Energy Efficiency Assessment in Production Line: An Approach towards Sustainable Manufacturing

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Abstract: Global demands of energy which causes a quick depletion of the natural energy reserves become a critical concern. Industrial sector is concerned to be the largest energy consumer compared to other sectors. Thus, an energy efficiency improvement tends to be a proper solution in addressing this problem. This work aims to analyse a prospect energy efficiency improvement within a production line. A discrete-event simulation (DES) was used to investigate the energy saving potential and a case study was conducted in a crumb rubber company. Three parameters were taken into consideration to calculate the energy consumption, i.e. processing time, working shift schedule, and machine states. An initial model which represents an actual condition of the manufacturing production line was developed. From the analysis of the initial model result, a recommendation scenario was built. It was shown that a reduction of 8.22% in the energy consumption is achievable by implementing the suggested scenario.

Keywords: energy efficiency; discrete-event simulation (DES)

1. Introduction
The combustion of fossil fuels generates and releases greenhouse gas (GHG) emissions which predominantly composed by CO2 to the atmosphere as the by-product of the energy use. Industrial sector plays a vital role of the occurred global environmental changes, since it contributes to around a half of the total share of the global energy consumption [1]. Moreover, it is projected that the trends of the energy consumption in this particular sector will exhibit a significant growth to up to 38% between 2017 – 2050 [2].

Responding to such associate environmental drawback which doubtlessly may harm the ecosystem and the life in the future, a conversion from the prevailing production system into more sustainable system is becoming an imperative resolution [3]. To date, discussions associated with the energy measurement, monitoring, modelling, and optimization in machining facilities are significantly high [4]. Cai et al. [5] suggested that in order to boost the energy efficiency in the manufacturing system, a possible solution is by shifting the prevailing energy intensive production facilities into highly efficient machining tools. Jirasuwankul [6] conducted a research on improving energy efficiency use in induction motor drive system using fuzzy logic. Liu et al. [7] proposed an approach for acquiring the real-time energy efficiency (REE) of machining tools. De Carvalho & De Oliveira Gomes [8] investigated the reduction of electrical energy consumption during standby mode. An exploration of possible improvement of the energy consumption through visualization of manufactured parts in the machining systems is provided by [9]. These research are mainly conducted at product and machining level. However, analyses specifically on the products or machining tools do not adequately represent the manufacturing system as an entire. Thus, a more holistic view would be required.

Production line is considered to be the foremost intensive energy consumer in a manufacturing system. Each machine is operated differently and consume energy unequally subject to different products being manufactured, processing time, machine states, etc. Energy consumed in production processes can be divided into two categories: value added energy (VAE)
and non-value added energy (NAE) [10]. Non-value added energy can be considered as waste and need to be reduced. Thus, this paper aims to investigate the attainable energy efficiency improvement in the production line by considering the value-added and non-value added energy consumption. The analysis was carried out by employing a discrete-event simulation (DES) approach to simulate the material and energy flows of production line. Three parameters were taken into consideration to calculate the energy consumption, i.e. processing time, working shift schedule, and machine states.

2. Energy Consumption in the Production Line

2.1 Research Framework
In order to achieve the goal on measuring the energy consumption and determine the energy efficiency improvement in a production line, a comprehensive research framework is necessary to introduce. The research framework presented here is an adaptation of a proposed steps in simulation study [11].

The initial step of the simulation study is by defining the problem formulation and setting of objectives. Afterwards, the next step is continued to establish a conceptualized simulation model, and the collection of the supported data. The simulation model conceptualization has a strong interplay with the data collection as the complexity of the model changes, it directly changes and affects the required data elements. The fifth step is the translation of the real-world system into a computer-recognizable format or the artificial environment.

This model translation would be executed in a simulation software, namely Tecnomatix Plant Simulation®. The next step is the verification to ensure the simulation model accurately represent the actual system condition. If the input parameters and logical structure of the simulation model is judged acceptable, thus the verification and validation have been completed. In order to investigate the determined goal which in this case is the energy efficiency improvement, the experimental design of alternatives condition should also be developed. The evaluation is used to estimate the improvement of the energy efficiency potential. Finally, the models and the associated results should be documented and reported.

