Modeling Energy Efficiency As A Green Logistics Component In Vehicle Assembly Line

MODELING ENERGY EFFICIENCY AS A GREEN LOGISTICS COMPONENT IN VEHICLE ASSEMBLY LINE

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Abstract. This paper uses System Dynamics (SD) simulation to investigate the concept green logistics in terms of energy efficiency in automotive industry. The car manufacturing industry is considered to be one of the highest energy consuming industries. An efficient decision making model is proposed that capture the impacts of strategic decisions on energy consumption and environmental sustainability. 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. SD is the chosen simulation method and the main green logistics issues considered are Carbon Dioxide (CO2) emission and energy utilization. The model will assist decision makers acquire an in-depth understanding of relationship between high level planning and low level operation activities on production, environmental impacts and costs associated. The results of the SD model signify the existence of positive trade-offs between green practices of energy efficiency and the reduction of CO2 emission.

1. Introduction

The nation of green logistics can be considered as a part of green supply chain management (GSCM); which seeks the integration of environmental thinking into closed-loop supply chain management [1]. While another definition of green logistics mentioned in [2], states it is the integration of the environmental features into logistics activities and managing in a way that considers the environment in every decision making process across logistics networks. Nevertheless, in many industries the terms such as green logistics, green supply chain and reverse logistics are used to refer to implementation of sustainable proactive environmental protection measures on manufacturing and transportation.

As shown in [3] logistics is nowadays extensively used to describe the activities involving the transport, storage and handling of products as manufactured goods moving from raw material source, throughout the production system to the sales point or consumption as the final destination of the products. The main objective of logistics is the coordination of typical logistical activities which consist of freight transport, storage, inventory management, materials handling etc, with convenience

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to the customer requirements at minimum cost. The management of logistics focuses on the integration of the entire the activities required to move products through the supply chain. In the past logistical costs were determined based on mere purely monetary terms. However; concerns of increasing environment issues were noticed. Such as the impacts of CO2 emissions which have been recognized on climate change by governments, international organization and companies.

As a result, proposal of mitigation policies such as emissions trading schemes, green taxes and environmental management systems has been put forward [4]. Therefore it is indispensable to consider the external costs of logistics associated primarily with climate change, air pollution, noise, vibration and accidents etc as mentioned in Piecky et al. (2012). There are number of ways of reducing environmental adversaries in logistics. For example, depending on the nature of the organization, inventory strategy can be ways of mitigating. One strategy is known as the shipment consolidation (SCL); which is s the purposeful intervention by management to frequently join several small shipments so that a larger load may be dispatched on the same vehicle [6]. Traditional the SCL based decisions were employed to minimize total inventory and transportation costs. It has been presented in [7] analytical models for joint stock replenishment and temporal shipment consolidation decisions and compares their relative cost effectiveness. The models were based on shipment release policies; both time-based and quantity-based. Many research has been conducted on green logistics across varied industries as mentioned in [8,9]. Green logistics research on automotive industry; which compromises all the facilities, processes and activities involved in the manufacture of motor vehicles is limited. In this paper green logistics will be assessed in automotive assembly line. Within this context, green logistics initiatives focus on minimizing greenhouse gasses (which raise the temperature near the surface of our planet) such as carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) , re-use and recycling of materials, waste disposal and optimal utilization of energy as shown in [10–12]. In this research the environmental externalities are CO2, and energy wastage from automotive assembly line and while the energy conservation is considered as a green (environmentally friendly) objective.

However; before the construction of the model is commenced it is fundamentally important to obtain a suitable conceptual model that can fit the description of the high level view of green logistics infrastructure. Figure 1 shows the causal loop diagram (CLD) of the model. The CLD serves as the visualization tool. This is a high level system consideration of how different variables in a system are interrelated. As can been below, the diagram consists of a set of nodes and edges. The nodes represent the variables while the edges are the links that represent a relation or a connection between the two variables. A connection marked positive specifies a positive relation and a connection marked negative specifies a negative relation. A positive causal link means the two nodes change in the same direction while a negative causal link means the two nodes change in opposite direction. Table 1 illustrates the various relationships existing can arise between factors affecting the assembly line energy consumptions i.e. the green operation policy has positive relationship with Maintenance and control and while the green operation policy has negative relationship with the Painting Booths.

