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Procedia Engineering 100 (2015) 960 – 969

Procedia Engineering

www.elsevier.com/locate/procedia

25th DAAAM International Symposium on Intelligent Manufacturing and Automation, DAAAM 2014

A hybrid Simulation model for Green Logistics Assessment in Automotive Industry

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Abstract

The aim of this paper is to assess green logistics practices in automotive industry by using simulation method. In automotive industry logistics involves the integration of manufacturing, assembly, and distribution activities. The proposed model will assist decision makers acquire an in-depth understanding of environmental impacts and costs associated. The main issues that should be considered include: Carbon Dioxide (CO_2) emission, re-use and recycling of material, waste disposal and energy utilization. A combined model of system dynamics (SD) and discrete event simulation (DES) will be used. The trade-offs between costs and environmental protection will be analyzed. The results indicate that there exist positive tradeoffs between green practices (CO_2 reduction, promoting recycling, and water and energy conservation) and operational costs.

Peer-review under responsibility of DAAAM International Vienna

Keywords: Green Logistics; Hybrid Simulation; Discrete-event simulation; System dynamics simulation; Automotive industry; Transportation

1. Introduction

Traditionally, in logistics there are several problems that industries should solve in practice, such problems include stockpiling, distribution system, material flow, etc [1]. The term 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[2]. The management of logistics focuses on the integration of the entire the activities required to move products through the supply chain. The main objective of logistics is the coordination of typical logistical activities which consist of freight transport, storage, inventory management, material handling etc, in such a way that

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Peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2015.01.455

convenient to the customer requirements at minimum cost. Previously logistical costs were determined based on mere purely monetary terms. However; concerns of increasing environment issues were noticed , it is then essential to consider the external costs of logistics associated primarily with climate change, air pollution, noise, vibration and accidents etc [3]. Green logistics 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 as defined by Pishvee et al.[4]. 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. Many research has been conducted on green logistics has across varied industries as mentioned in [6,7]. 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. As mentioned in [8], [9] & [10]; in automotive industry green logistics initiatives focus on minimizing greenhouse gasses (which raise the temperature near the surface of our planet) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) , re-use and recycling of material, waste disposal and optimal utilization of energyy. In this research the considered environmental externalities are CO_2, and waste from automotive assembly line. While the promotion of reuse and recycling of material, the conservation of energy and water are considered as green (environmentally friendly) objectives.

2. Problem definition

Since the introduction of ISO 14000 standard[11], 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[12]. Since the environmental sustainability such as the reduction of Carbon Dioxide (CO_2), energy and water conservation in automotive industry create unfavourable conditions for the inventory and production costs. However, there has been limited research on green logistics modelling and simulation in automotive industry. In this paper, a simulation model is produced that can capture environmental concerns such as CO_2 emission, recycling of material, waste disposal and energy utilization. Two problems will be investigated in this study. First, the impact of decisions from strategic management has on production costs and environmental sustainability. Secondly, the degree of influence by which operational activities have on environmental sustainability and production costs. 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 CO2 emissions, energy and water conservation[8]. The outcome of the model is expected to assist decision making processes; the SD model should support high level decision making and the DES will assist in the operational level management to understand the impact of tactical and operational decisions.

3. Background

In the past, it was widely accepted that logistics research were entirely influenced by two factors; economic and behavioural factors. As indicated in [13] the economic approaches focused its interest on cost minimization and profit maximization whilst behavioural approaches focused on psychological and sociological aspects. Now environmental concerns play a major role in any transformation of logistics. It is a must that all organizations should have environmental friendly policy. This has been intensified after the introduction of the ISO 14000 standard, published in 1996, which is used as a reference model for the implementation of environmental management systems in organizations[11]. Literature shows research on green logistics problems has attracted significant academic attention in the recent years as show in [2,3,5,6–8,10,11,14–18]. Previous studies [19,20] indicate that the requirement for corporate sustainability has been recognized over two decades ago, although it has just in recent times increased its attention throughout the business world because of the growing public consciousness of global warming. Nowadays, the organizations are becoming more environmentally responsible and revisiting their supply chains to incorporate environmentally sustainable processes[21,22].

