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Project Scheduling in the Financial Management of Supply Chains

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of the requirements for the degree of

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in

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by

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ABSTRACT OF THE THESIS

Project Scheduling in the Financial Management of Supply Chains

by

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This study models the supply chain related financial performance of a retailer evaluated by the accumulated cash at the end of a one-year period. The aim of this study is to provide a comprehensive approach for modeling of financial supply chains and to show how some of project scheduling techniques aiming to improve the Cash Conversion Cycle (CCC), e.g., Lead Time crashing or delaying the payments to the upstream supply chain partners, may affect the financial performance. We simulated a retailer over a one-year period using Monte Carlo Simulation. While traditional approach promotes shorter CCC, our simulation results show that there are optimal values for the components of CCC that constitutes optimal Cash Conversion Cycle level below which the company profitability can be harmed. So, by analyzing the results our study finds that the optimal financial and operational policies for the company and the corresponding optimal CCC level.

TABLE OF CONTENTS

	Page
List of Figures	vii
List of Tables	viii
I. Introduction and Problem Definition	1
II. Issues Affecting The Financial Management Of Supply Chains	6
III. Literature Review	8
IV. Model	14
V. Computational Experiences.....	25
VI. Conclusions	33
VII. References	35

LIST OF FIGURES

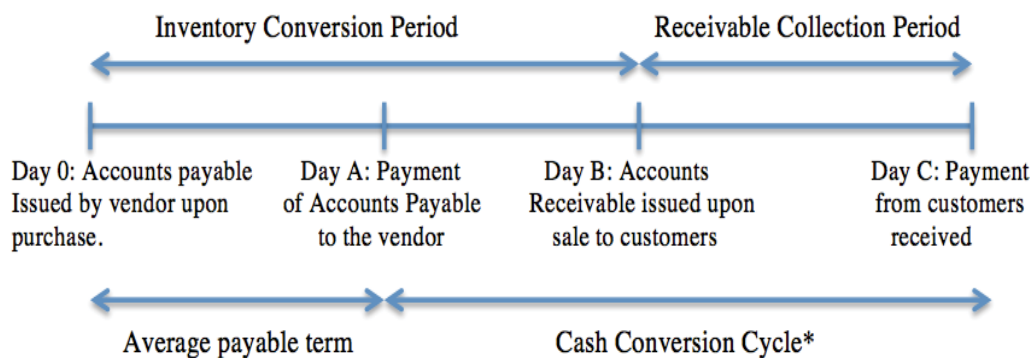
	Page
Figure 1. Cash Conversion Cycle	1
Figure 2. Supply Chain Levels	4
Figure 3. Time/Cost tradeoffs in activity crashing	8
Figure 4 Cash Conversion Cycle considering Lead Time Factor	15
Figure 5. Cash inflow on day t	21
Figure 6. Accumulated Cash and Total Cost vs. Lead Time	29
Figure 7 Lead Time vs. Inventory Conversion Period.....	29
Figure 8. Change in Reorder Point and Optimal Order Quantity vs. Lead Time	30

LIST OF TABLES

	Page
Table 1. Demand Distribution, Unit Cost, Sales Price and CSL.....	26
Table 2. Manufacturer's Contract Terms with Customer and Vendor	26
Table 3. Lead Time Crashing Parameters	26
Table 4. Optimal CCC components and Corresponding optimal CCC value.....	30
Table 5. Effect of change in r on optimal payment term	31
Table 6. Effect of change in Lead Time 2 on optimal payment term and accumulated cash	32
Table 7. Effect of change in CSL on optimal Lead Time	33

I. PROBLEM DEFINITON & INTRODUCTION

In literature, numerous publications on managing supply chains exist most of which has focused on the physical aspects of the supply chains. Although the bottom line is very important for managers, there are a limited number of publications that combine the financial management of supply chains with the physical management. Those studies address the supply chain financial performance measurement with different approaches and measures; one of which has been Cash Conversion Cycle (CCC). Cash Conversion Cycle is a metric that measures the time elapsed from the payment to the suppliers till the receipt of money from the customers. Thus it is a two dimensional concept that incorporates time and financial considerations simultaneously. In that respect it enables companies to integrate the operational scheduling with the financial scheduling. In parallel with Richards' and Laughlin's study (1980) Cash Conversion Cycle can be depicted as in Figure 1.