Table 1. Green Operational Policy

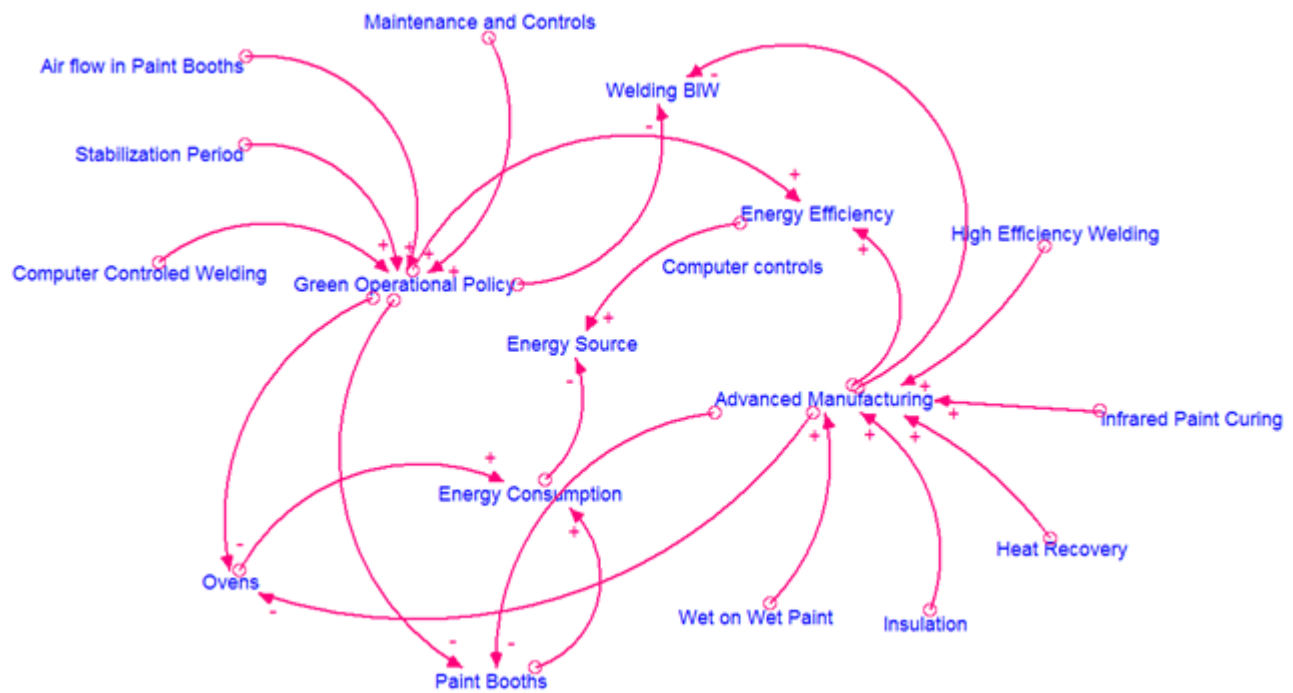| Green Operational Policy	Relationship
Maintenance and control	Positive (+)
Air Flow in Paint Booths	Positive (+)
Stabilization Period	Positive (+)
Computer Controlled Welding	Positive (+)
Energy Efficiency	Positive (+)
Painting Booths	Negative (−)
Painting System: Ovens	Negative (−)
Welding BIW	Negative (−)

Figure 1. CLD showing the cause and effect of Energy consumption in the Assembly Line

The CLD provides a diagram of the positive and negative reinforcements which describes the system behaviour. A shown on Figure 1, for example, the Green Operational Policy and the Painting Ovens share negative (−) relation. From logical perspective, this is true. As the Green Operational Policy increases, the energy consumption at the Ovens decreases. The factors that have positively effect on Green Operational Policy are: Maintenance and Control, Air Flow in Paint Booths, Stabilization Period and Computer Controlled Welding. As these factors increase, it will also increase the standard of the Green Operational Policy.

Table 2. Advanced Manufacturing

Advanced Manufacturing	Relationship
High Efficiency Welding	Postive(+)
Infrared Paint Curing	Postive(+)
Heat recovery	Postive(+)
Insulation	Postive(+)
Wet on Wet Paint	Postive(+)
Energy Efficiency	Postive(+)
Painting System: Ovens	Negative (−)
Welding BIW	Negative (−)
Painting Booths	Negative (−)

The factors such as High Efficiency Welding, Infrared Paint Curing, Heat recovery, Insulation, Wet on Wet Paint and Energy Efficiency have positive reinforcement link to Advanced Manufacturing. While the Painting Ovens and Booths, Welding of BIW have negative reinforcement link to Advanced

Manufacturing. Table 2 summarizes such relationships. As can be seen from figure 1 energy efficiency is affected by Green Operational Policy and advanced manufacturing. Therefore, Green Operational Policy and advanced manufacturing are the tools for improving the energy efficiency. Basically, Advanced Manufacturing is the integration of innovative of technology based on used to improve products or processes. While within the scope of this paper Green Operational Policy are the set of rules and regulations to make the production facility environmentally friendly by reducing energy consumption.