Merrick & Bookbinder[12] cite that transportation as the main source of environmental risks in the logistics system. Therefore, reducing the vehicle kilometres travelled (VKT) is regarded as a reasonable green technique to enhance organizational environmental practices. The amount VKT depends on the required distance between facilities and the number of trips required between nodes. Nikbakht et al. [23] used genetic algorithm to minimize mix integer linear for model fuel consumption that collects and recycles automobile alternator at the end of their life cycle. According the author after adding a test function, the total fossil fuel consumption in the reveres logistic was minimized. Pierreval et al. [24] developed a model for automotive supply chain using system dynamics approach. The author considered the production units are at a macroscopic level. Dynamic behaviours of products flowing through logistic units were studied so as to better understand the global performance of the supply chain and how it reacts in particular circumstances. This research was based on factories located in different places in France and simulation technique was used to a subset of this network, a supply chain that produces engines. According to [24], the simulation results have turned out to be very useful because it indicated that global system can have an undesired behaviour. This can be negative behaviour that can create delivery shortages or in increased lead-times depends on the initial level of inventories and the volumes of the orders. Thomé et al. [25] conducted research on the development of empirical multitier studies capable of investigating the inter-organizational components concept of supply chain flexibility (SCF). This research has selected three representatives from the supply chain of the Brazilian automotive industry. The author highlighted that there is a lack of SCF empirical research in the literature analyzing concurrently the interrelations of multitier supply chains. However; this study did not show any numerical results indicating improvements within this topic. A case study was conducted on the sales and operations planning problem based on the actual situation of the Renault, a French global automobile manufacturer Laurent Lim et al.[26]. The flexibility rates are defined to limit orders of a given type of vehicles, during a certain period and the author developed a simulation model capturing the dynamics of the sales and operations management. Also mathematical study has been presented by using industrial data. According to [26] the results highlight factors should be improved for the system performances and several policies are compared.

The several analytical models for automotive logistics and supply chain discussed in the above paragraphs are based upon various reasonable assumptions which, when they hold, lead to important results. However sustainability in automotive industry was not considered. In this paper, simulation modelling is employed to incorporate a more general set of circumstances relating to green logistics particularly the effect of carbon emissions in transportation, re-uses and recycling of material, waste disposal and optimal utilization of water and energy.

A comprehensive review of the literature on green logistics is given by [5,7,17,27]. On this paper the relevant references include the following. Jain et al. 2013[28] developed system dynamics and discrete event model for a case study of a closed loop supply chain of a forklift brake system. The SD model was used to assess the energy consumption across the supply chain system while the opportunity of reducing energy consumption through reduction in set-up times was evaluated using DES model. From literature the author discovered a number of potential reductions at different nodes and used to identify a target reduction of 29.4% across the supply chain. According to [28] the model represented detailed operation of a plant with offline set-up and estimated a 7% reduction in energy consumption.

Esmemr et al[29] developed a simulation model determining the optimum number of container handling equipment to increase the lean capabilities of a Turkish port and that the optimal number of equipment minimizing the environment damage has been reached. But did not mention what type of simulation used and how lean capabilities and environmental friendly methods were aligned. A bi-objective credibility-based fuzzy mathematical programming model for designing the strategic configuration of a green logistics network under uncertain conditions was proposed in[4]. The model aims to minimize the environmental impacts and the total costs of network establishment simultaneously in order to find a sensible balance between them. CO_2 was used as the environmental impact externality. In [4] , an industrial case study was presented to illustrate the applicability of the projected model as well as the convenience of its solution. Nonetheless; quantified results showing CO_2 reduction are absent. Numerous academicians have attempted to join pollution emissions and optimization models as part of their research. For example the city logistic models proposed by Taniguchi & Thompson [30] frequently integrate emissions into a transportation model as shown in [31]. Harris et al.[8], developed a simulation model assessing CO2 emissions in a case study of European automotive industry, considering strategic and operational level decisions simultaneously. The analysis of the model shows that the optimum design based on costs does not necessary associate with an optimum solution for CO_2 emissions. It is then concluded that there is a need to address economical and environmental objectives explicitly as part of the logistics design. Other simulation and Operational research(OR) modelling studies on green logistics can be seen in [17,32–34]. Nevertheless; literature on this area reveals the absence of modelling method that can combine a number of green objectives such CO_2 emissions, waste management, energy and water conservation, hence this is the basis of this paper; to develop a simulation model combining these environmental externalities.

