
**UNIVERSITI PUTRA MALAYSIA**

***DEVELOPMENT OF A TWO-LEVEL TRADE CREDIT MODEL WITH SHORTAGE FOR DETERIORATING PRODUCTS USING HYBRID METAHEURISTIC ALGORITHM***

**ZOHREH MOLAMOHAMADI**

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**By**

**ZOHREH MOLAMOHAMADI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**May 2015**

**DEDICATION**

*This thesis is dedicated to my parents*
*For their endless love, support, and encouragement.*

Abstract of thesis to be presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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**Chairman: Prof. Napsiah Ismail, PhD.**

**Faculty: Engineering**

In the classical inventory systems, it was implicitly assumed that the buyer pays to the vendor at the time of receiving the items. In real world, however, the vendor usually allows the buyer to defer payment. Among different types of delay in payment, trade credit has attracted many researches' attention and still has great potential for further studies. For example, most of the previous studies have considered constant demand, while the demand in real market is dependent to several factors such as price, time, inventory, etc. Besides, for simplicity in modelling and solving, the researchers often ignore shortage and deterioration rate which are parts and parcels of today's business. Two-level trade credit is another potential area for exploration. It is referred to the case that not only the vendor offers credit period to the buyer, but also the buyer allows its customers to delay payment. Furthermore, most of the previous studies have considered Economic Order Quantity (EOQ) model of a single member of the supply chain. However, assuming the Economic Production Quantity (EPQ) and formulating the integrated inventory system of the buyer and the vendor would be more practical. Considering these possibilities, this research develops a new inventory model for a supplier and a manufacturer under a two-level trade credit contract. The market demand is considered price dependent, and backorder and deterioration are also assumed. Moreover, the traditional inventory model and one-level trade credit are developed to make a comparison of the results and investigate the effects of delay in payment on the inventory system. The formulated models aim at helping the supply chain decision makers to determine the best delay strategy and find the optimal values for replenishment policy and manufacturer's selling price, with the objective of maximising the supply chain total net profit. A hybrid metaheuristic algorithm which combines Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm, is then developed to solve the established models. In order to evaluate the solutions of the hybrid algorithm, the models are also solved by a global optimization solver,

Branch-And-Reduce Optimization Navigator (BARON). Furthermore, the models and the solution methods are verified by applying numerical examples and real data from industry. The results of the proposed inventory systems are finally compared to explore the effects of trade credit on the supply chain net profit and the variables' sensitivity to the parameters are analysed. The examples demonstrate that although two-level trade credit is mostly more profitable for the supply chain and the manufacturer, the supplier benefits from a traditional supply chain. Besides, having obtained a p-value of 0.241 which is greater than 0.05 in a paired sample t-test shows that there is no difference between the results of BARON and the hybrid GA-PSO. This proves the capability of the developed hybrid algorithm in solving the formulated model.

Abstrk tesis dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN KREDIT PERDAGANGAN MODEL-DUA TAHAP DENGAN KEKURANGAN BAGI KEMEROSOTAN PRODUK MENGGUNAKAN ALGORITMA METAHEURISTIC HIBRID**