*Cash Conversion Cycle: Inventory Conversion Period + Receivable Collection Period- Average Payment Term

Figure 1. Cash Conversion Cycle

If we analyze the CCC elements in detail, inventory conversion period is the time during which a company must invest cash till it converts inventory to sales. It is calculated by the following formula (Belt,1990):

$$\text{Inventory Conversion Period (in Days)} = \frac{\text{Inventory (\$)}}{\text{Cost of goods sold}/365}$$

Since the cost of goods sold figure in the formula refers to the cost of items that a business has sold during one year period, the denominator shows the average daily cost of items sold. Thus, by dividing the value of average inventory on hand by the daily cost of sales, inventory conversion period calculates on average how many days the inventory stays in warehouse.

Receivable collection period, on the other hand, is the average time that it takes for a business to collect money from its customers upon credit sales; so its formula is as follows (Belt,1990):

$$\text{Receivable Collection Period (in Days)} = \frac{\text{Average Accounts Receivable}}{\text{Annual Sales}/365}$$

Denominator shows the average daily sales so the receivable collection period becomes on the average how many days of accounts receivables are outstanding.

Also known as Days Payable Outstanding, the Average Payable Term is the average time for a business to pay its suppliers. It is calculated by the following formula (Belt,1990):

$$\text{Average Payable Term (in Days)} = \frac{\text{Average Accounts Payable}}{\text{Cost of goods sold}/365}$$

The denominator again shows the daily cost of the goods sold which is purchased on credit thus the formula gives on average how many days of accounts payables are outstanding.

All in all, it can be deduced from the Figure 1 that the time passed since the payment was made to the manufacturers till the money received from the customers, which is defined as Cash Conversion Cycle, is equal to Inventory Conversion Period plus Receivable Collection Period minus Average Payment Term.

When the components of the CCC are examined separately; the Average Payable and Average Receivable Terms are related to the company financial policy and contract terms between supply chain partners. On the other hand, Inventory Conversion Period depends on the firm's inventory policy. Figure 1 assumes that the inventory is in retailer's warehouse on the same day with order placement to the manufacturer. Also it assumes that there is no outbound transportation time so on the day that inventory leaves the retailer's warehouse it is received by the customer and Accounts Receivable is issued. According to those assumptions Inventory Conversion Period depends on the optimal ordering quantity.

In the sense that, CCC is embracing Account Payable, Account Receivable and Inventory Conversion Period; first two are related to timing of cash inflows and outflows and the third is related to firm's operations policy, it is a bridging measurement between operational and financial planning. Also, since CCC is the time passed from cash outflow to cash inflow, it measures how long the firm needs outside financing. Thus many scholars (Farris and Hutchison (2002), Soenen (1993), Binti Mohamad and Binti Mohd Saad (2010)) stated that the shorter CCC the better the company finances are. However, there are some complications regarding the Cash Conversion Cycle metric approach in financial management of supply chains. Even though supply chain partners put considerable efforts to have control over the stream of cash inflow by managing payment terms, these cash inflows are mostly probabilistic due to unpredictable conditions of the downstream players. On the other hand cash outflows to the upper layers of the chain is deterministic; however this depends on the cash available at the time. Figure 2 depicts the "downstream" and "upstream" supply chain partners.