4. Simulation method: combined SD and DS

A model for decision making is constructed for the aforementioned problem concerning the automotive assembly line and green logistics so then it is possible to achieve a better decision making for this issue. The model can be created by using simulation method or operational research technique employing mathematical models.

4.1 Conceptual modelling

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 green logistics infrastructure. The data were collected from an actual automotive assembly. The name of the plant and its location is omitted for privacy related concerns.

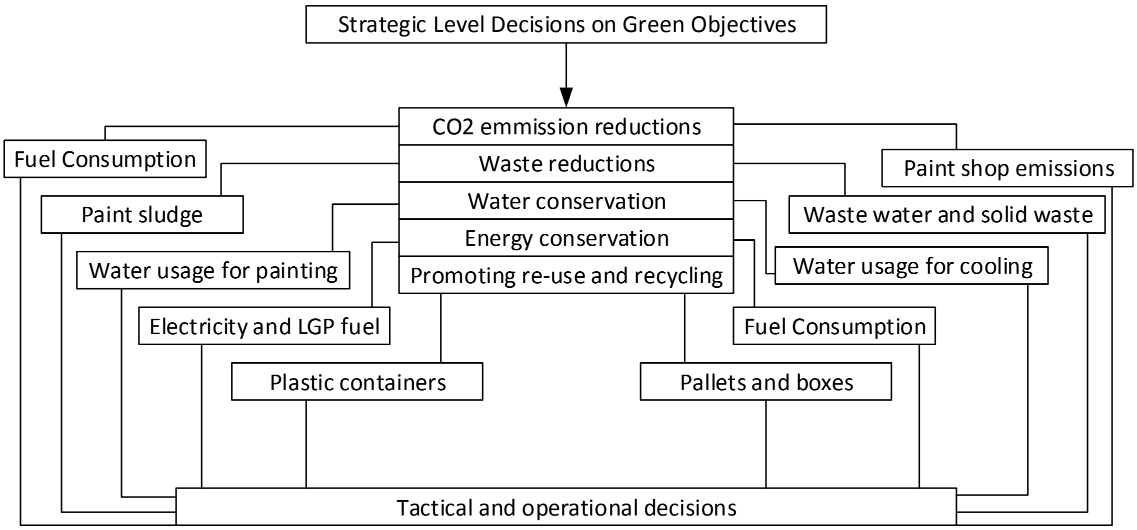

Fig. 1: Conceptual model of the automotive green logistics

Here the real system, under examination is described in Fig.1 as shown above and the objective is to capture the system logic and data necessary for the simulation modelling activity. Strategic level decisions based on green objectives are implemented in order to mitigate environmental issues related with CO_2 emissions, waste generation and water and energy consumptions. At a lower level tactical and operational decisions will enforce the policy.

In this research a combined simulation model of system dynamic (SD) and discrete event simulation (DES) is the adopted methodology.The simulation approach in this study is summarized in Fig.2. The concept was adopted from [28]. Here, the simulation approach comprises of five steps. The first step is to build the model and it starts with the creation of a System Dynamics (SD) or high level model that utilizes data from the manufacturing logistics. The SD model inputs are the numerical figures of water and energy consumption, CO_2 emissions, and waste generated. The iThink 10 software package from the ISEE system dynamics simulation tool was used to develop this model.

