industries consume high energy due to the processes of manufacturing. Organizations within the automotive manufacturing sector are placing important emphasis on efficient energy consumption due to the steady increase of energy prices and negative environmental impacts caused by energy consumption. Governments and companies are both determined to discover the most efficient procedures to enhance energy efficiency in manufacturing processes. Literature shows that in recent years, research on energy efficiency has increased as shown in [6]–[15]. In the following paragraphs detailed descriptions of energy efficiency policies both from review papers and analytical research models will be discussed.

Simulation is considered as a popular and valued analytical technique. In many situations surveys of simulation practitioners demonstrate that simulation is among the top techniques in popularity and in use[16]. Many analytical software models for energy sustainability were developed as can be seen in[14], [17]–[21]. The use of an energy oriented simulation model for the planning of manufacturing systems based on two industrial case studies was demonstrated by [22]. The simulation model shows all pertinent energy flows of factories that were simulated with the sole objective of identifying areas of improvement for efficient energy consumption and then selecting measures for enhancement. However; this study did not show any numerical results indicating improvements that can be compared with an actual manufacturing plant. The increased assessments of the economic system wide energy efficiency performance was mainly caused by the global awareness on energy security and climate changes. Analytical model based on data envelopment analysis (DEA) was presented in [23] This research claims that most of the DEA-related energy efficiency studies do not focus on the modeling of CO2 emissions. Nevertheless numerous past researches have contributed to the evaluation of energy efficiency performance exploiting different analytical methods including DEA[23]. This research has indicated the construction of static and dynamic energy efficiency performance indexes to measure the energy efficiency industrial sector by using a number of environmental DEA models for modeling CO2 emissions.Wu et al[23] claims their empirical results of the study illustrates energy efficiency in China's industrial sector has improved and was mainly determined by industrial technology improvement.

Optimizations based on energy efficiency do not always generate cost-savings results. This is because of the fact that energy inputs are diverse and dissimilar. In automobile production sector, Q. Zhu et al. [8] presented a research that demonstrated Model Predictive Controller (MPC) based on linear programming optimizer for energy management. This model was designed to provide assistance to the decision makers and energy planners for a better control required energy mix for the facility and to predict the future energy needs. This research has indicated the significance of decision making tools for energy accounting and planning, in industrial settings since different recommendations can be considered due to the existence of different performance indicators and penalty functions. The MPC results pointed out that the cost oriented optimization generated very close energy predictions to the actual plant expenditures. Furthermore, the energy-efficiency oriented optimization demonstrated a remarkable potential for energy savings.

A compressive review of energy and resources efficiency in industrial sector, particularly in the domain of discrete part manufacturing can be found in[11]. This review outlined a systematic overview of the state of the art of the methods and techniques used to increase the efficiency of energy and resources. Nevertheless the research did not produce results of numerical figures for measuring the improvement of the energy efficiency and recourses, but the research has put forward structured approach by distinguishing different system scale levels, such as unit process focus level, multi-machine, factory, multi-facility and supply chain levels were covered. The review highlighted and summarized important opportunities for systematic efficiency improving procedures.

According to[24] the industry sector comprises an immense potential for energy efficiency. This is coupled by the fact that the industry sector is also facing a great diversity of options for improving energy efficiency. Such options are attracted not only technical merits and qualities but by the site-specific energy markets, economic environments, business situations, managerial priorities and implementation barriers. As claimed in [24] A survey of more than 300 policies, containing approximately 570 procedures or measures, implemented by some of the governments of the IEA member countries. The [24] research outlined the measures' main features, their frequency of use, and their associations with specific technical actions and key stakeholders such how and where measures affect the energy efficiency of industry. However; The IEA is made up of 29 member countries but this research only focused on such countries as Brazil, China, India, Mexico, Russia and South Africa. On the other hand; the study examined the significant characteristics underlying the methods for success such the capability and the possibility of lowering high energy utilization, energy waste and cost-efficient emissions of CO2 emissions cost-efficiently. And a further look into the ease of policy development, execution and assessment and secondary societal effects has shown there is a need to conduct a well rounded and knowledgeable research that can create a multifaceted deeper understanding of how the components of different policies across industries complement one another, and how policy consistency is sustained to guarantee the overall effectiveness and cost-efficiency. A research based on the results of energy efficient manufacturing from EU-funded road-mapping project, has emphasized on the needs of industrial companies for incorporating energy efficiency performance in production management as claimed by [1]. This EU-funded project named projectIMS2020 has focused on five key areas of sustainable manufacturing, energy efficient manufacturing, key technologies, standards, and education.