2. Background Study

Sustainability is very important in today`s life. As indicated in [13], since the introduction of ISO 14000 standard, it is recognized worldwide that sustainability is increasingly becoming an important business factor, organizations are now looking for methods and tools to help assess the fuller picture of the environmental impacts associated with their manufacturing and supply chain activities. From economics perspective the logistics and transportation frequently conflict with sustainable design of logistics and environmental responsibility[6]. Energy efficiency has attained fundamental importance in the industrial sector because of the growing energy costs and the associated environmental impacts [14]. The environmental policy implications of lower energy use have led to the development of voluntary government programs for energy efficiency. Environmental sustainability such as the reduction of Carbon Dioxide (CO_2), energy and water conservation in automotive industry creates unfavourable conditions for the inventory and production costs.

It is a norm that even the most successful automotive companies in the world believe that environmental responsibility is not only good for business; bit it is becoming an integral part of the way vehicles are marketed, purchased and driven. With this in mind there has been limited research on green logistics modeling and simulation in automotive industry. 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 [15]. Many analytical software models for energy sustainability were developed as can be seen in [16–20]. The use of an energy oriented simulation model for the planning of manufacturing systems based on two industrial case studies was demonstrated by [21]. 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 [19]. This research claims that most of the DEA-related energy efficiency studies do not focus on the modeling of CO_2 emissions.

Nevertheless numerous past researches have contributed to the evaluation of energy efficiency performance exploiting different analytical methods including DEA[19]. 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 CO_2 emissions. Wu et al [19] 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. The results of the simulation model will provide answers on how to improve significantly the conflicting tradeoffs between the operating costs of automotive assembly line and reasonable solutions to environmental adversaries. And to what degree changes can be made on logistical policies that can satisfy both requirements provided the fact that optimum logistical design based on costs does not necessary equate to an optimum solution for CO_2 emissions, energy and water

conservation[10]. The outcome of the model is expected to assist decision making processes; the SD model should support high level decision making.

3. The Assembly Plant

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 four (24) to twenty (28) automobiles per day for 10 hours per day (one 8 hour shift, including 2 hours overtime).

Only the assembly will be done in the plant no parts manufacturing. All parts and components will be delivered from outside suppliers. Just like any other automotive industry here, Just in sequence (JIS) inventory strategy is employed which matches just in time (JIT) strategy. JIS strategy offers a fit in sequence with variation of assembly line production. All need components and parts arrive at the assembly line right in time as scheduled before they get assembled.

In this paper, a simulation model is produced that can mimic and capture environmental concerns such as CO_2 emission and energy utilization. In this study two issues will be investigated. First, the impact of decisions from strategic management has on production costs and environmental sustainability. Secondly, the best way of aligning the conflicting tradeoffs between environmental sustainability and profit will be investigated.

3.1. Logistical flow in the assembly plant

As usual most of the automotive assembly plants usually are divided into five major departments. In this study considered assembly line has five important departments: (1) body shop (or Body in White), (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 2, the flow of materials, from inventory (parts and components) arrival to a finished passenger car (stored in the motor pool).
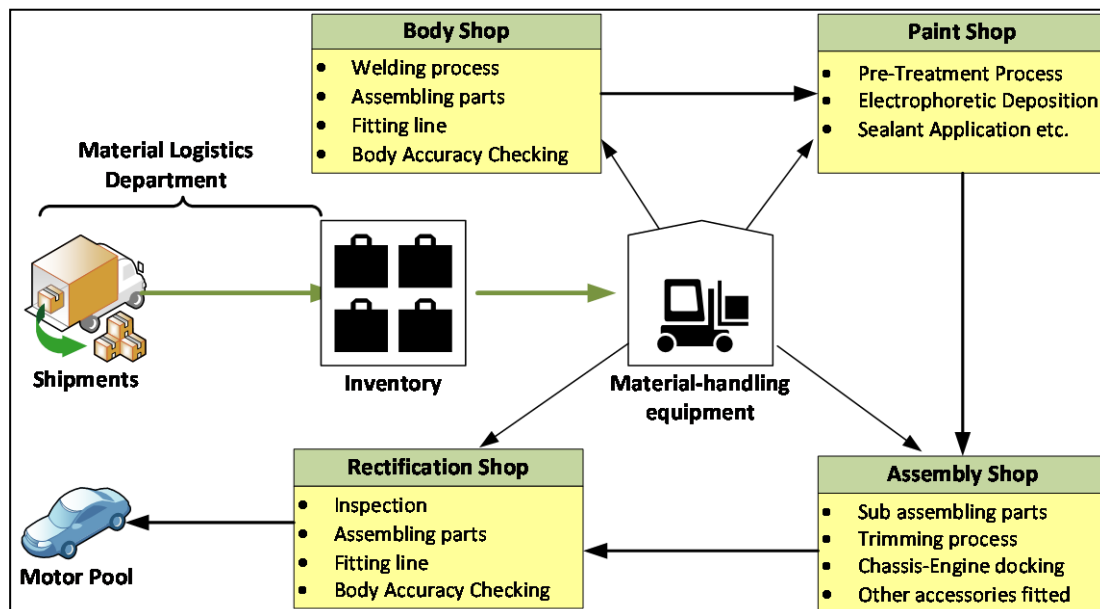

Figure 2. Overview of logistics flow at the assembly

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. Body in white (BIW) is will be used to refer processes and tasks that has been performed in the body shop.