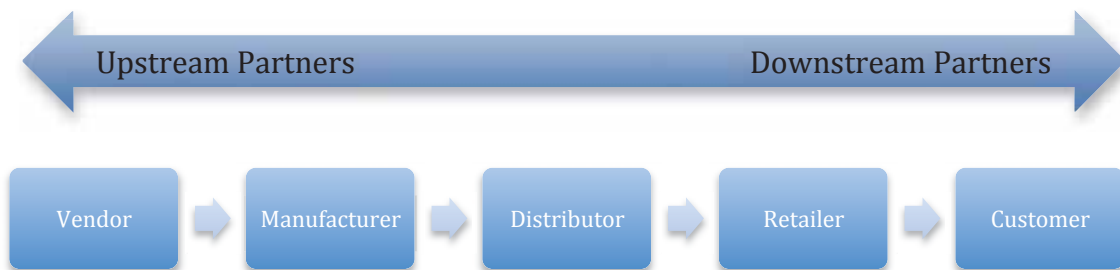


Figure 2. Supply Chain Levels

As seen from the Gupta and Dutta's study (2011), the early payment of the debts result in the lowest cash outflow at the current period, yet it does not necessarily result in the lowest present value of the cash outflow. Thus managing cash flows in an efficient way is not an easy task taking into account the probabilistic inflows in addition to the tradeoffs between prompt payment of the debt, which reduces the amount to be paid, and late payment, which increases the interest earned on cash deposits.

Those financial considerations become even more complicated for supply chains with long Lead Times. So Lead Time reduction has a huge strategic importance for successful operation of those chains. Nevertheless, managing Lead Time, which is mostly deterministic, is not an easy task either because it affects the cash flow stream in direct or indirect ways. Indirectly, Lead Time reduction affects the cash flows by improving customer service and responsiveness to demand shifts. First of all, Lead Time compression is a costly process including labor cost and additional transportation cost. Second, inventory holding cost can be reduced due to lower requirement for safety stock. Third, reducing Lead Time reduces the Cash Conversion Cycle. As the Cash Conversion Cycle measures how long the company's cash is tied to accounts payables and inventories till fulfilling an order; shortening the Lead Time decreases cost of borrowing, and also it enables the company to deliver the products or services sooner; thus the receivable collection period starts earlier.

Although many scholars worked on Lead Time compression in supply chains such as Beesley(1996) and Towill (1996) they both ignore the investment costs needed to achieve a reduction in Lead Time. Also neither Beesley nor Towill touch the cost of borrowing issue, but rather they emphasize the indirect financial effects of time reduction, such as fast response to market and enabling a more accurate demand forecast. What is more, most of the supply chain financial modeling articles are not taking into account the time flexibility factor. As known, companies can reduce Lead Times in exchange for a cost. So while studying the financial aspects of the supply chain this flexibility should be taken into account.

Whereas Ben-Daya and Raouf's (1994) study focuses on the Lead Time flexibility issue by studying the costs of Lead Time reduction along with the effects on the inventory policy such as reorder point and optimal order quantity which affects ordering and inventory holding costs, their study doesn't model a whole supply chain where the transactions with upstream players are taken into account.

To sum up, in literature there is lack of a comprehensive approach for the financial management of the supply chains. Also today's increasingly dynamic companies cannot be managed with static models. Thus, predictive integrated models that take in to account instable financial markets and also capable of ensuring required liquidity while providing timely and efficient response to orders is crucial. So, with the purpose of building a comprehensive approach that embraces time and money considerations simultaneously, our study uses Cash Conversion Cycle as the decision variable with respect to which we assess the Financial Performance. By using project-scheduling methods in timing of the operations and payments, our study aims to find the optimal Cash Conversion Cycle that generates the highest accumulated cash at the end of the one-year period. However, in our model cash inflow is probabilistic thus we don't have control over its effect on

the optimal CCC. As a result some of the values that are changed in order to find the optimal CCC are order quantity, reorder point and the Lead Time and Payable term.

So our study starts with analyzing the issues affecting financial management of supply chains and then covers the related previous work that the model is built upon. In the next issues affecting the financial management in SC are discussed. In section III review of the literature is presented and in Section IV the mathematical model is presented with the objective of maximizing the accumulated net cash at the end of a one-year period. The model considers timing of the cash inflow and outflows and Lead Time crashing costs simultaneously. Finally illustrative example and sensitivity analysis are presented followed by the conclusion part summarizing findings of the study.