This research has reviewed the concepts and tools for measurement, control and improvement of energy efficiency in production management and also indicated that there exists a gap between the available proposed solutions and the actual implementation in industrial companies[1]. This research will improve energy efficiency opportunities in an automobile assembly line. There are varieties of opportunities that exist within in the vehicle assembly plants; so it is possible to be used for the reductions of energy consumptions and the enhancement or least the maintenance of the productivity of the plant. The energy efficiency measures can be categorized into two categories. (1) The utility systems energy efficiency measures (general, motors, compressed air, heat, and steam distribution, lighting, HVAC, material handling). (2) The energy efficiency measures that are process-specific, characterized by the process to which they apply (painting, welding, stamping). While according to[25] the energy consumed by various activities of manufacturing application is categorized into two groups: Direct and Indirect Energy. By which the Direct Energy (DE) is similar to process-specific energy, whereas the Indirect Energy (IE) is the same as energy used by the utility systems. The research problem in this paper is how to improve energy efficiency and reduce energy consumption for vehicle production assembly line focusing only process-specific energy efficiency. This will be based on an actual case study. The objectives of this paper focus on the improvement of energy efficiency and reductions of energy wastage for the process-specific energy measures of body shop, paint shop, and assembly shop processes in the facility. The emission of CO2 is not quantified in this paper. Energy used in stamping process which is also process-specific measure is not considered due to the fact that most of the vehicle assembly plants do not have stamping manufacturing facilities on-site.

2. Process description and Data Modelling

This section covers the actual layout of the assembly line, detailed description of the vehicle assembly processes, and data collection. The data on the company and plant performance is being held strictly confidential. In addition to that data modelling will be conducted to find the goodness-of-fit for the distribution of the collected data samples. The goodness-of-fit can achieved by using statistical test built-in the Arena Input Analyzer tool.

2.1. Description of the assembly line and data collection

This case-study problem is about a plant that involves in automotive manufacturing, assembly and distribution industry. Trucks, buses, motorcycles, and different types of passenger car are assembled in this plant. In this paper only one type of passenger car assembly line is considered. The assembly line has a product flow layout, capable of producing between twenty eight (28) to thirty five (35) automobiles per day for 10 hours per day (one 8 hour shift, including 2 hours overtime). This facility is only for assembling tasks and not for parts manufacturing.

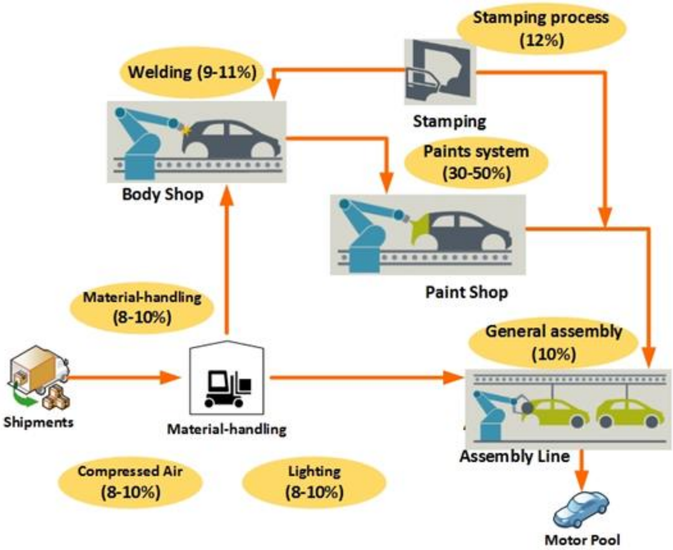

Figure 1. A typical vehicle assembly process and its energy distribution adopted from [26].

Most of parts and components will be delivered from outside suppliers. The supply of car manufacturing materials arrives as a CKD (Complete Knocked Down) from overseas countries. The CKD are then stored in warehouses within the facility. The CDK eliminates the stamping and metal forming processes. Just like any other automotive industry here, Just in sequence (JIS) inventory strategy is employed which matches just in time (JIT) strategy. All the required components and parts arrive at the assembly line right in time as scheduled before they get assembled. As usual most of the automotive assembly plants usually are divided into five major departments. The assembly line considered in this study line has five important departments: (1) body shop, (2) paint shop, (3) assembly shop (trim-chassis-final), (4) rectification shop and (5) material logistics department. This is the actual organization of the assembly plant. A summary of the logistical flow is depicted in Figure 1, the flow of materials, from inventory (parts and components) arrival to a finished passenger car (stored in the motor pool). The material logistics department receives inventory, ensuring they match the purchase order specifications, and applying receipt and storing procedures. The main function is to receive and deliver parts for the weld, assembly and paint departments on a 'just in time' basis. The body shop produces complete welded car bodies from supplied panels. The car body then moves through a series of spot-welding operations, both robotic and manual, to assemble the body. The car bodies are then moved into the paint shop, where a series of processes are performed to paint the car body. The painted car bodies are then transported to assembly shop for trim-chassis-final. Finished passenger cars are then finally transported to motor pool area for storage before shipping to the business dealers.

The data is collected from each relevant department of the assembly plant and from the Enterprise resource planning (ERP) system of the IT department. The collected data will be used as the input of the simulation model. The collected data are summarized in Table 1 and Table 2 below.

Table 1. Electricity consumption.

Department	KWh per month	Percentage
Assembly shop	48,810.40	5.0%
Body shop	58,572.48	6.0%
Paint shop	706,761.37	89.0%
Total	964,087.75	100%

Table 1 shows the data pertaining to monthly electricity consumption. While Table 2 data are specific to fossil fuel (in this case LPG) consumption; which are mostly used for the paint shop operations. A detailed data of monthly energy consumption for three years were gathered from the relevant departments.