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Dalam sistem inventori klasik, hal ini diandaikan sebagai pembeli membayar kepada pembekal semasa menerima sesuatu item. Walaubagaimanapun, di dalam dunia sebenar, penjual biasanya membenarkan pembeli untuk menangguhkan pembayaran. Di antara jenis kelewatan dalam pembayaran, kredit perdagangan telah banyak menarik perhatian penyelidik kerana masih berpotensi besar besar untuk diteruskan kajian. Sebagai contoh, kebanyakan kajian yang lepas adalah mempertimbangkan permintaan yang berterusan, manakala permintaan dalam pasaran sebenar adalah bergantung kepada beberapa faktor seperti harga, masa, inventori, dan lain-lain. Selain itu, untuk pengurangan dalam pemodelan dan penyelesaian, penyelidik sering mengabaikan kadar kekurangan dan kadar kemerosotan yang merupakan bahagian dan bungkusan dalam bidang perniagaan pada hari ini. Kredit perdagangan dua peringkat adalah salah satu lagi bidang yang berpotensi untuk diteroka. Ia merujuk kepada kes yang bukan sahaja penjual menawarkan tempoh kredit kepada pembeli, tetapi pembeli juga membolehkan pelanggannya untuk melambatkan pembayaran. Tambahan pula, kebanyakan kajian sebelum ini menganggap model perintah kuantiti ekonomi (EOQ) seseorang anggota tunggal rantaian bekalan. Walau bagaimanapun, dengan mengandaikan kuantiti pengeluaran ekonomi (EPQ) dan rumusan sistem inventori bersepadu kepada pembeli dan penjual akan menjadi lebih praktikal. Berdasarkan kemungkinan ini, kajian ini dibangunkan sebagai model inventori yang baru untuk pembekal dan pengilang di bawah kontrak kredit perdagangan-dua peringkat. Permintaan pasaran diukur bergantung kepada harga. dan kekurangan dan kemerosotan juga diandaikan. Selain itu, model inventori tradisional dan kredit perdagangan satu tahap dibangunkan untuk membuat perbandingan keputusan serta menyiasat kesan kelewatan/penagguhan dalam pembayaran pada sistem inventori. Model dirumuskan bertujuan untuk membantu pembekal pembuat keputusan rantaian bekalan untuk menentukan kaedah kelewatan/penagguhan yang terbaik dan mencari nilai optimum bagi dasar dan pengisian semula harga

jualan pengilang, dengan objektif untuk memaksimumkan jumlah keuntungan bersih rantaian bekalan. Algoritma metaheuristic hibrid yang menggabungan algoritma genetik (GA) dan pengoptimuman zarah swarm (PSO) algoritma, dibangunkan untuk menyelesaikan model yang dihasilkan. Dalam usaha untuk menilai penyelesaian algoritma hibrid, model ini juga diselesaikan oleh penyelesaian pengoptimuman global, cawangan-dan-mengurangkan navigasi pengoptimuman (BARON). Tambahan pula, model dan kaedah penyelesaian ini telah disahkan dengan mengunakan contoh berangka dan data sebenar daripada industri. Keputusan sistem inventori yang dicadangkan akhirnya dibandingkan dengan meneroka kesan-kesan daripada kredit perdagangan ke atas keuntungan bersih rantaian bekalan dan kesan parameter untuk pembolehubah yang telah dianalisiskan. Contoh berikut menunjukkan bahawa walaupun kredit perdagangan dua peringkat adalah kebanyakannya lebih menguntungkan untuk rantaian bekalan dan pengilang, pembekal berkeuntungan lebih daripada rantaian bekalan tradisional. Selain itu, setelah mendapat satu-nilai p 0.241 lebih besar daripada 0.05 dalam sampel berpasangan ujian-t menunjukkan bahawa tidak ada perbezaan antara keputusan BARON dan hibrid GA-PSO. Ini membuktikan algoritma hibrid yang dibangunkan berkeupayaan dalam menyelesaikan model yang dirangka.

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I certify that a Thesis Examination Committee has met on 8 May 2015 to conduct the final examination of Zohreh Molamohamadi on her thesis entitled "Development of a two-level trade credit model with shortage for deteriorating products using hybrid metaheuristic algorithm" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the (insert the name of relevant degree).

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| | |
|---|---|
| WIP | Work In Process |
| VMI | Vendor Managed Inventory |
| CI | Consignment Inventory |
| C&VMI | Consignment Vendor Managed Inventory |
| EOQ | Economic Order Quantity |
| EPQ | Economic Production Quantity |
| PSO | Particle Swarm Optimization |
| DCF | Discounted Cash Flows |
| Df | Degree of freedom |
| GAMS | General Algebraic Modelling System |
| GA-PSO | Genetic And Paritcle Swarm Optimization |
| MILP | Mixed Integer Linear Program |
| MINLP | Mixed Integer Nonlinear Programming |
| MIP | Mixed Integer Programming |
| NLP | Nonlinear Programming |
| GA | Genetic Algorithm |
| BARON | Branch-And-Reduce Optimization Navigator |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Introduction

Supply chain is a network of different companies, so-called members, participating in producing goods and services to satisfy the end customers' demands. The members of the supply chain may include suppliers, manufacturers, distributors, retailers, and even the customers who are linked together through information, material, and financial flows.

