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Research paper

A Framework for Developing Green Coordinated Decision Model In Supply Chain

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Abstract

In the supply chain (SC), cost reduction always becomes the main aspect for the success of the competitive market. Minimizing costs in SC can be obtained through various methods. One of the methods is to coordinate decisions among members in SC. In the recent competitive, cost reduction is not only the main objective but also carbon emission reduction has become serious problems in SC. To achieve that, coordination in SC should cover both performances to achieve green SC. Therefore, this paper proposes a framework for developing a green coordinated decision model (GCDM) under costs and carbon emissions consideration. The model considers the decision-making process for solving inventory replenishment problem in SC to solve the economic and environmental problem. The developed framework is based on reviewing the past literature on the SC decision model. There are four major steps of the proposed framework: 1) defining actors and operations involved in supply chain, 2) defining parameters, variables, and performance of the model, 3) defining the modeling process, and 4) verification and validation of the model. This framework contributes to the knowledge where the modeler can provide an insight in generating an accurate decision model and its solution to improve the environmental performance.

Keywords: *carbon emission reduction; cost reduction; framework; green coordinated decision model; supply chain.*

1. Introduction

Supply Chain Management (SCM) has become a key component to ensure the product demand is fulfilled with affordable price and high responsiveness between the different organizations of Supply Chain (SC). The key benefit of SCM is used to face the rising competition triggered by globalization and outsourcing has forced the SC members to work coherently with each other [1]. At this point, SC coordination is importantly used as an effective approach to improve the performance of all members by integrating streamline operations/processes between individual members.

Several international industries like IBM, Procter & Gamble, and Wall-Mart have demonstrated their coordination with their vendors or buyers by jointly optimizing their SC performance (e.g. maximizing profit, reducing cost, risks and benefit sharing, and improving quality and service level) [2]–[4]. In this matter, one organization should have a better control and coordination with their buyers or outsourced operations [5]. One of the coordination mechanisms to enhance relationship is the sharing of information where the organization can share its internal or external data. Therefore, an organization that collaborates for information sharing can help SC members in joint decision-making.

Generally, the decision-making process in SC coordination needs mutual exchange information regarding operation planning among SC members. The objective is to make a high accuracy and robust decision which result in a flexible response to change and improve the business performance [6], [7]. As gaining much interest, the research on SC coordination model has been increasing over the last decades. The main coordination problem is the imbalance inventory replenishment decision where vendors and buyers are acting independently in optimizing their own objective [8], [9]. Non-coordinated SC result in one player get benefit and disadvantage to the other players [9]–[13]. Starting with Goyal [14] and Banerjee [15] who have been introduced coordination model between vendor and buyer to improve their business performance. As the basic model, its development still attracting many researchers up to present. The current literature studies on SC coordination model have been comprehensively reviewed by Glock [10], Arshinder et al. [16], Bahinipati et al. [17], Ben-Daya et al. [18], Thomas & Griffin [19]. So far, most coordination models emphasized optimizing the different SC processes, including procurement, production planning, inventory, logistic, and transportation. The main objective of the model is to minimize total SC costs.

With the ever-growing on environmental awareness, SC models are now moving toward greener as there is high pressure for reducing the environmental impact from SC process. Incorporating environmental management principles into SCM was to be expected given the nature of the term Green Supply Chain Management (GSCM) [20]. GSCM is an approach that optimizes of material and information flows along the value chain. The main objective is a stronger focus on environmental aspects when making managerial decisions [21]. Therefore, any SC models which are extended by revisiting environmental objective are designated as green SC models.

Recent literature studies on green SC decision model can be found in Bazan et al. [22], Brandenburg et al. [23], Bushuev [24], Dekker et al. [25], Igarashi et al. [26], and Seuring [27]. Most of the green SC models that they review facilitate in managerial decision-making for broader field include inventory lot sizing, supplier selection, facility location, logistic, reverse or forward SC, and closed-loop SCM. However, the existing literature does not explicitly discuss the importance of the coordination model for improving environmental objective. So far, the recent review on SC coordinated decision model conducted by Glock [10], Bend-Daya et al. [18], and Goyal & Gupta [28], do not report any environmental aspect.