Table 2. LPG

Department	MMBtu per month	Percentage
Paint shop		
-Spray booths	1,340.00	57%
-Ovens	727.00	31%
-Others	280.00	12%
Total	2,347.00	100%

Table 1 and 2 above show paint shop is by far the highest consumer of electricity at the facility and an average of 706,761.37 KWh of electricity per month is used. Body shop and assembly shop also use electricity. In addition to the consumption of LGP for boiling and burning processes, the paint shop is by far the most costly department within the facility.

2.2. Goodness-of-fit Tests for Distributions

The goodness-of-fit of a distribution to a sample is assessed by a statistical test. Such statistical measures provide in an advisory capacity: They need not be used as definitive decision rules, but merely provide guidance and suggestive evidence[27]. In numerous circumstances, there is no clear-cut best-fit distribution. However, goodness-of-fit tests are useful in providing quantitative measures for decision rules. The chi-square test and the Kolmogorov–Smirnov test are the most widely used tests for goodness-of-fit of a distribution to sample data. The probabilistic properties of random variables are characterized by their distribution functions (often abbreviated to distributions). These functions assume various forms, depending on the type of the associated random variable and the nature of its state space (numerical or not). In particular, a distribution function is continuous or discrete (or mixed) according to the type of its associated random variable. Random variables are classified according to their associated state space. A state space is said to be discrete if it is countable, or continuous, if it is not (it can also be mixed with discrete and continuous components). Every discrete random variable X has an associated probability mass function (pmf), P_X (x) defined by

$$P_X(x) = \Pr\{ X = x\}, \quad x \in S \qquad (1)$$

Thus the pmf is always guaranteed to exist, and has the following properties:

$$0 \leq P_X(x) \leq 1, \quad x \in S, \qquad (2)$$

And

$$\sum_{x \in S} P_X(x) = 1. \qquad (3)$$

Every real-valued random variable X (discrete or continuous) has an associated cumulative distribution function (cdf), F_X (x), defined by

$$F_X(x) = Pr\{ X \leq x\}, \quad -\infty \leq x \leq \infty. \qquad (4)$$

Therefore, it is possible to use both probability mass function (pmf) distributions and cumulative distribution function (cdf), for a discrete event simulation (DES) model. A DES approach is adopted for modelling this project; because DES approach fits and is considered appropriate to model based on the nature of data collected and the problem being investigated. Therefore, continues modelling which are based on a probability density function (pdf), is believed not to be appropriate to model for this particular problem.

A chi-square test and Kolmogorov-Smirnov (K-S) test from the the Arena Input Analyzer were used to compute the corresponding test statistic and the associated p-value. In here, the chi-square test compares the empirical histogram density constructed from sample data to a candidate theoretical density. While the chi-square test compares the empirical (observed) histogram pdf or pmf to a candidate (theoretical) counterpart, the Kolmogorov-Smirnov (K-S) test compares the empirical cdf to a theoretical counterpart. Statistical tests were performed using the arena input analyser for a data collected from the assembly plant paint shop for 250 days of electricity consumption. Figure 2 shows that the best fit distribution for the data will be Triangular distribution.

The chi-Square test gives a corresponding p-value of greater than 0.75(p-value > 0.75). This is considered to be a good for a triangular distribution. And the Kolmogorov-Smirnov test has shown a corresponding p-value greater than 0.15 (p-value > 0.15). This is good fit because the smaller is the observed value of the K-S statistic, the better the fit. The dataset were based on triangular distribution for. The expression Tria (2,6.43,9) corresponds to 2,548.73 kWh, 7,073.96 kWh, and 9,316.27 kWh daily consumption of electricity at the paint shop. Making use of the Arena Input Analyzer tool; which provided as a standard component of the Arena environment, all the collected data in table 1 and table

2 were analyzed. Both of the assembly shop and the body shop data on electricity consumption were tested for goodness-of-fit of a distribution; by which all achieved a very good confidence level.

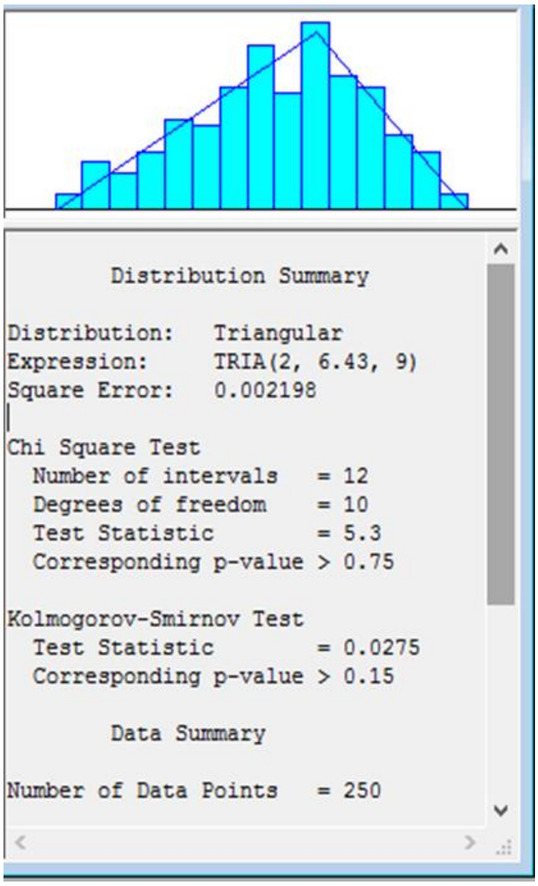

Figure 2. Paint shop electricity consumption for period of 250 days.