Any firm in this chain has to deal with some operational processes such as sourcing raw materials, producing goods out of the purchased raw materials, and delivering the manufactured products to the customers. Managing these processes, reducing their operational costs, and increasing the company's productivity and efficiency are of great importance to every company included in the supply chain.

Although all members of the supply chain have their own specific goals, they must work towards a unified system and cooperate with each other to contribute to the supply chain growth. Achabal et al. (2000) stated that the performance of the supply chain depends not only on how well every supply chain member manages its functions, but also on how well the members coordinate their operational processes and decisions. Aligning the decisions of the supply chain members would result in eliminating excess inventory, reducing transformation costs, as well as enabling the manufacturer to utilize the resources more efficiently (Gümüş, 2006). Some other benefits of supply chain coordination include reducing lead times and manufacturing expenses, improving customer service, increasing sales and revenue, retaining customers, and enhancing efficiency and flexibility of the firms and enabling them to cope with demand uncertainty (Fisher et al., 1994 and Horvath, 2001).

Coordination can be viewed across various activities and functions performed by the members of the supply chain to manage material, financial, and information flow. These activities include logistics, inventory control, forecasting, and transportation. Moreover, different interface between supply chain members including supplier and manufacturer, manufacturer and distributor, distributor and retailer, and so on can be managed effectively and efficiently by applying coordination (Kanda and Deshmukh, 2008).

Moreover, due to the rapidly changing customers' demands and market conditions, supply uncertainties, conflicting strategies of the supply chain members, daily technology development, and lack of information transformation between the members, inventory related factors are highly dynamic and coordinating the inventory management of the supply chain as a unity is of major

significance. Efficient and effective inventory management of the supply chain remarkably improve the final service provided to the customer (Lee and Billington, 1992). Furthermore, since demand forecasting, transportation costs, lead time, pricing, and marketing policies may all affect and even be affected by inventory related issues such as economic replenishment quantity and optimal ordering time, there is a considerable overlap between inventory management and other operational functions of the supply network.

In the traditional inventory management systems, the supply chain members did not share their information and the payment of the ordered goods must be settled at the time of receiving them. However, regarding the importance of inventory decision coordination between the vendor and the buyer and its effects on increasing profitability, some other coordinating contracts such as vendor managed inventory (VMI), consignment inventory (CI), and consignment vendor managed inventory (C&VMI) have been considered. These approaches will be explained in the next chapter.

## 1.2 Problem Statement

In conventional business transactions, it was implicitly assumed that the retailers must pay for the procured items as soon as they are received. However, in today's intensely competitive market, such an assumption would no longer be practical. Delayed payment is an invaluable promotional tool for the suppliers to increase profit through stimulating more sales and a unique opportunity for the retailers to reduce demand uncertainty and its associated risks. In other words, when the supplier sends the ordered units to the retailer without being paid, he actually transfers the storage responsibility and costs to the retailers, while bearing the demand uncertainty risk. Therefore, trade credit can be considered as an effective and efficient strategy for the supply chain memebrs to maximise their obtained profit and survive in the global market, especially when the economy turns sour (Chang and Teng, 2004; Ouyang et al., 2005).

Moreover, External financing is one of the most reliable sources for companies in funding their operations (Li et al., 2014). However, due to the information asymmetry between the depositor/borrower and the debtor/lender, high capital cost of the debtor, expensive cost of monitoring the credibility of potential depositors, credit rationing- limiting the supply of additional credit to the borrowers, and high cost of loan terms, it might be difficult and expensive for the depositors to obtain external financial sources (Cuñat and Garcia-Appendini, 2012).