One of the serious environmental problems considered in this paper is carbon emission. In SC, carbon emission is generally emitted from the full life cycle of the SC process or product and it measured in mass units of carbon dioxide equivalent (e.g. kgCO_2-e) [29]. The release of carbon emission into the atmosphere contributes to climate change and global warming. As a result, carbon emission reportedly can cause damage to the environment. One of the solutions to prevent higher emission is to study carbon emission measurement across SC and analyze its impact on SC performance. Moreover, integrating carbon emission into the decision-making process with the focus of coordinating SC is a new challenge today. This decision process related to optimizing the operational decision inter-organization includes procurement, production, transportation, and inventory as a means of low carbon emission. Therefore, this paper proposes a framework for developing green coordination model with consideration of carbon emission. In order to easy mentioning the model, this paper uses the term Green Coordinated Decision Model (GCDM) for the overall paper.

The proposed framework provides a contribution to knowledge for helping SC researchers and practitioners to better understand how GCDM was developed not only to reduce costs but also carbon emission across SC. Also, this study can help firms to operate SC by simultaneously controlling their carbon emission through the use of energy efficient in all SC process.

2. Insight from Non-Coordinated to Coordinated Decision under carbon emission consideration

Before discussing Green Coordinated Decision Model (GCDM), the non-coordinated decision under environmental concern is briefly discussed in this section. This paper mentioned it as Green Non-Coordinated Decision Model (GNCDM). GNCDM is a decision based on a mathematical model which developed under a viewpoint of an internal company without involving their partners in SC. Traditionally, the main objective of the model is to improve economic aspects.

With the increasing environmental awareness, carbon emission becomes an integral part of the modeling process which can no longer be marginalized to be embedded in the decision-making process. Indeed, this is an effort to make environmental friendly which focuses on improving environmental performance for a single company only. In this case, GNCDM is an early research before GCDM are developed. Therefore, the importance of this section is to provide a basic understanding of how to transform GNCDMs toward GDCM.

Most of GNCDM studies have been linking with inventory or lot sizing problems where carbon emission was also inclusively considered. Most of the models were the evolution of classical inventory models (e.g. economic order/production quantity EOQ/EPQ and lot sizing) [30]–[34]. Such models solve the inventory problem by minimizing the sum of inventory, production, and setup/order costs. Particularly, the EOQ model reaches the objective by determining economic replenishment quantities (order quantity, production quantity, inventory carried, etc.), under deterministic demand for an infinite planning horizon. Meanwhile, lot sizing model is solving production planning by determining the periods where production should take place and the quantities to be produced in order to satisfy demand in dynamic condition under a finite planning horizon.

EOQ models have received much attention in the academic area due to the model is mathematically proven and correct but the model still has been questioned on its practical and unrealistic assumptions embodied in the model [35]. Hence, the EOQ model has been massively revised to reflect real industrial problems and constraints. In this case, the increasing concern on environmental issues stresses the need to treat inventory management decisions as a whole with economic and environmental objectives.

GNCDMs are structured with a set of economic and environmental parameters that form cost and carbon emission functions. It can be illustrated in Fig. 1. For environmental standpoint, most researchers develop carbon emissions function as same as cost function structure [30]–[33]. So, the parameter in the EOQ model only changes its dimensional units. Based on Fig. 1, cost and carbon emission performance is influenced by the order quantity (Q). If the solution (Q_c) of EOQ function with ecthe onomic objective is applied to the EOQ function with environmental objective, it might result in a trade-off between economic and environmental performance. Moreover, it also happened otherwise if the solution (Q_e) of EOQ the model with the environmental objective is applied. Therefore, several researchers try to analyse the balance decision (Q) in order to have minimum cost and carbon emission [31], [33], [36]. Based on Fig. 1, the optimal order quantity that minimize both cost and emission is between Q_c and Q_e. In other words, it might larger than Q_c and smaller than Q_e. By using such GNCDM, companies could balance their costs and carbon emission throughout the decision-making process.

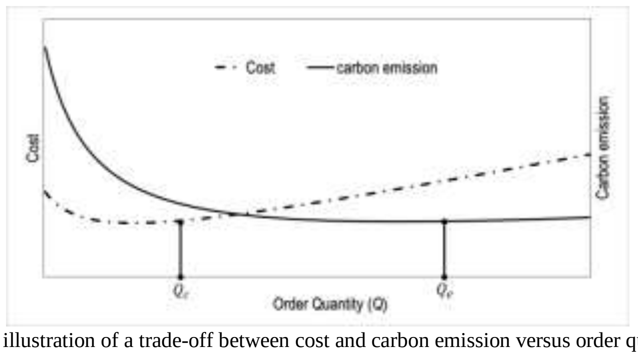

Fig. 1: illustration of a trade-off between cost and carbon emission versus order quantity

Due to the willingness of companies to engage in green activities while cost reduction remains a top priority, most researches try to extend GNCDM toward GCDM. Although the development of GNCDM is greener than classical EOQ model, the solution of GNCDM still cannot reach optimum if SC is not considered as a whole.