3.2. Data Collection

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. A detailed data of monthly energy consumption for three years were gathered from the relevant departments. A detailed data of monthly energy consumption for three years were gathered from the relevant departments.

Table 3. Electricity Consumption

Department	KWh per month	Percentage
Assembly shop	62,536.82	6.5%
Body shop	194,789.56	20.20%
Paint shop	706,761.37	73.30%
Total	964,087.75	100%

The collected data are summarized in Table 3 above and Table 4 below. Table 3 shows the data pertaining to monthly electricity consumption. While Table 4 data are specific to fossil fuel (in this case LPG) consumption; which are mostly used for the paint shop operations.

Table 4. LPG Consumption

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

Table 3 above shows 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. The next section will cover SD modeling of the energy consumption combined with energy efficiency techniques.

4. Simulation Model

As mentioned earlier, this research work deals with automotive assembly plant environmental externalities such as CO2 emission and energy utilization. The data were collected from an actual automotive assembly. The name of the plant and its location is omitted for privacy related concerns. The authors adopt as support tool a simulation model capable of recreating the high level decision making on green logistics.

The simulation model is implemented using the commercial system dynamics simulation software Ithink ISEE systems[22]. The Ithink package is one of the popular tools for SD modelling as motioned

in (Hao, Tam, & Yuan, 2010, Merrick & Bookbinder, 2010). This package is specifically designed for communicating interdependencies between processes and problems. It is allowed the structure of a process or strategy to be rigorously linked to the associated dynamics. Its key features of mapping and modelling include (ISEE systems, 2104): stock and flow diagrams support the common language of systems thinking and provide insight into modelled business processes, casual loop diagrams present overall casual relationships, model equations which automatically generated and sub-models for supporting hierarchical model structures.The central "Ithink" window is separated into four tabbed sheet: the Map, Model, Interface, and Equation. Each tab stand for a distinctive layer in the model and each one offer a different technique of creating and formulating a model. The Map layer provides mechanism of thinking in the form of a map. As for the Model layer is used for converting maps into simulated models. The Interface layer provides mechanisms of it transforming a model into a powerful platform for learning. The last layer is the Equation layer which lists all the equations that make up the model.

In this paper five sub-models were developed for energy consumption and CO2 emissions. This SD sub-model was built using data collected from paint shop department LGP usage, electricity and consumption, assembly shop and body shop for electricity consumption. The energy consumption model before and after the implementation of green policy is depicted in Figure 3 below. According to Ngai et al. [20] 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 greenhouse gases is the control and reduction of unnecessary energy and utility consumption.

In order to achieve efficient environmentally friendly production system, a green policy was enforced based behavioral changes on energy consumption. This can be jointly implemented with engineering practices based on modifications and the use of energy efficient equipments in paint shop (boilers and burners), body shop and assembly shop departments. There are five components that will be used to represent the structure and behavior of the chosen system: stocks, flows, information flows, convertors/constants and a source/sink. An icon represents each component.
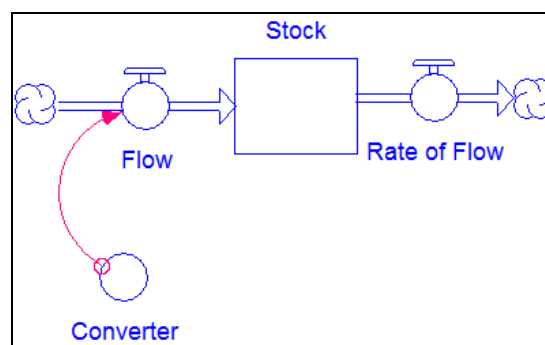

Figure 3. The components of the Model

Figure 3 shows the basics of the Stock and Flow systems modelling. The Stock and flow diagrams provide a richer visual language than causal loop diagrams.

Stocks: Quantities that can be accumulated over a period of time by inflows or depleted by outflows.

Flows: Flows represent the rate at which the stock is changing at any given instant. Flows connect stocks or source/sinks. The flow will increase any stock that it flows into or decrease a stock that it flows out of. All the flows that are connected to a stock will have the units of whatever the units of the stocks are per time.

Connectors: Much like in causal loop diagrams the connectors of a system show how the parts of a system influence each other.

Source/Sink: These are stocks that lie outside of the models boundary – they are used to show that a stock is flowing from a source or into a sink that lies outside of the models boundary.