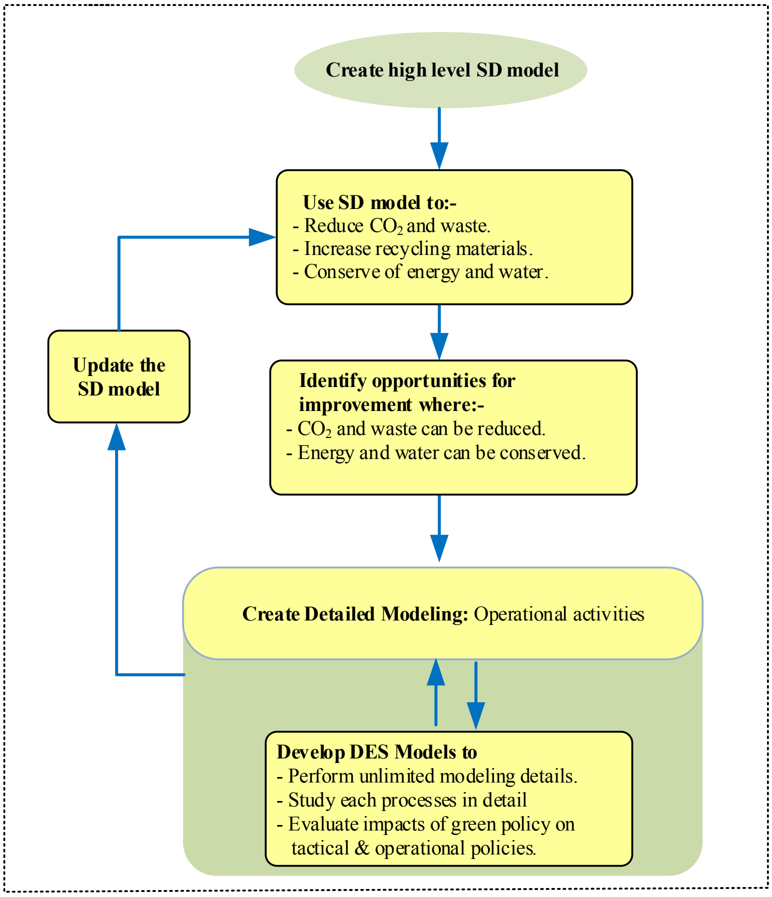

Fig. 2: Steps of simulation approach.

Next the utilization of the SD model commences to analyze any tradeoffs at a high level. At this level the model is catering for the decisions regarding tradeoffs of reducing environmental externalities and increasing profit. The SD model results must be validated via the review of the relevant experts and the decision makers. After using the SD model, areas that require further analysis should be identified so that environmental externalities can be reduced. If the identified area is one involving with complex operation, a more detailed model should be built.

DES model will be created if there is an opportunity to model at detail level. The development of DES model can offer unlimited lower level analysis of the operational processes. Here the DES model is employed for tradeoffs at detailed level to alternate operational strategies for reducing the environmental issues within the assembly line.

Finally if necessary the SD model is updated, this is an adjustment of the high level SD model with the improved information obtained from the detailed DES model. The updating of the model will illustrate the impact of changes made at the detailed level on the overall material flow.

4.2 System dynamics model

A system dynamics model was built using the data collected from the logistics and production nodes of the automotive assembly plant. A detailed data of monthly energy consumption for three years, monthly waste generated for one year, and water consumption for one year were gathered from the relevant departments. Four sub-models were developed, namely Energy consumption model, water consumption model, and CO2 emission model. The energy consumption model before the implementation of green policy is depicted in Fig.3 below.