By taking an advantage from coordination model based on the current literature where coordination model successful to have greater saving in SC system, researchers hence attempt to integrate the coordination approach to optimize environmental aspect as well. Therefore, GCDM is proposed to align all SC decisions to satisfy global system objectives include cost and carbon emission to achieve a cleaner and cost effective for all members of SC.

In order to help the modeler to model SC coordination that can minimize cost and carbon emission, this paper proposes a framework for developing GCDM. The proposed framework was developed based on a review of the literature on SC models. Some research questions have arisen when proposing GCDM that consider economic and environmental features: How many actors involved in SC? What kind of input parameters and variables that influence economic and environmental performances? What kind of model types, modeling techniques, and solution approach to solve GCDM by finding the effective decision in improving the model performance? What kind of validation techniques used for validating the model? Based on such research questions, this paper contributes to the knowledge on developing the SC decision model by providing a theoretical insight.

3. Methodological framework of GCDM

The strength of this framework is to provide the steps that should be followed by the modeler to develop a robust GCDM that can optimize the SC system by finding an optimal decision for improving cost and carbon emission performance. The proposed framework is limited to the model case under economic and environmental considerations. It means that the decision should cover both performances to achieve a green SC. Fig. 2 is given to provide the steps for developing GCDM to minimize costs and carbon emission in SC to clearly show the proposed framework. These steps will be discussed further in the next section.

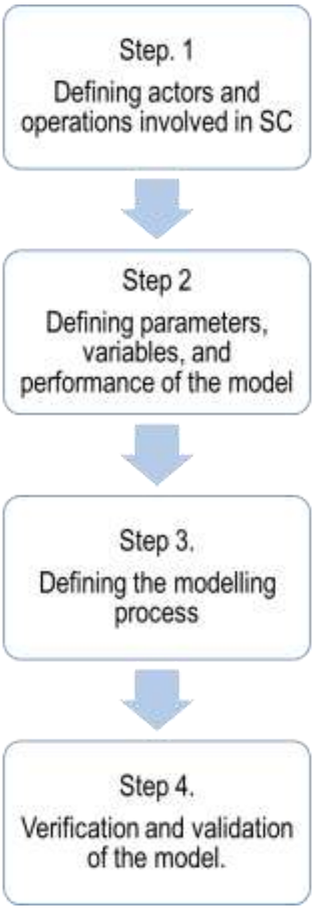

Fig. 2: A proposed framework for developing GCDM Adapted from Brandenburg et al. [23]

4. Methodology

4.1. Defining actors and operations involved in SC

SC actors have important roles in business processes because they can define an organization culture and influence the situation. The situation means the performance of an organization. Meanwhile, SC process is the way of transforming a set of inputs into outputs. Therefore, SC actors should be involved together in taking an action to run SC process. This action refers to decisions which impact to the improved performance of the actors or processes.

In order to generate a good decision, coordination concepts should be adopted by all SC actors. Moreover, they can implement a coordination mechanism which is joint decision making. The joint decision means two or more parties in SC jointly plan and work together on the basis of which the production and replenishment processes are determined [7].

For developing GCDM, the modeler should set the SC actors and processes to be considered in the modeling process. This step is categorized in SC dimensions. It is presented in Table 1.

Table 1: SC dimensions

SC dimension	Categories
Actor	Vendor/supplier, manufacturer, distributor, third-party logistics provider, warehouse, wholesaler, retailer, buyer/customer.
Structure	Two-stage, multi-stage
Process/operation	Raw material purchasing, production, inventory & material handling, transportation.

The categories of actor in SC were adopted from the literature review study presented by Min & Zhou [37] and Halldórsson & Arlbjørn [38]. In the context of the modeling process, the modeler should consider the scope of decision for the two-stage or multi-stage model. It is also considered as the SC structures [10]. Two-stage models consist of two echelons in which each echelon has one or more actors. Meanwhile, multi-stage models have more than two echelons. Most of SC processes considered in developing decision model are purchasing/procurement, production, inventory & material handling, and transportation. Interestingly, analysis of SC dimension in GCDM studies provides understanding that the series of actors, structure, and process considered in the model will have a different impact in replenishment control. Moreover, the more actors, complex structure, and many processes included in the model, the optimum model solution or decision are difficult to find [39]. Therefore, the decision will be optimum depending on the structure and design of the SC being considered in the modeling process. As a model builder, they should know which aspects of the SC dimension should be modeled to reflect the real-manufacturing application. Hence, the model can be benefited for managerial ability to integrate and coordinate all SC members.