Comparing to suppliers, banks have usually lower capital costs and easier access to capital. So, if the latter are able to assess the ability of the manufacturers in repaying the debt, they can offer cheaper-rate loans. However, lack of information causes the banks to offer unfavourable terms or even deny providing loans to the manufacturers. On the other hand, as the suppliers are operating in the same industry as manufacturers, firstly, they have occasionally better estimation of the demand distribution for manufacturers' goods than banks and secondly, the suppliers' competition in selling their goods to manufacturers

provide motivation for lending to manufacturers easier than banks. Moreover, suppliers have information advantage over banks and it is easier for the suppliers to monitor and control the borrowers' actions (Burkart and Ellingsen, 2004; Cuñat, 2007). Thus, even with higher cost credit terms than bank loans, the relatively easy access to supplier financing would motivate the manufacturers to have contract with the suppliers who offer trade credit (Cuñat and Garcia-Appendini, 2012).

Trade credit can be also applied as a strategy to reduce the transaction costs of cash management. Companies that are facing uncertainty of the delivery time can use trade credit for advance predicting of the time of cash inflows or outflows. This helps the buyer in determining when the timing of the cash flows will occur and therefore reduces the costs of obtaining liquidity. Besides, a vendor that is facing random cash inflows is motivated to have a more predictable stream of cash and manage its liquidity more efficiently. Besides, trade credit is a powerful policy for companies facing cash requirements to minimize liquidity management costs related to excess borrowing. Firms can gain liquidity through factoring receivable accounts when short of cash (Cuñat and Garcia-Appendini, 2012).

Another incentive for offering and accepting trade credit among supply chain members is that it is a response to imperfect market competition. When the market is not very competitive, selective offering of trade credit may be more profitable than the traditional payment without any delay.

On the other hand, delay in payment contract is worthy to the customers as they do not need to invest their capital on inventory and it is advantageous to the vendor in attracting more customers and selling new and unproven products. It can also act as a strategic tool for the weak vendors to satisfy the requirements of strong customers. Gümüş et al. (2008) mentioned Automation and Drives division of Siemens as an example of CI in which springs and nuts can be consigned from the suppliers although the demand per year is quite stable. Therefore, it is concentrated on two-level trade credit contract in this thesis and the results are compared with one-level and traditional inventory system to provide a condition under which both of the supply chain members benefit.

Besides, in reality, some companies have high backorder costs, especially when the provided goods or services are affecting people health. So, they must keep a certain amount of inventory to reduce shortages. There are some other companies, however, for which shortage is not extremely improrant at the time of order its related cost is not considerable. In the latter case, the buyer may use the inventory model with shortage as a strategy to reduce inventory related costs and increase its net profit (Chang et al., 2008). Regarding the importance of shortages in replenishment policy, it is assumed that the manufacturer encounters shortages which are completely backlogged to the next period.

Deterioration is another major concern of today competitive industry. Almost all of the products deteriorate and lose their effectiveness and value over time; For some products such as glassware the deterioration rate is small while for others like medicine it is notably high (Thangam and Uthayakumar, 2010). This necessitates considering deterioration rate in establishing the inventory models which are formulated in this research.

Since the established inventory models are mixed integer nonlinear programming (MINLP), which are challenging optimization problems, their solutions cannot be easily obtained by mathematical solutions. Such kinds of problems have the difficulty of optimizing integer variables as well as dealing with nonlinear functions (Bonami et al., 2012). Therefore, in order to determine the optimal replenishment policies of the supplier and the manufacturer and the manufacturer's selling price, a hybrid metaheuristic algorithm is developed in this research. For this purpose, particle swarm optimization (PSO) algorithm is used as a genetic operator in genetic algorithm (GA) to take advantage of exploitation and exploration of both of these algorithms simultaneously and enhanced the new hybrid algorithm's performance.

## 1.3 Objectives of the Study

This study aims at extending the previous researches of delay in payment in order to make it more applicable. Moreover, it aims at determining how to coordinate the two-echelon supply chain with price dependent demand in a way that the total net profit of the supply chain is maximised. Therefore, the main objectives of this study include:

1) To formulate profit maximisation inventory models for traditional inventory system, one-level trade credit, and two-level trade credit.
2) To develop a hybrid metaheuristic algorithm to maximise the developed models and obtain the variables' optimal values.
3) To verify and validate the formulated models and the developed metaheuristic algorithm through literature and real case studies.