2.2 Conceptual Simulation Model
A conceptual simulation model is designed to show the essential features of the problem. Certain bound parameters are considered in order to analyse the energy efficiency throughout the production process. The model takes into consideration three parameters which represent the dynamic characteristic of the production system in terms of energy consumption: processing time, material flow, and machine states (e.g. idle, setting up, stand-by, operational, production, and breakdown).

According to [12] three alternatives are often considered to set up the duration and power for each operational or machine state: a constant value, a predetermined probability distribution function, and a mathematical equation of the existing empirical models of the unit process. A few operational states possess relatively constant trends such as standby, idle, rump up, etc. Hence, the first two options are sufficient to configure the aforementioned conditions in the simulation. The last option is regarded to be the foremost adequate to characterize the energy consumption and process parameters which featuring dynamics behaviour. In order to realize the target and to facilitate a much better understanding upon the proposed methodology, this conceptual model is divided into sections to introduce the interlinked relationships of the mentioned parameters with the quantity of energy consumption.

2.3 Production energy consumption
Numerous parameters associated with the machine state would directly specify the performance of machine tools in terms of energy consumption. The production line produces energy profiles dynamically over time that consists of many intense energy consuming components depending
on the process parameters and the actual states of the machine [13]. According to [14], the energy consumption at a facility can be formulated with the subsequent equation:

\[ E^k = e_r^k T_r^k + e_s^k T_s^k + e_b^k T_b^k + e_i^k T_i^k \]  

(1)

where:
- \( E^k \) = Total energy consumption in facility \( k \),
- \( e_r^k \) = Energy consumption per unit time during run state in facility \( k \),
- \( e_s^k \) = Energy consumption per unit time during setup state in facility \( k \),
- \( e_b^k \) = Energy consumption per unit time during breakdown state in facility \( k \),
- \( e_i^k \) = Energy consumption per unit time during idle state in facility \( k \),
- \( T_r^k \) = Run state time in facility \( k \),
- \( T_s^k \) = Setup state time in facility \( k \),
- \( T_b^k \) = Breakdown state time in facility \( k \),
- \( T_i^k \) = Idle state time in facility \( k \)

2.4 Machine States

Every production activity that employs machinery habitually experiences several conditions. Each condition consumes a totally different quantity of energy due to undertaken at different processing times. There are at least five operational states exist during the production period and are defined as follows:

- Setting up: refers to the period of time which correlates with the adjustment for production product changing.
- Production: refers to the state or condition when the machine is performing work to produce desirable products, it is typically associated with the value-adding condition.
- Stand-by: refers to the state or condition when the machine remains activated at the operational readiness for performing tasks.
- Idle: refers to the condition or the state when the machine is not doing any useful work or no material order to be processed, however certain necessary components remain activated (e.g. control panel).
- Breakdown: refers to the condition or the state when the machine fails to produce products and should be deactivated for maintenance due to experiencing certain troubles.

3. Research Methodology

The research framework presented here is an adaptation of a proposed steps in a simulation study by [6]. The initial step of the simulation study is by defining the problem formulation and setting of objectives. The next step is continued to establish a conceptualized simulation model, and the collection of the supported data. The simulation model conceptualization has a strong interplay with the data collection as the complexity of the model changes, it directly changes and affects the required data elements. The fifth step is the translation of the real-world system into a computer-recognizable format or the artificial environment.

In order to investigate the determined goal which in this case is the energy efficiency improvement, the experimental design of alternatives condition should also be developed. The alternatives experimental design is required for the decision making support which the result is compared with the initial system condition. Subsequently, the alternative model is executed. The result of the initial and the recommendation models should be evaluation. The evaluation is used to estimate the improvement of the energy efficiency potential. Finally, the models and the associated results were documented and reported.