The fossil fuel (LPG) data used in the paint shop processes of the spray booths, the ovens and others processes within the paint shop as shown in table 2 were also tested for the goodness-of-fit; in which the data has achieved a very good fit.

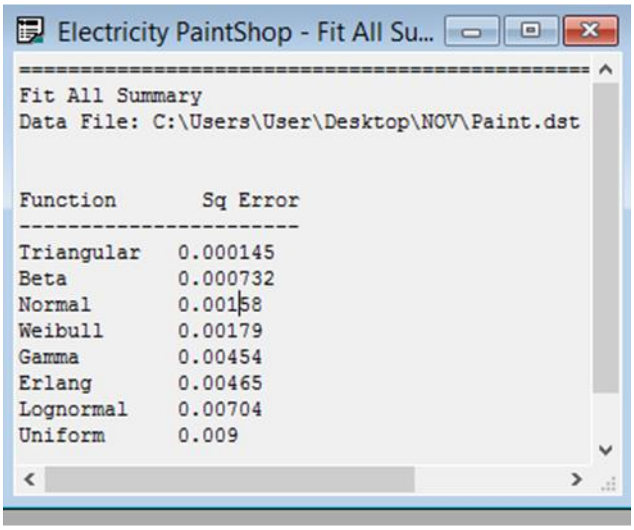

Figure 3. Fit all summary report for the sample of the paint shop electricity consumption data.

Finally a fit all summary was conducted in which the objective is to determine the best-fit distribution over all distribution classes supported by Arena as well as the associated parameters. For example as shown in Figure 3, the data of electricity consumption at the paint shop was found to have the best distribution of Triangular with an square error of 0.000145, while the next best fit distribution would be a Beta distribution with an square error of 0.000732.

3. Simulation Model

This research deals with automotive assembly energy utilization and the efficient use of the energy. The data pertaining to this project were collected from an actual automotive assembly. The name of the plant and its location is omitted for privacy related concerns. The authors adopt a discrete event simulation model capable of recreating detailed low level operational decision making on energy efficiency. The simulation model is implemented using commercial DES software called Arena TM developed by Rockwell Automation. This discrete event modelling empowers the optimization of complex processes. Discrete event modelling is the process of depicting the behaviour of a complex system as a series of well-defined and ordered events and works well in virtually any process where there is variability, constrained or limited resources or complex system interaction [28]. The package uses SIMAN processor and simulation language. It is a general purpose simulation package; which is widely used software in both industry and academia [2]. This model was built using data collected from the paint shop department for LGP (fuel) usage, assembly shop and body shop for electricity consumption. The complete energy consumption model is depicted in Figure 4 below.

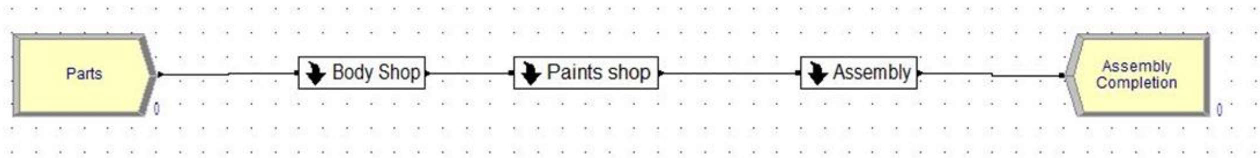

Figure 4. The complete models of the assembly line in terms of energy consumption.

According to [28] energy consumption in manufacturing and logistics is considered as one of the biggest contributors of the supply chain carbon footprint. One of the most important ways of reducing Energy greenhouse gases is the control and reduction of unnecessary energy and utility consumption. In order to achieve efficient environmentally friendly production system, energy efficiency policy was enforced based behavioural changes on energy consumption. This can be jointly implemented with engineering practice on operating procedures and the use of energy efficient equipments in paint shop (boilers and burners), body shop and assembly shop departments.

3.1. Body Shop

The body shop facility commences the manufacturing operations for body-in-white (BIW). BIW refers to the stage in automotive manufacturing in which the vehicle body sheet metal (doors, hoods, and deck lids) has been assembled but before components (chassis, motor) and trim (windshields, seats, upholstery, electronics, etc.) have been added. According to US Department of Energy[29], the BIW process-specific energy use includes production of first stage BIW (first dimensional sets), parts assembly, two-stage spot welds (initial and final structure) and robot-intensive assembly. However; in this case study, the process-specific energy is directly under the sub-assembly processes of BIW. Here the BIW sub-assembly processes are five (5): Front-Under (FU), Roof and Floor(R&F), Side Structure (SS), Fitting (FT) and Mainline (ML) assembly.

Table 3 shows the BIW assembly process timings in process. This data was extracted from the vehicle tracking system (vts) computer software. The data shows the date and time by which a CKD components enter the facility , CDK_T_In (Complete Knocked Down Time In), the Inter arrival time (IAT) of the CKDs, the BIW_T_Out (BIW Time In) and the Cycle Time (CT). Based on the documented from the assembly line the cycle time reported was 15 minutes for the completion assembly of one unit of BIW. In the BIW assembly, there are 31 stations running for 480min per day. And the capacity of BIW production is 24 units per day.