Converter: Also known as constant is used for storing constant values that can be used for making calculations. Converters either represent parts at the boundary of the system (i.e. parts whose value is not determined by the behaviour of the system itself) or they represent parts of a system whose value can be derived from other parts of the system at any time through some computational procedure. The total energy consumption in terms of MMBTU for the painting systems both as electricity (after converting to MMBTU) and LPG is 4,756.71 MMBTU. Therefore energy is measured in MMBTU throughout the model. Below is show in the mathematical formulation of the model in terms of BIW, Assembly Line and Painting Systems.

The actual Energy consumption for BIW:
  *Actual_EC_BIW(t) = Actual_EC_BIW(t - dt) + (Actual_EC_Rate_BIW) * dt*
  Actual_EC_Rate_BIW = RANDOM(630, 664, 13)

Improved Energy consumption for BIW:
  *Improved_EC_BIW(t) = Improved_EC_BIW(t - dt) + (Improved_EC_Rate_BIW - Rate_in_BIW) * dt*
  Improved_EC_Rate_BIW =
  *Actual_EC_Rate_BIW ((Process_Tuning+Advanced_Manufacturing)*Actual_EC_Rate_BIW)*

The actual Energy consumption for Painting:
  *Actual_EC_Painting(t) = Actual_EC_Painting(t - dt) + (Actual_EC_Rate__Painting) * dt*
  Actual_EC_Rate__Painting = RANDOM(4680, 4756, 17)

The Improved Energy consumption for Painting:
  *Improved_EC_Painting(t) = Improved_EC_Painting(t - dt) + (Rate_of_Usage - Rate_in_Painting) * dt*
  Rate_of_Usage = (Actual_EC_Rate__Painting)-(Reduction_of_Energy_Usage)

The actual Energy consumption for Assembly:
  *Actual_EC__Assembly(t) = Actual_EC__Assembly(t - dt) + (Actual_EC_Rate_Assembly) * dt*
  Actual_EC_Rate_Assembly = RANDOM(190, 213.21, 11)

The Improved Energy consumption for Assembly:
  Improved_EC__Assembly(t) = Improved_EC__Assembly(t - dt) + (Imporved_EC_Rate__Assembly -
  *Rate_in_Assembly) * dt*
  Imporved_EC_Rate__Assembly =
  *(Actual_EC_Rate_Assembly)-(((Advanced_Manufacturing)+(Process_Tuning))*Actual_EC_Rate_Assembly)*

Energy efficiency for BIW and Assembly line:
  Process_Tuning = 0.05
  Advanced_Manufacturing = 0.05

Energy efficiency for the painting systems:
  *(Advanced_Manufacturing+Maintenance_and_controls+Airflow_in_Booths+Stabilization_Period+Insulation+Heat_recovery)*Actual_EC_Rate__Painting*
  Airflow_in_Booths = 0.01
  Heat_recovery = 0.02
  Insulation = 0.01
  Maintenance_and_controls = 0.01
  Stabilization_Period = 0.015

The above formulation is mathematical formulas, ratios, and initial value of the model created using the system dynamics method. EC is an abbreviation of Energy consumption, and the EC at Painting, BIW, and Assembly were all modeled. The energy consumption at the BIW has two scenarios, first is the actual energy consumption and the second is the improved energy. Similarly, the painting system and assembly line has also an actual energy consumption and improved energy consumption.