3.1 Initial Model Development

A discrete-event model simulation is employed to experiment and analyse the energy consumption as well as the energy saving potential of the production line in manufacturing system. The simulation was developed by using Tecnomatix® simulation software. To represent
the actual condition of the company’s production line, an initial simulation model is developed. Several variables and parameters, such as processing time, working shift schedule, and energy input if machine states have been defined as the input data for the simulation. Figure 1 and figure 2 below depict the layout design of the facilities and the hotspot plotting of the simulation running result indicating which facilities possess larger energy consumption. Working shifts of the wet and dry processes were set up to control the working period of the production line.

![Figure 1. Initial production line simulation model](image1)

![Figure 2. Hotspot plotting](image2)

Besides hotspot plotting, the simulation running of the initial model also showed a distribution of the energy consumption in each facility according to the machine states as depicted in figure 3 below.
3.2 Alternative Scenario Model Development
The energy efficiency can be attained by reducing the non-added energy expenditures. In the alternative scenario a modification of the parameter setting was done for the hammermill B machine due to it consumed larger energy for non-added activities as indicated in the initial simulation result. The hammermill B consumed the largest portion of the non-added energy value, in the form of operational or idle time. In the actual condition, the hammermill station which consists of two machines, namely hammermill A and hammermill B are utilized interchangeable in random scheduling during the production process. However, both machines are still kept active, even though only one machine is undertaking the production activity. This operational configuration is applied to minimize the pre-production time during a sudden breakdown which occurs quite often of either machine being operated. Besides that, several peripheral elements such as a water pump, which integrated with both machine is activated while one of the machines is turned on. This led to high energy consumption of unfortunately associated with the non-added value. A scenario was suggested to reduce the non-added proposed to improve the energy efficiency in the simulation is by adjusting the associated operational state condition. It is assumed if both machines have separate water pump installation in each machine, so that when one machine is turned off, the operational energy can be lowered.

4. Result and Discussion
This part will discuss the result of the simulation into details. The result consists of the energy consumption estimation and its distribution according to the machine state, which is a parameter that influences the fluctuation of the energy consumption of a facility. The energy efficiency saving potential from the comparison of the initial and the alternative model is also explained.

4.1 Initial Simulation Result
A simulation approach is conducted to estimate the energy consumption of the production line in the manufacturing company. Several variables and parameters, such as processing time, working shift schedule, and energy input of machine states have been defined as the input data for the simulation. Figure 4 (a) and (b) below depict the fluctuative power consumption and the hotspot plotting of the simulation running result indicating which facilities possess larger energy consumption. Working shifts of the wet and dry processes were set up to control the working period of the production line. From the simulation result of the case study, it shows that the energy expended in the production line behaves dynamically depending on certain factors as illustrated in figure 4 (a). Energy input, processing times, working schedule, and machine state are among
the driving factors of the fluctuation of the energy consumption. Figure 4 (b) shows the allocation of the energy consumption distribution based on the machine states of the production facilities.

![Power Consumption](image1)

![Energy Consumption of the Selected Resources](image2)

**Figure 4.** (a) Energy plotter; (b) Energy distribution chart of initial model

From the figures above, it can be seen that the energy was mainly expanded during the working, operational, and failed states. An insignificant amount of energy was expended on the stand-by state. Energy expenditure can be classified into two main categories, namely added-value energy and non-added value energy. The added-value energy is defined as the energy consumed when a machine is running due to the existence of a material being processed. Energy consumed during the working state is considered to be an added-value energy, while on the other hand, the other states are considered to be the non-added value energy since they do not directly correspond to the material processing activities.

Apron dryer, mangal machine, and hammermill B machine were the major consumers of the energy in the production line. However, the mangal machine and the apron dryer consumed energy majorly for the value-added purposes, whilst the energy in the hammermill B machine was much more expended for the non-added value one in terms of operational or idle time.
4.2 Model Validation
The model validation was used input-output validation technique. The sample data were collected from the company’s historical documentations and the available data from the company were hourly power documentations in February 2018. The total actual energy consumed is obtained from company’s energy bill in February 2018. To validate the model, the total actual energy consumed within the production line is compared with the energy consumption resulted from simulation. The confidence interval is set to 95% for the simulation.