Table 3 BIW assembly process timings

Date	CKD_T_In	IAT	BIW_T_Out	C T
4-oct-15	9:13 am	28:14	10:49:42 am	11:27
4-oct-15	9:41 am	12:58	11:01:09 am	22:16
4-oct-15	9:54 am	60:55	11:23:25 am	15:58
4-oct-15	10:55 am	0:04	11:39:23 am	17:15
4-oct-15	10:55 am	29:17	11:56:38 am	21:35

However; the data collected from the VTS indicates a cycle time of 20 minutes. Nevertheless, the objective is to model the energy consumption of the BIW processes. Energy consumptions of the BIW sub-assembly process was computed based on the amount of time and energy used to complete a sub-assembly process. The energy here is mainly electricity and it is measured in kWh.
As indicated in US Department of Energy Report, these processes rely primarily on electricity and are characteristically complex, computer-controlled systems utilizing large amounts of robotic and automated processes[29]. The simulated energy consumption variables here are first stage BIW, Parts Assembly, two-stage spot welds and robot-intensive assembly. Figure 5 shows assign module of the Arena Model, which is used for assigning new values to variables, entity attributes, entity types, or other system variables.

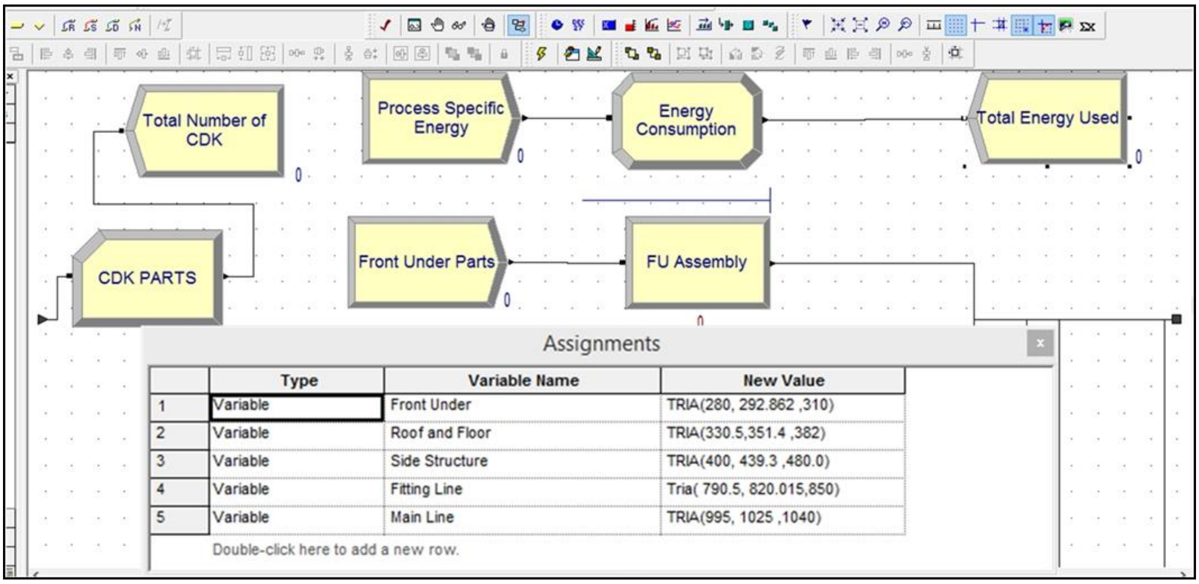

Figure 5. BIW processes as a sub-model shown with energy consumption.

Multiple assignments can be made with a single Assign module. The Module shows the BIW processes (Front Under, Roof and Floor, Side Structure, Fitting Line, and Main Lin electricity consumptions) as energy consumption variables with energy values measured in kWh. The BIW sub-assembly variables of electricity consumption are based on triangular distribution as shown in Figure 5. This agrees with Goodness-of-fit Tests for Distributions described in section 2.2.Based on the technological roadmap report in 2008 from US Department of Energy(Various, 2008); which provided extensive description on energy reduction in automotive industry, the energy reduction for the BIW processes can achieved through: (1) evolutionary changes; and (2) catalyzing revolutionary changes by means of creating new designs and introducing new materials. The roadmap indicated these changes will need strong attention on both near-term (improving today's designs) and longer term (ideal designs of future vehicles structures) opportunities. However; in this paper the BIW energy improvement is not on the vehicle body technology but rather on BIW assembly process. Techniques of reducing energy involving the vehicle body technology such as Energy-Efficient Joining Technologies, Design for Life-Cycle Energy Reduction of Body Structures, energy efficient stamping and casting technologies are beyond the scope of this paper.

3.2. Paint Shop

As indicated in Figure 4, the paint shop sub-model occurs right after the BIW (body shop) sub-model. In this facility, the task of automotive painting process is conducted. This is the multi-layer painting process of the interior and exterior body structure from BIW. Here the body structure from BIW goes through a series number of operations to complete the painting of both the interior and exterior of the hallow BIW structure. The automotive painting system typically multi stage processes; which consists of the following: painting (i.e., colour coating and baking, including painting booths and ovens), repair (spot repair and panel exchange), rework (where jobs will be resent to painting process again) and inspections, which are immediately after each operation(Guerrero et al., 2011). Figure 6 below illustrates the simulation model of the paint shop; with triangular energy consumptions of the of ovens and spray booths etc.