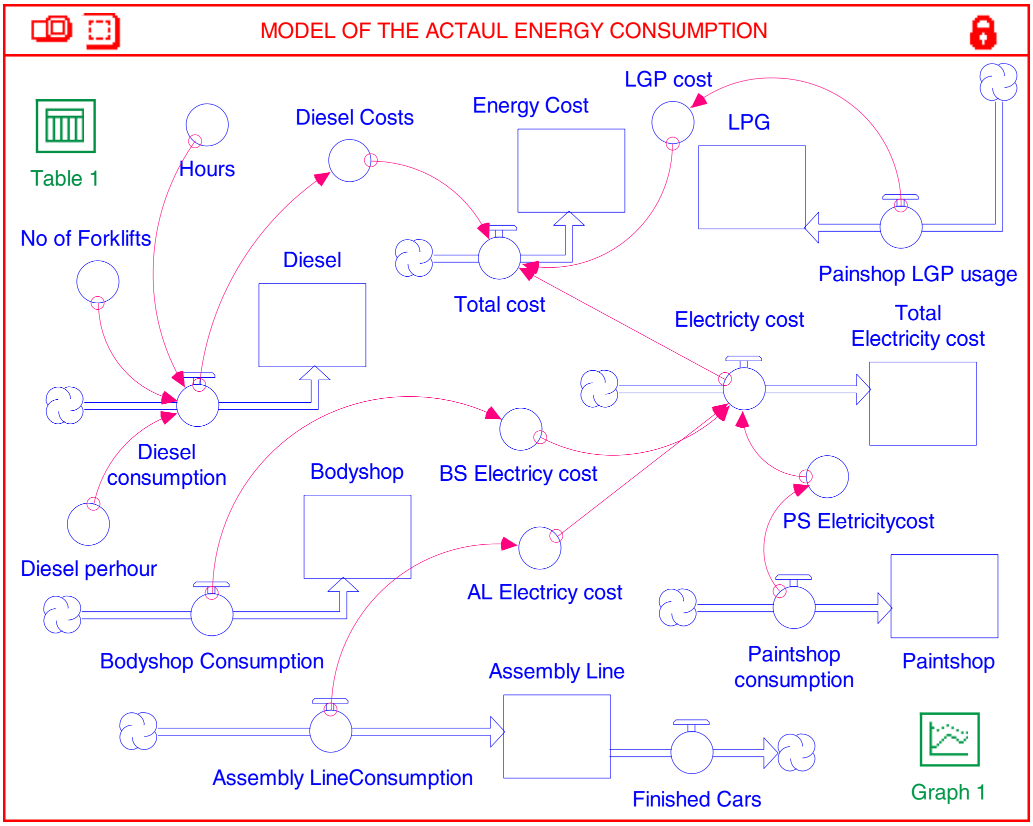

Fig. 3: Energy consumption sub-model

Within the energy consumption model, assessments were made on to various facilities consuming different types of energy. Electricity is mainly consumed in Body shop (BS), Assembly line (AL), and Paint Shop (PS). Liquefied petroleum gas (LPG) is consumed for boiling and burning processes in the paint shop, while diesel fuel is used by forklifts for outdoor material movements. Following the implementation of Green Policy (GP), the model captures the tradeoffs between diesel, LPG, electricity usage and associated costs. The CO_2, water consumption, and waste models with the implementation of green policy are depicted in Fig.4 below. About 85% of the water is consumed in paint shop for painting processes and 15% of water is used for cooling at the assembly line. This statistics is based on data from the assembly plant.

Waste water and semi solid wastes are mainly generated from the paint shop while solid wastes are generated from the material handling processes; specifically the packing waste. However; in automotive plants, the main source of hazardous waste is from paint shop, mostly from cleaning processes in the paint department. It is classified as harmful waste due to the solvents and heavy metals left in residues.
The green policy will employ alternatives of reducing water consumption such changing behavioural practices of water usage at the facility and engineering practices based on modifying or replacing equipment with water-saving equipment to reduce overall water consumption. Similarly the green policy will reduce waste generation and CO_2 emission.