II. ISSUES AFFECTING THE FINANCIAL MANAGEMENT OF SUPPLY CHAINS

Bullwhip effect: It is one of most significant reasons of supply chain inefficiency. It is the amplification of demand variance as the demand information passes from the lower levels (customers) of the supply chain to the upper levels (manufacturers level). It may be severely destructive for the financial management of the supply chain as a whole, particularly the upper levels are the ones most affected.

Each partner, knowing that the forecasts they retrieve from the lower partners are not one hundred percent accurate, builds safety stock. Thus the orders to the upper levels increase as more and more safety stock is built in the system, which leads the upper tiers to have an impression that the demand is more than its actual level. So longer Lead Times result in higher safety stock levels which in turn leads bigger amplifications in the upper levels as known as the Bullwhip Effect.

Demand forecast: For make to stock inventory systems demand forecast is the most important aspect of production management. As cycle time increases, forecasts have to be made for farther periods, which in turn increases the forecast errors. And when the accuracy of the forecast decreases, firms are forced to keep more safety inventory and thus incur higher inventory holding cost. On the flip side of the coin, even if a firm decides to keep low inventory levels, in such a blurry environment there is high probability that it falls short in responding to customer orders which hurts the profits as much as the inventory holding costs. Thus, by shortening the supply chain cycle time the entire chain benefits from accurate demand forecast.

Cost of borrowing/ investing: Cost of borrowing is another key aspect of the financial management of the supply chain. Since more interest is charged with the time elapsed over the issue date of the debt, firms should ensure collection of money from the customers as early as possible in order to pay the debts. Apparently, collection period's primary determinant is the cycle time since the customers usually are not willing to pay before they receive the product unless some incentives such as discounts are offered in advance.

Inventory holding cost: According to Ben-Daya and Raouf's (1994) economic order quantity (EOQ) model, as Lead Time increases, optimal order quantity Q^* increases; therefore the average inventory held by the firm over the year, and corresponding holding cost increase. Apart from the physical cost of inventory holding, higher obsolescence cost related to higher levels of inventory should be taken into account in case of change in technology or new trends in demand. What is more, opportunity cost is another side of the inventory holding in the sense that the capital is tied to inventory rather than other money-making investments.

Lead Time crashing cost: Firms can shorten the time needed to produce and deliver the products to customers but this can be done at a cost known as reduction or crashing cost. Lead Time vs. crashing cost graph is negative exponential (decreasing function). Crashing process starts with the

longest lead (processing) time for the activities which corresponds to the least cost, then as the Lead Time is reduced the cost increases exponentially as illustrated in Figure 3. Consequently, the total Lead Time can be decomposed into components depending on the amount invested in reducing/crashing the Lead Time.