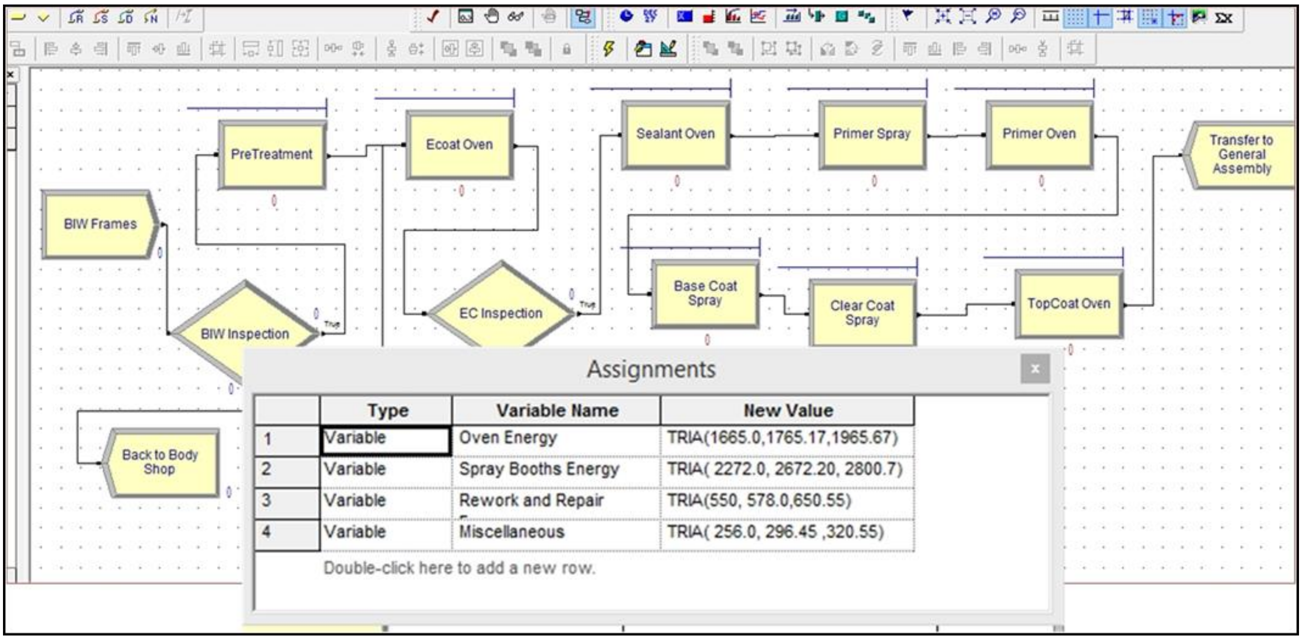

Figure 6. The Paint Shop model showing process-specific-energy consumption.

The first process on the shell of the BIW is the application of pre-treatment and electro-coating, the second process is the sealant application process on the BIW; this is followed by application of the primer layer. Finally, after the primer is cured, a topcoat of basecoat and clear-coat is applied and cured. In this case study, the paint shop facility has four (4) ovens; which are the E-coating oven, Sealant oven, Primer oven, and Topcoat oven. There are also three (3) Spray booths; which are Primer spray booth, Basecoat spray booth and Clearcaot spray booth. The paint shops are the main energy-consuming facility for automobile assembly plants. Here the energy is used for theregulation and conditioning of the air to enable the painting and drying steps. Energy is also used in curing (drying) process and for treatment and abatement of the emissions[29]. The processes of curing rely heavily on steam and natural gas. These curing processes are mostly automated to some degree and utilize numerous robots and computer-controlled systems. According to [29], Ford claimed that 70% of total energy costs are used in the painting operations while all other vehicle assembly processes approximately just use only 30% of its energy costs. According to [29] in Germany, the paint shops utilize about 50% to 60% of the fuel in the assembly plants. Such fuels are primarily used for heating vats(Metal treatment tanks used for the application apply a metallic coating to surfaces), for processes of conditioning the air and thermal oxidation of VOCs in the exhaust. The spray booths are the largest energy consumer in the painting process, while the curing ovens are the second largest energy consumer.In this paper, the considered energy specific processes of the painting job are the Spray Booths (Primer, Basecoat & Clear-coat), Ovens (E-coating, Sealant, Prime & Topcoat), Rework & repair (Defective pain operations job) and miscellaneous (pre-treatment, abatement, etc) as can be seen in the simulation model(figure 6).