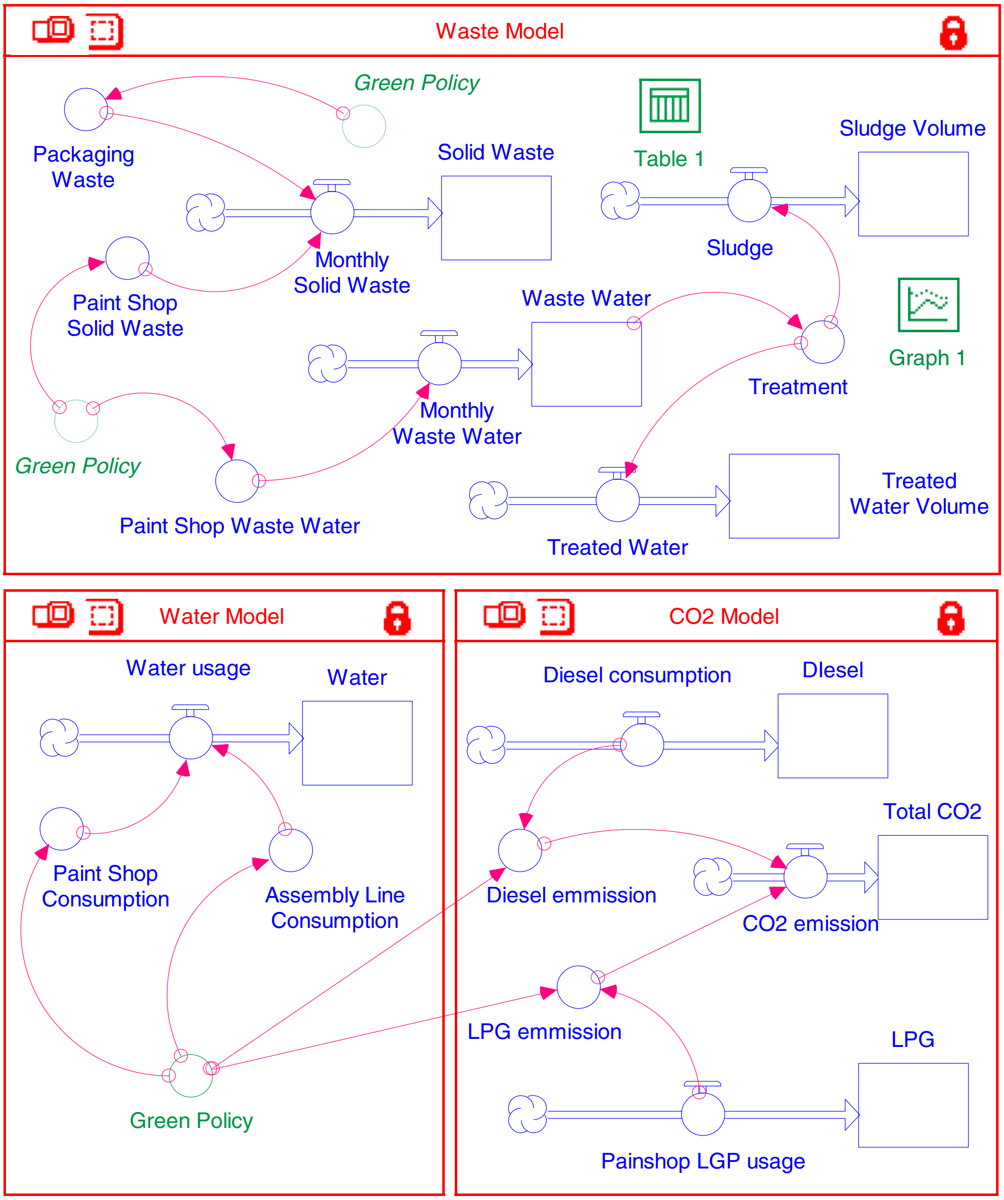

Fig. 4: Waste and CO_2 sub-models

Waste can be reduced through recycling, reuse, changes in procedures and work habits. Sludge which is considered as a hazardous waste can be reduced by the use of water based paints. While fuel consumption reductions such as the LPG and battery powered forklifts, and use of energy saving equipments can result in significant reductions of CO_2 emission.

4.3 Discrete event approach

The Discrete event simulation (DES) model was designed to model in detail the operational processes of the automotive assembly line. The processes involving material handling, body shop, paint shop and assembly line were modeled using Arena simulation package as shown in Fig. 5.The inventory and warehousing sub-model involve processes of materials arrival rate, transporting (using forklifts) and warehousing. In this sub-model reduction of forklift fuel consumption is the green objective. Unpacking and segregation sub-model engages the processes of preparing material used for assembling the car. Waste minimization is the green objective for this sub-model.

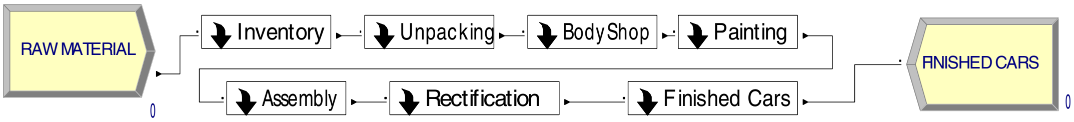

Fig. 5: DES sub-models

The assembly line and body shop sub-models; reduced water and energy consumption are the green objectives. Finally the paint shop sub-model involves modeling the painting operations; which involves waste water generation, and the highest consumption of energy and water in the assembly line. The results of the DES model was used an input data for updating the SD model so that improved results of model can be achieved.

5. Results and discussion

The results of the combined SD and DES model indicated improved consumptions of water and energy, and reduced waste generation. The emissions of CO_2 were mitigated and costs of energy and waste treatment were reduced. Water consumption and CO_2 emissions before and after the adoption of green policy are shown in Fig 6.