The entire energy consumption model of the assembly line is illustrated in Figure 4. The sub-models are separated by sectors. The first sub-model shown here is the painting systems and below is the sub-model for BIW and Assembly. The two sub-models are then connected energy to efficiency opportunities as another sub-model. The variables for energy efficiency opportunities were adopted from previous research   conducted by [24]; this research mainly focused on the potentials energy efficiency opportunities for vehicle assembly plants. Within this context, the energy efficiency opportunities can be initiated by improved management and maintenance of the painting, BIW and assembly lines, optimization of heat distribution and recovery in existing paint lines, changes in painting, BIW and Assembly systems. This also includes the optimization process tuning and advanced manufacturing for all the assembly plant departments.
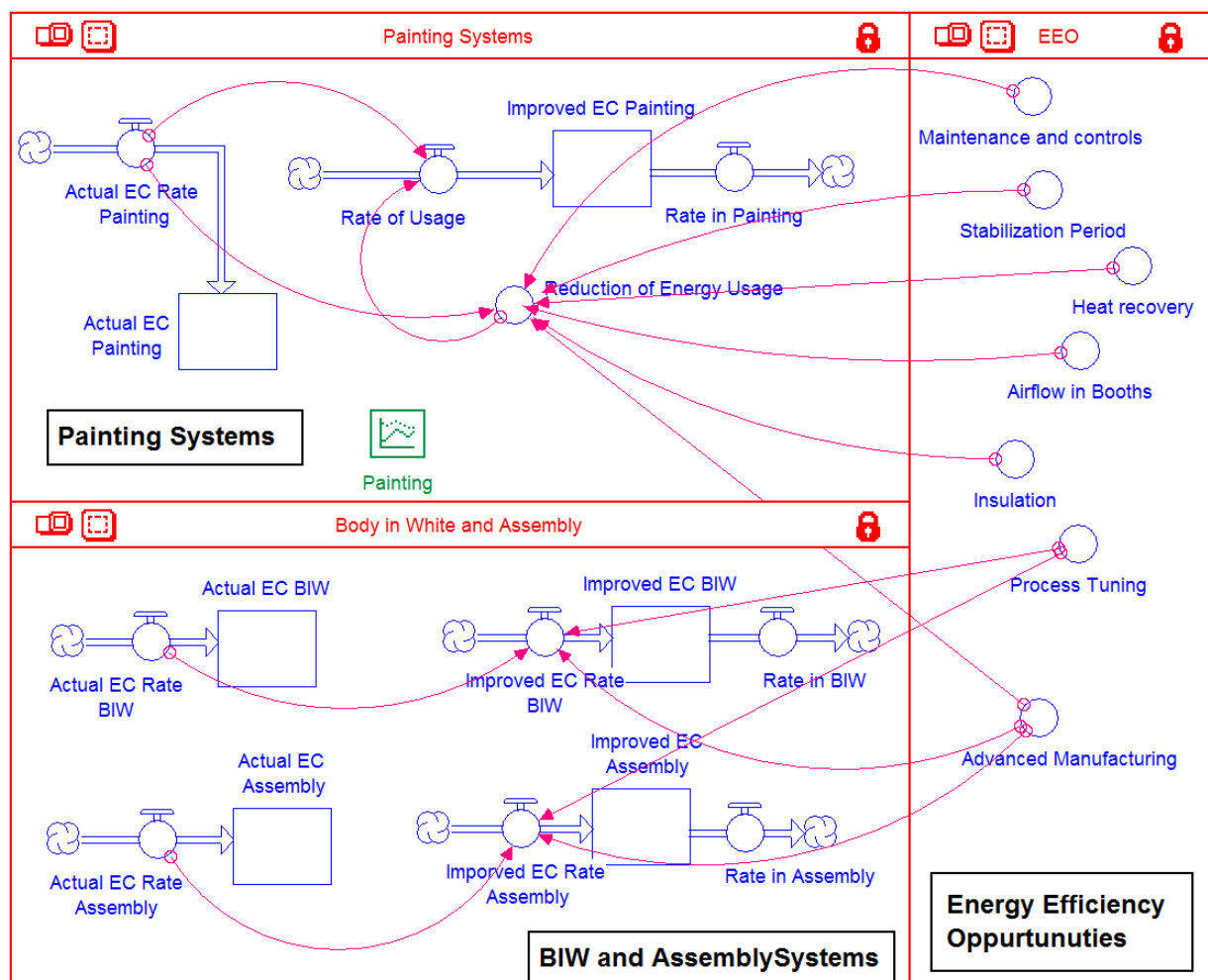

Figure 4. Stock and Flow modelling of Energy efficiency for Painting, BIW and assembly systems

The energy efficiency measures can be categorized into two categories. The first category is the utility systems energy efficiency measures (general, motors, compressed air, heat, and steam distribution, lighting, HVAC, material handling). And the second category is the measures of energy efficiencies which are process-specific, characterized by the process to which they apply (painting, welding, and stamping). The model only captures the process-related energy efficiency measures for the vehicle assembly industry of painting systems, BIW and assembly.

Therefore, energy efficiency measures for general, motors, compressed air, lighting, HVAC, material handlings are beyond the scope of this model. The model is also incorporated with CO_2 emission converter in which both the emissions from the actual assembly plant energy consumption scenario and the improved energy usage were included. Less energy consumption signifies less CO_2 emission.

5. Simulation Results

The results of the SD model are summarized in graphs (from Figure 5 to Figure 8). The model indicated improved consumptions of energy. The emissions of CO_2 were also mitigated; which eventually will reduce the costs of energy. In general the SD models focus on the dynamic behaviour of systems or time paths; that is the behaviour of systems over time. Figure 5 illustrates the behaviour of the painting systems over period of 12 months.