3.3. Assembly

This is called the Final Assembly or the general assembly and it encompasses the final steps to produce a finished vehicle. This stage of the vehicle assembly has the highest concentration of supply chain parts that are being assembled in both manually and automated method. The first process started with the body shells (BIW frames) arriving from the paint facility; which started the first stage of the process that will transform the BIW shell into a finished product. This is by its nature a manufacturing process in which the parts are added to the BIW in a sequential method utilizing an optimally planned logistics of all the required parts. This optimally planned logistics enables creation of a finished product much faster than with handcrafting methods. The final assembly, the body, power train, and chassis of the vehicle are integrated with all the final parts. The parts that are added and integrated with the BIW, the power-train, and chassis include seats, dashboard assemblies, interior trim panels, wheels, windshields, and many other interior and exterior trim components. These processes are garnered from the culmination of efforts across numerous departments and suppliers, and the success of assembling a vehicle depends on the reception of each and every one of the components that are necessary to assemble the vehicle; which are produced elsewhere in the plant or by outside suppliers.
The assembling process ranges range from highly-automated robotic systems to a mixture of manual and automated methods. However; regardless of how much the assembling process gets highly automated and complex with use of robots and other automated systems (windshields installation), still the assembling process requires human touch and judgment. In this case study, the facility of the final assembly has a conveyor system for chassis and final line, automatic liquid dispensing equipment, racks and pallets and various other tools.

The process specific energy usage in the final assembly processes rely mostly on electricity and compressed air due to the extensive use of robotics, conveyors, tools and other automated systems results. Energy saving opportunities can be applied assembly operations within the manufacturing facility. There are also external operations outside the facility, such as the suppliers and producers of the components. The external suppliers for assembly line, body shop and paint shop are beyond the scope of this paper. The energy improvement opportunity that exists within this processes include the material handling (reduces length of conveyor systems, reduce plant square footage, and reduce energy in transporting materials). Another opportunity is the creation of appropriate methods a well maintained just-in-time sequencing policy for the arrival of parts and inventory. In addition to that another phase is the engineering aspects of using efficient tooling equipment and the suitable design and layout of assembly system

4. Results and Discussion

The results of the DES model are summarized in graphs (from Figure 7 to Figure 12). Each graph shows two scenarios. The first scenario is based on the actual modelled case of the assembly plant. The second scenario is based on enhanced model in terms of technical improvement of energy efficiency for the automotive industry. The plan is to establish the measurement of the effectiveness of energy reduction initiatives in terms of a technical improvement that corresponds to a certain structural change within the assembly line processes. Figure 7-8 shows the body shop the model which indicated improved consumptions of energy. As has being discussed in section 3.1 the body shop involves the process of creating BIW frame. Figure 7 illustrates the BIW sub-assembly processes Front-Under (FU), Roof and Floor(R&F). The actual process-specific energy scenario of the assembly line is illustrated as the Front-Under, Roof and Floor. While the improved energy efficiency process is indicated with asterisk symbol (*) as can be seen in Figure 7, Front-Under* and Roof and Floor*.

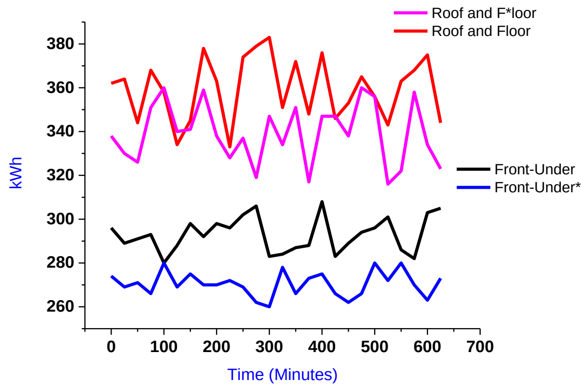

Figure 7. Front-Under (FU), Roof and Floor(R&F energy consumption

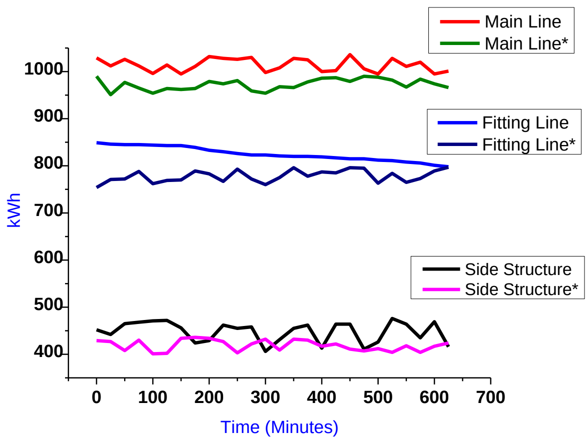

Figure 8. Main line, Fitting Line and Side structure energy consumption

The final assembly, the body shop and paint shop processes were all run in simulations of 625 minutes (10.42 working hours) per day. The body shop processes are the second highest energy consumption; energy consumption was reduced approximately 10% in the assembly of BIW frame. The results of the paint shop model are illustrated in Figure 9-10.

The paint shop has the highest energy usage; the model has indicated improved consumptions of energy (7% in both electricity and LPG). As discussed in section 3.2 the paint shop involves multi stage processes. The process-specific energy consumption at the spray booths, oven, repairing and reworking processes, and miscellaneous or other processes within the paint shop have been modeled and significant differences can be seen from the graphs in terms of technical improving in order to achieve a better energy efficient painting facility.