4.2. Defining parameters, variables, and performance of the model

GCDM consists of minimum two parties in SC include vendor and buyer. The SC process of each party is modeled into mathematical formulation or function. The function consists of parameter and variables that have a causal relationship with the performance of each party [27]. Hence, the term of coordination in GCDM is the integration of vendor and buyer functions. Meanwhile, the main performances of GCDM are costs and carbon emissions.

The variables are usually related to the decision that has been made taking into account the parameters of the model that could directly influence the performance. Moreover, the decision should follow a hierarchical decision-making process that covers a planning in SC including strategic, operational, and tactical decisions. Due to GCDMs related to inventory replenishment process in SC, then the decision variables generally include:

1. Order quantity. The number of the unit product that a company should order to other company for adding their inventory.
2. Production quantity. The number of the unit product that a manufacturer company should be produced to satisfy the buyer's demand.
3. Replenishment time. The total period of time which is manufacturer or buyer required to produce or order the products.
4. Inventory levels. The current amount of product that manufacturer/buyer should maintain in stock.
5. Delivery lots, etc. The quantity of product shipped from a manufacturer/vendor to the buyer.
6. Number of shipments. Delivery activities that related to the amount of truck use to ship the product from a manufacturer/vendor to the buyer.

The decision variables might not be limited to the above examples. It depends on the problem that the modeler faces in the real SC practices. In inventory replenishment problem, modeler usually models the SC processes by translating them into costs. These costs are known as a model parameter. For example, order quantity, inventory level, and replenishment time will interact with ordering/purchasing costs and inventory costs. Meanwhile, delivery lots and number of shipments could influence the total transportation costs. Moreover, other costs such as production costs and setup costs could be influenced by production quantity and replenishment time.

Due to the environmental aspect is considered in GCDM studies, decision variables should also be linked to SC processes that generate carbon emission. Generally, carbon emission emits from production and transportation operations [40], [41]. The most common decision variable that affects production emission is the production quantity. Meanwhile, order quantity, delivery lots, and a number of shipment affect to the total transportation emission.

Another point of view to manage carbon emission in inventory replenishment is integrating common carbon policies such as strict carbon cap, carbon trading, and carbon tax [42]–[44]. These carbon policies have been adopted by the countries who follow the international agreement regarding environmental regulations like the Kyoto Protocol and the European Union Emission Trading Scheme (EU ETS) [45], [46]. Such policies can be incorporated into the inventory replenishment model due to it serve as economic incentives for the company [47]. Therefore, one of the challenges for modeler is to formulate cost functions linked to carbon policies. It generally forms by considering parameters such as carbon emission capacity, carbon trade, and carbon emission right prices [48]. After that, the function should also have a relationship with decision variables being considered to optimize the performance of SC.

To solve GCDM under costs and carbon emission, information sharing among SC members are needed. For example, all information about costs, production, and demand for vendor and buyer have to be known by a decision maker in SC. Therefore, under coordination approach, buyer determines their own objective with considering vendor's objective. For example, the buyer can coordinate their orders with the vendor, hence vendor can determine their decision in the sequential process. However, solving GCDM under costs and carbon emission is not an easy task. The complexity in finding an optimum decision that makes efficient in production, inventory control, and distribution strategies depend on the interactions of various levels in the SC. To deal with complexity, the modeler needs to capture the situation and all data needed in order to develop the model correctly, hence, the model solution can be derived that can minimize SC system-wide costs and carbon emission.

4.3. Defining the modeling process

The representation of the reality is well-known as a model. GCDM is a model that represent inventory replenishment processes which are measured by the cost and carbon emission. In inventory replenishment problem or well-known as lot sizing problems can be divided into two categories based on the nature of the product and the prevailing supply and demand condition that is stationary models vs dynamic models [49]. Each model is also classified into two categories whether deterministic or stochastic models. The detailed structure of the lot-sizing problem can be presented in Fig. 3.