## 1.4 Research Scope

This thesis hypothesizes that comparing to the conventional inventory system, trade credit would be more profitable to the supply chain. For this purpose, mathematical modelling is used to optimize the total net profit obtained by a supply chain including a supplier a manufacturer. Three different inventory systems have been established in this thesis: 1) inventory sytem without delay in payment, 2) one-level trade credit in which the supplier offers trade credit to the manufacturer, and 3) two-level trade credit where not only the suppier proposes trade credit to the manufacturer, but also the manufacturer allows its customers to delay payment. It is assumed that the manufacturer receives the raw materials from the supplier and starts producing some kind of product that may deteriorate during the time. Moreover, completely backlogged shortages are assumed at the manufacturer. For making the model more practical, the demand function is also defined as price sensitive. The objective of the developed inventory models is to help the supply chain experts all around the world to decide whether trade credit contract is profitable for their supply chain or not and determine the optimal replenishment policy and selling price.

Due to the complexity of analytical solving of the proposed mixed integer nonlinear programming models, a new hybrid metaheuristic algorithm is

developed in this thesis and the optimal inventory policy of the supplier and the manufacturer and the selling price are obtained, with the objective of maximising the supply chain's total net profit. The models are also solved by applying a global optimizer solver to validate the developed algorithm. The models are then verified and validated by using the numerical examples and benchmarks from the literature and the real case data. They are finally analysed to test the sensitivity of the variables on parameters' changes and the three systems' performances are compared.

In order to develop the inventory models of the manufacturer and the supplier, MATHEMATICA software is applied in this research to formulate the inventory function at different time periods and calculate integrals. Moreover, MATLAB software is used to code the proposed hybrid metaheuristic algorithm and obtain the optimal values of the variables. For validating the developed metaheuristic algorithm, Branch-And-Reduce Optimization Navigator (BARON) is used as the global optimization solver and the inventory models are also coded in General Algebraic Modelling System (GAMS) software.

## 1.5 Research Contributions

This study mainly focuses on trade credit, the most essential short term external financing for the buyer and a critical strategy for the vendor in attracting more buyers. In order to investigate the effects of trade credit on the profit of supplier, manufacturer, and the supply chain, the joint inventory models of the supply chain members under three different payment policies, (i) traditional inventory system, (ii) one-level trade credit contract, and (iii) two-level trade credit contract are formulated. Moreover, a hybrid metaheuristic algorithm, consisting of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) algorithm, is developed to solve the model and obtain the proper solutions for the manufacturer's replenishment policy and selling price, and the supplier's cycle time. After verifying and validating the proposed models and solution algorithm, the effects of parameters on the decision variables have been analysed. Furthermore, by comparing the results of the traditional inventory system with trade credit contracts, the impacts of trade credit on the supply chain is investigated.

Thus, the major contributions of this research can be mentioned as

I) The joint net profit models of a supply chain including a manufacturer and as upplier are developed under three different payment contracts: conventional inventory system, one-level trade credit, and two-level trade credit, in which deterioration rate and backlogged shortages are assumed.

II) A hybrid metaheuristic algorithm is developed for solving the formulated mathematical model.

## 1.6 Organization of the Thesis

This thesis includes the following chapters; Chapter 2 reviews the literature of trade credit exclusively in order to determine and recognize the existing gaps in this research area. Chapter 3 discusses the notations and assumptions and sets the infrastructures for models' formulation and solution algorithm. Chapter 4 develops the inventory models of the traditional inventory system, one-level trade credit, and two-level trade credit based on the obtained cost and revenue terms in Chapter 3. Moreover, the models are solved in this chapter to find the values of the decision variables and maximise the supply chain total net profit. All of the models are also verified and validated by using numerical examples and benchmarks from the existing studies and real case study from industry. The proposed hybrid metaheuristic algorithm is also verified by using a global optimizer solver. Sensitivity analysis and models' comparison is also conducted and the results are presented in this chapter. The findings of this thesis and suggestions for future research are summarized and discussed in Chapter 5.

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