The simulation model has been set to run for a month. The total monthly energy consumed from the simulation result is 642235.50 kWh. This value is generated by summing the total energy consumed during each machine states of each facility, processing time, and working shift schedule. Figure 2 depicts the total simulated energy consumption of the initial model in the production line. In addition, the actual energy consumption as shown on energy bill in February 2018 is 633984.20 kWh. Table 1 shows the comparison of the simulation result and the actual data.

| Table 1. Comparison of the simulated result and the actual data |
|---------------------------------------------------------------|
| Actual | Simulation | Difference | Percentage |
| Energy Consumption (kWh) | 633984.20 | 642235.50 | 8251.30 | 1.30% |

From the table above it can be seen that the percentage error of the simulation result and the actual data is 1.30%. Thus, the simulation result is considered valid since it is within the targeted percentage error.

4.3 Alternative Scenario Simulation Result
The energy efficiency can be attained by reducing the non-added energy expenditures. In the alternative scenario a modification of the parameter setting was done for the hammermill B machine due to it consumed larger energy for non-added activities as indicated in the initial simulation result. The hammermill B consumed the largest portion of the non-added energy value, in the form of operational or idle time. In the actual condition, the hammermill station which consists of two machines, namely hammermill A and hammermill B are utilized interchangeable in random scheduling during the production process. However, both machines are still kept active, even though only one machine is undertaking the production activity. This operational configuration is applied to minimize the pre-production time during a sudden breakdown which occurs quite often of either machine being operated. Besides that, several peripheral elements such as a water pump, which integrated with both machine is activated while one of the machines is turned on. This led to high energy consumption of unfortunately associated with the non-value added energy. A scenario was suggested to reduce the non-value added energy by assuming both hammermill machines have separate water pump installation, so that when one machine is turned off, the operational energy in both machine can be lowered. From the figure 5, it can be seen that by applying the proposed scenario a reduction on the non-added value energy in the hammermill B machine is achievable.
4.4 Energy Efficiency Evaluation
The simulation of both conditions resulted a significance difference. A proposed improvement scenario which can be done to minimize the energy expenditure is by implementing a reduction of non-added value energy. The implementation has been made within the hammermill B machine. After the suggested scenario executed by using the simulation, a promising energy efficiency improvement has been achieved. The initial simulation model generates energy of around 642,236.5 kWh a month, whilst after the alternative scenario has been implemented, the system only consumes 589,418.3 kWh a month. Thus, the energy efficiency can be improved for around 8.22%.

5. Conclusions
An investigation conducted in the system could give a chance to achieve a potential reduction of the consumed energy. In this paper an energy assessment by employing a discrete-event simulation (DES) approach is presented. Initially, a model which represents the actual condition was established, afterwards the simulation was run and analysed. From the analysis of the initial simulation result, an improvement scenario can be developed. Certain parameters, such as processing time, working shift schedule, and machine states was taken into account to see the significant impact of the expended energy quantity. A measure that can be done to minimize the energy expenditure is by reducing the non-added value energy within the production system. In the case study, the hammermill B machine was the major consumer of the non-added value energy, in the form of idle time. Thus, a suggestion proposed to improve the energy efficiency is by separating water pump installation in each machine, so that when one machine is turned off, the operational energy can be lowered. This modification is directly related to an adjustment of the machine states, which is one of the parameters included in the study. By implementing the suggested scenario, 8.22% of the energy consumption reduction can be achieved.

This study was solely conducted to investigate the electrical energy efficiency within a production system, without considering other economic or environmental impacts evaluation. Furthermore, beside energy intensive, crumb rubber manufacturing is also water intensive. An effort to manage the water consumption would be beneficial to pursue the sustainability manufacturing.

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