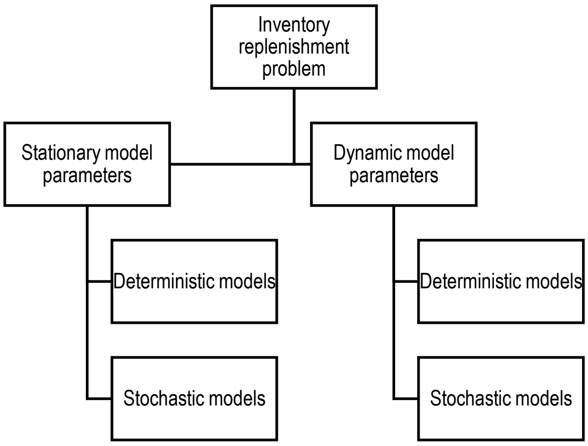

Fig. 3: Structure of inventory replenishment problem [49]

As the first aspect, the modeler should distinguish the replenishment problem based on the parameter being considered in the model. For stationary model, the model parameter is not changed over time. Meanwhile, a dynamic model is opposite to the stationary model. These classifications are called by attribute of inventory replenishment model. Moreover, the stationary and dynamic model can be structured by the deterministic model (model parameters are known) and stochastic (model parameters are random properties). This first step can help modeler to assign which model suit to the SC's case study with assumption inherent to the model.

After modeling GCDM based on its attribute of inventory replenishment problem, GCDM should be solved by finding an optimum solution (decision variables) that can minimize costs and carbon emission in SC. Hence, the modeler should develop a precise mathematical procedure to achieve that objective. Brandenburg et al. [23] have defined the type, technique, and solution approach to solve SC problem. Table 2 presents the modeling dimension approach commonly used in solving SC problem [23]. This second step can help a modeler to find the best type, technique, and solution approach of the model that can improve decision outcomes.

Table 2: Model dimensions

Modeling dimension	Model categorical
Type	Analytical, heuristics, hybrid, mathematical programming, simulation.
Technique	Artificial intelligence, business game, discrete-event simulation (DES), game theory, meta-heuristics, multi-criteria decision making, multi-objective, simple heuristics, single objective, spreadsheet calculation, system dynamics, systemic models
Solution approach	Single/multi-objective (Linear programming, goal programming, dynamic programming, queuing models, non-linear programming, mixed integer linear programming) Artificial intelligent (Petri net, case-based reasoning, Bayesian networks, fuzzy logic, neural networks, rough set.) Meta-heuristic (Genetic algorithm, particle swarm optimization, differential evolution, ant colony optimization, simulated annealing) Systemic models (Life cycle analysis, input/output analysis, metrics)

4.4. Verification and validation of the model

Constructing GCDM based on a mathematical optimization model which reflects the important aspect of SC system need to be verified and validated its applicability to solving inventory replenishment problem. For illustrating the proposed model, a numerical example should be provided together with the verification process. The process of verification includes identification, quantification, and error elimination in coding/programming. This purpose is to have a highly accurate numerical solution; therefore, we can conclude that the model can be performed correctly according to the modelers' conceptual model.

In addition, validation based sensitivity analysis is commonly used to test the proposed model. It is also known as a pre-testing the model. Generally, sensitivity analysis is conducted by experimenting the input parameters of the model toward the output of model performance [50], [51]. This is used to identify and analyze the behavior of model performance and solution as the result of changing the input parameter. The result of conducting sensitivity analysis provides important information for modeler or decision maker in SC to analyze the model performance that is highly or slightly sensitive to changes in the parameter. Therefore, a decision maker can understand the impact of a range of variables has on a given outcome.

Lastly, validating the model with the real system data or scenario is the most challenging task. Validation is the way to decide whether the model has an accurate representation of the real system or not. It means that testing the model with real data is to ensure the decision is effective to be applied in optimizing the performance of the model. However, the validation process generally needs an iterative process because sometimes it happens inconsistencies between the implemented model and the real system. Therefore, the modeler should improve their model each time an inconsistency is identified.

5. Conclusion

This paper presents a framework for developing GCDM in SC under cost and carbon emission consideration. The proposed framework was developed based on reviewing the past literature on SC decision models. The framework provides a guideline to develop the model that study coordination approach among members of SC which can minimize costs and carbon emission in SC operations. In detail, the expected result of the framework is to build a model that can effectively be applied in solving inventory replenishment problem in SC. The problem can be solved if joint operational decision related among members of SC can be obtained so that they can jointly optimize their performance. Moreover, the generated decision should tackle a balance between costs and carbon emission. The contribution of this proposed framework is to provide an insight on how the model and its solution are developed to improve economic and environmental performances.

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