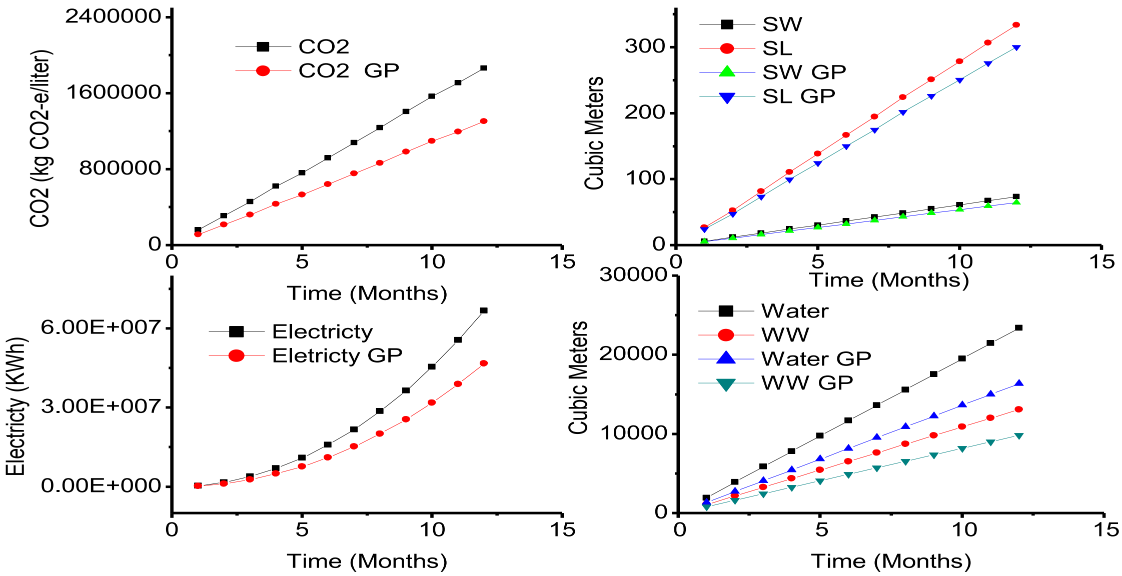

Fig. 6: Results of the overall model

In Fig.6, the acronyms of GP, WW, SL and SW stand for green policy, waste water, sludge and solid waste respectively. The replacement of solvent-based paints to water-based paints reduced the amount of water used for cleansing and as a consequence sludge volume was reduced. Hence, sludge disposal cost was minimized. Effective policy on the reuse and recycling of solid waste indicated reduced cost reductions and reduced amounts of solid waste. The model did show that electricity consumption was reduced around 20% equivalent to (202,776 kWh) per month by using the green policy. The usage of LPG was reduced slightly at the paint shop, roughly 8% equivalent to (7,795 liters or 4,288 Kg) per month. The diesel consumption was totally eliminated by replacing the diesel powered forklifts to LPG and battery powered ones. This has shown reductions of CO_2 emission but also slight increase of operations cost. Water consumption was reduced approximately about 30% equivalent to 1,680 cubic meters (m^3) per month, waste water 25% corresponding to 1,250 m^3, sludge generation decreased 10% and solid waste was reduced 12% corresponding to 2688Kg and 735Kg respectively. The overall CO_2 emission reduction was approximately 30% corresponding to 62,036 KG of CO_2 per month. This is due to the green policy practices of changing the habits of using fuel and the replacement of diesel powered forklifts to LPG or battery powered, and provided the fact that LPG produces less CO_2 than diesel, since the emission factor LPG is 1.58 KG of CO_2 per liter (kg CO2-e/liter) while diesel has emission factor of 2.7KG of CO_2 per liter. The model results further justify previous research as shown in [9, 12].

6. Conclusion and future research directions

This paper presented a combined SD and DES simulation models for assessing the adoption of green logistics practices in automotive industry. The method utilizes SD simulation with a high level representation of the logistical activities within the assembly line to assess waste, CO_2 emissions, consumption of energy and water. The DES models are used for assessment of chosen opportunities at the detailed level. 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 and water consumptions, reduced CO_2 emissions and decreased generations of waste. Similarly costs associated with energy, water and waste were reduced. But slight increase of costs was observed on operational costs. Nevertheless, after adopting the green policy, the model did indicate improved results of environmental sustainability and cost reductions on water, energy and waste. In the future, further research will focus on development of Decision Support System (DSS) for green logistics and supply chain in automotive industry. In addition to that independent DES models that can capture complex operations involving the automotive assembling processes and green manufacturing will be created. Other environmental factors will also be included in the model such carbon emissions trading and the emissions Volatile Organic Compounds (VOCs) from the paint shop activities.

Acknowledgements

This paper was supported by the Internal Grant of the University Malaysia Pahang (RDU: 130328). The authors gratefully acknowledge the support from Department of Research and innovation, UMP.

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