As for Figure 5, the graph compares modeled actual data of energy consumption from the painting system and improved model of the energy consumption at the facility. The graphed data of the graph was generated from the stock component of the model; which acts as an accumulative tool. Therefore, this is a cumulative data for 12 months.
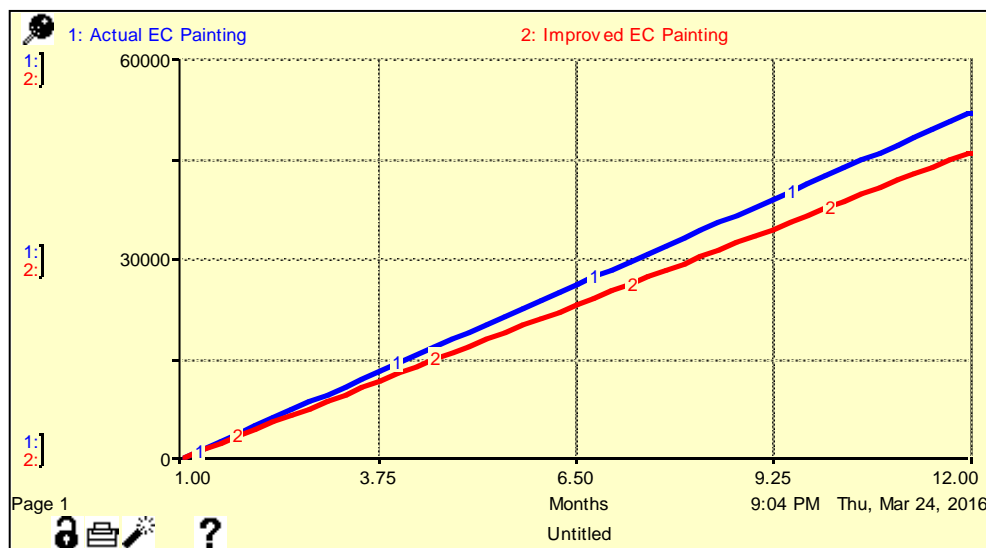

Figure 5: Cumulative of the monthly consumption of energy for painting systems

The difference between can be seen in the graph; the blue line represents the actual Energy consumption (EC) of the painting systems in MMBTU. While the red line represents the Improved Energy consumption (EC) for the painting systems in MMBTU. Figure shows similar scenario for body in white (BIW) and assembly facilities.

The red line represents the actual EC for BIW while the pink line represents the improved EC for the BIW facility. The green and the orange line and represent actual EC for Assembly and improved EC for the assembly facility, respectively. A substantial energy saving can be achieved with the implementation of Green Operational Policy and a suitable integration of advanced manufacturing.
In system dynamics modelling oscillations are one of the most common dynamic behaviours; which are characterized by many distinct patterns. Figure 7 and 8 illustrate chaotic oscillations of the energy consumptions and CO_2 emissions.
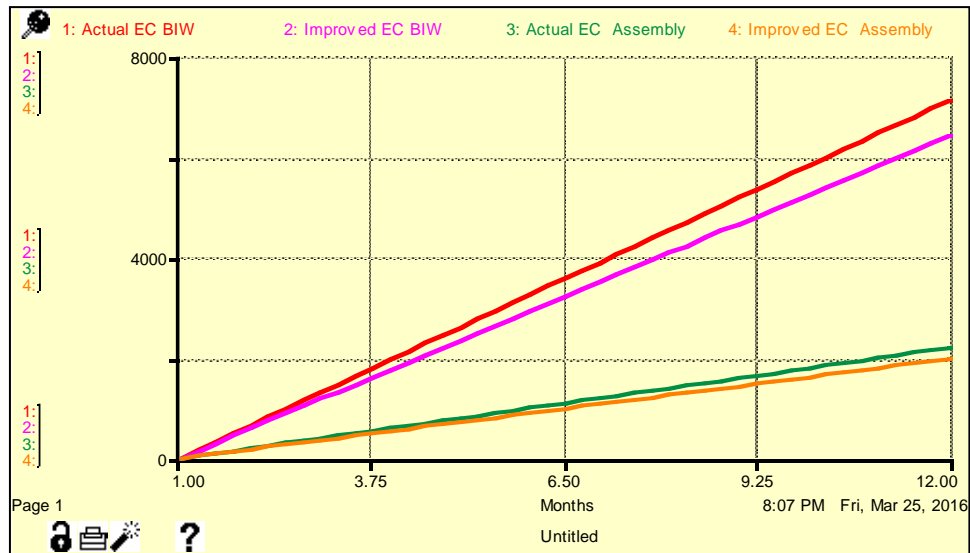