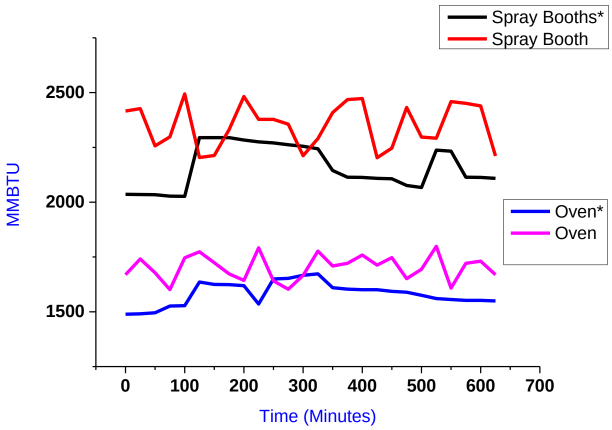

Figure 9. Spray booths and Ovens Energy usage

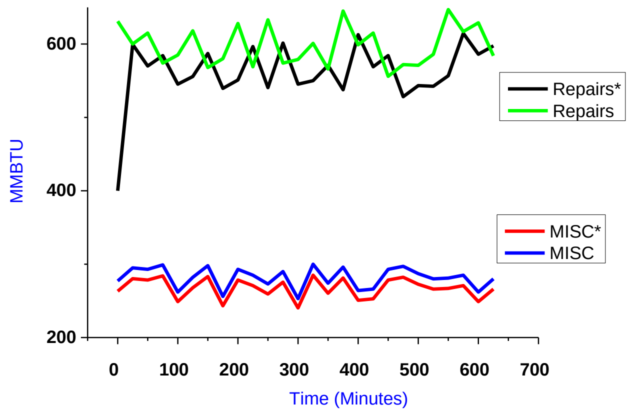

Figure 10. Repairs and miscellaneous Energy usage

Such technical improvements include, for example, within the painting processes improved energy efficiency can be achieved through preventative maintenance. Another example is adjusting the stabilization period to minimum pre-heating time for stabilizing the required temperature of the paint booths and Ovens.

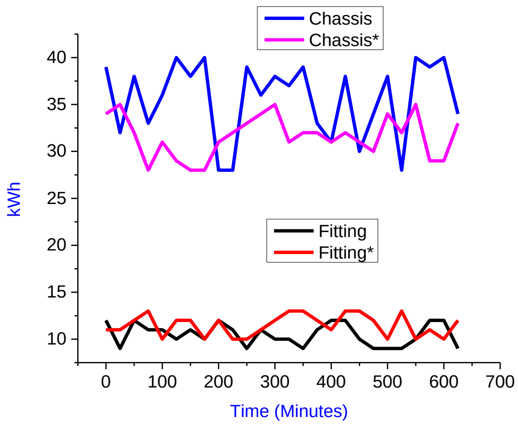

Figure 11. Chassis assembly and fitting line Energy usage

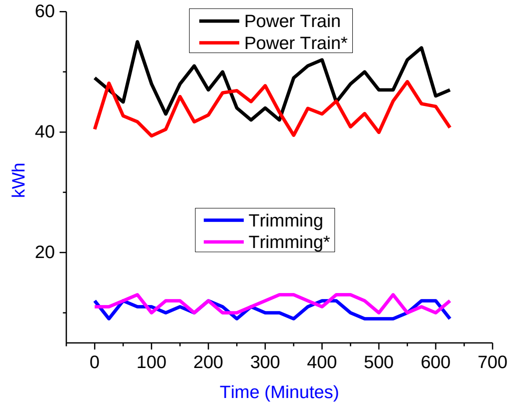

Figure 12. Power Train assembly and Trimming energy usage

The model results of the process-specific energy consumption of the final assembly tasks can be seen in Figure11-12. This facility has the least energy usage. However; reduced energy consumption of the chassis and power train assembly can be seen. Similar results are achieved for the processes involving at the fitting line and trimming jobs. Over all about 11% of electricity consumption at the assembly shop has been reduced.

5. Conclusion and Future research

The presented study demonstrated the use of DES simulation model to assess the energy efficiency of vehicle assembly plant. The DES model was developed using Arena Rockwell automation; in which a detailed model was constructed. The same DES model was then used to improve the energy efficiency by making use of the existing opportunities (weaknesses of efficient energy usage) within the facility. The results of the model indicated weaknesses of energy consumptions. Highest energy consumption for both electrical and non electrical energy (in here LPG) occurred at the painting systems. The BIW assembly processes were the second highest energy consumption, and then followed by final assembly line energy usage as the third highest. From there on technical improvements on the energy efficiency were incorporated to the model and as a consequential of the model change substantial energy was saved.

These results are shown in Figure 7-12 indicating both the actual and also the improved scenarios. The objectives of this paper focus on the improvement of energy efficiency and reductions of energy wastage for the process-specific energy measures of body shop, paint shop, and assembly shop processes in the facility. The body shop energy usage was reduced to approximately 10% in the assembly of BIW frame. The paint shop has the highest energy usage; the model has indicated improved consumptions of energy (7% in both electricity and LPG). And for the assembly shop a reduction of 11% electricity consumption was achieved.

Acknowledgment
This paper was supported by the Internal Grant of the University Malaysia Pahang (RDU: 140311) and Fundamental Research Grant Scheme (FRGS) grant of Malaysian Ministry of Higher Education (RDU140109). The authors gratefully acknowledge the support from Department of Research and innovation, UMP.

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