Figure 6. Cumulative of the monthly consumption of energy for BIW and assembly

As can be seen in Figure 7 the actual EC consumption for the painting system; which is represented by the red line is more chaotic and at the same time uses far more energy than the improved EC model. This indicates that Green Operational Policy combined with advanced manufacturing can smooth the spikes of the graph (which indicates high energy consumption on monthly bases) for painting system.
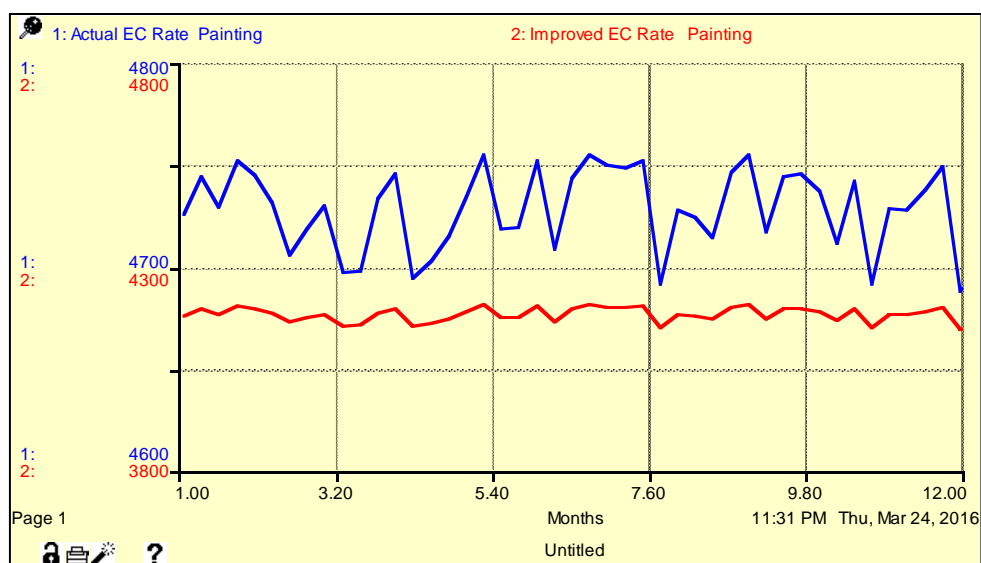

Figure 7. Comparison of the monthly consumption of energy for painting systems

Shown in Figure 8 is the overall CO2 emissions of the facility. The red line which is the actual CO2 emissions for BIW, assembly facility and painting system; which is on average about 75000 Kg of CO2 per month. The blue line of Figure 8 represents the CO2 emissions resulting from the of the improved EC model. This is roughly around 66000 Kg of CO2 per month.
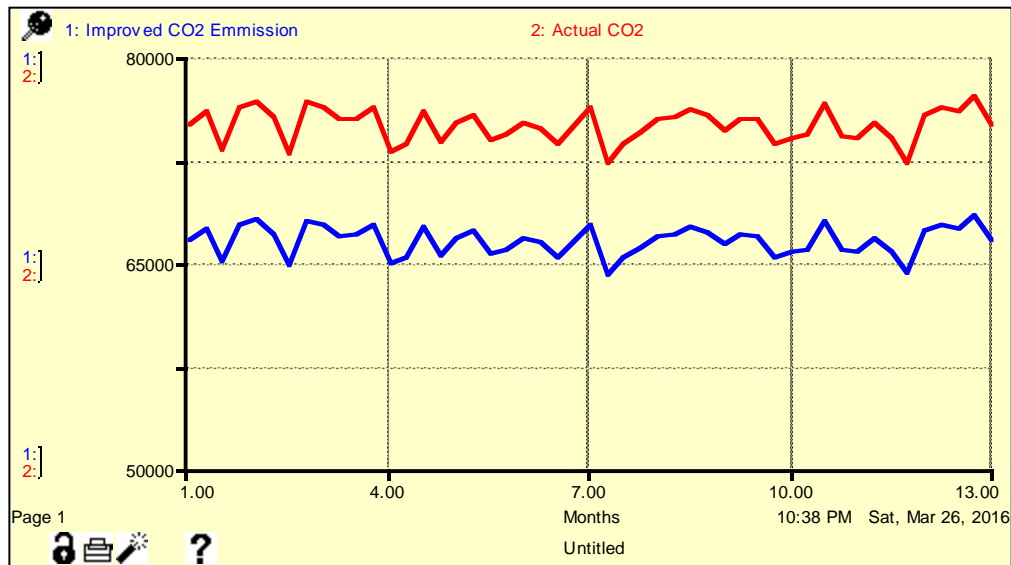

Figure 8. Comparison of the overall monthly CO2 emission

6. Conclusion

This paper presented a system dynamics (SD) simulation to investigate the concept green logistics in terms of energy efficiency in automotive industry. Energy consumption in automotive industry is considered one of one of the highest energy consuming industries. An efficient decision making model for energy and CO2 was developed to handle the impacts of strategic decisions on energy consumption and environmental sustainability for a period of 12 months. The sources of energy considered in this research are electricity and fuel. The model incorporated Green Operational Policy and advanced manufacturing to improve energy consumption of process-specific energy measures of painting, welding, and assembling processes. The results of the model indicated it can practically assist decision makers by providing an in-depth understanding of environmental impacts and costs associated. The model had shown substantial reductions of energy, reduced CO2 emissions for all the modelled facilities of BIW, assembly and painting systems. Similarly costs associated with energy were reduced.

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