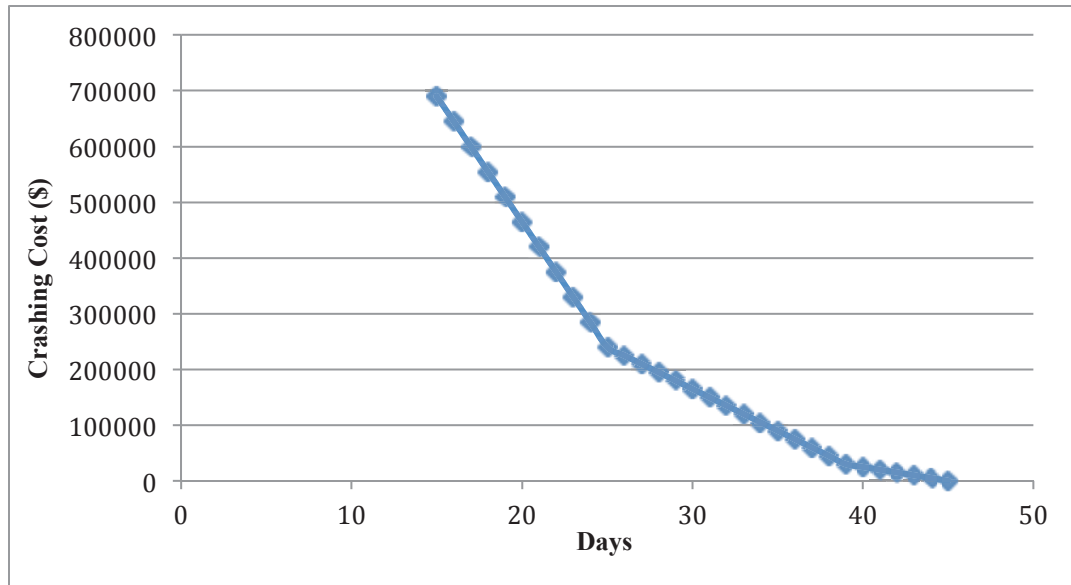


Figure 3. Time/Cost trade offs in activity crashing

III. LITERATURE REVIEW

Cash to Cash cycle, which is first defined by Gitman (1974) was further examined by Gallinger (1997) as the length of the period that the firm's operating cycle needs to be supported by costly financing. And he adds; "You can think of the operating cycle as the number of days sales are invested in inventories and receivables" (Gallinger, 1997). As seen from Gallinger's definition longer Cash Conversion Cycles damage company finances in terms of cost of borrowing/financing the necessary funds. Thus, shortening the CCC is a key metric for the company financial management. In that sense, further analysis of the CCC made by Soenen (1993) decomposes it into three sections:

1. The length of the credit term that the company gets from its suppliers,
2. The length of the production process, and
3. The number of days the final products remains in inventory before they are sold.

So, in this study we are going to examine the effects of lead-time reduction; in other words shortening the total lead time along with the optimal timing for Accounts Receivables and Payables on financial management of the supply chain.

Besides reducing the CCC, Lead Time compression benefits the organizations in other ways too. Beesley (1996) states that, the idea of quick response in the retail environment and that of just-in-time (JIT) in the manufacturing arena are two important aspects where time reduction plays a critical role. The value of time in marketing is vital says Beesley and adds, as businesses become more and more competitive, the time factor becomes more critical. What is more, according to him, since the end consumers demand high variety of choice, retailers today should hold minimal stock so that they can maximize the product range held under one roof and also offer a better service through faster replenishment. The author states that although these factors give competitive advantage to the companies, customers may not be willing to pay more for speed and variety.

The aim in “time compression” is to cut the amount of time consumed by business processes; therefore the process of converting inputs into outputs (manufacturing time) takes a shorter period of time. Thus the key to achieve time compression is getting rid of wasted time and rearranging the sequence of the activities accordingly. However Beesley draws attention to a very important fact that the logistical strategies are most effective when applied to the supply chain in its broadest context where the scope of supply chain is anything that converts a resource into a

delivered, consumable product or service. This is called the “holistic approach” or a total system view according to Beesley. So, according to him in his paper “ Time compression in the Supply Chain”, competitiveness should come from the whole supply chain system, not just from the company (producer) itself.

Besides shortening the Lead Time another way to improve the Cash Conversion Cycle is extending the average accounts payable term according to Farris and Hutchison (2002). Since it is the time elapsed between issuance of the debt and the cash outflow, longer payable terms enables companies to obtain interest-free financing. However Farris and Hutchison omit the penalty that the manufacturers may charge for a longer payment term, which will increase the cash outflows. What is more, when stating the primary leverage points to manage CCC, they put emphasis on reducing the average accounts receivable term however in order to encourage the downstream partners of supply chain to make early payments, the company should offer discount, which in turn reduces the amount of cash inflows. And finally, reducing the total Lead Time is not free of charge to companies. In that sense Nobanee (2009) worked on an improved way of modeling the optimal CCC for supply chains where he defines the optimal CCC as follows, See Figure 1:

Optimal Cash Conversion Cycle = Optimal Inventory Conversion Period + Optimal Receivable Collection Period – Optimal Payable Deferral Period.

As seen from Nobanee’s equations compressing each component to its shortest time will not necessarily lead to better financial results. The optimal points should be found for each component of the lead-time.

Since the Cash Conversion Cycle measures how long the company's cash is tied to fulfilling an order until the company receives cash, shortening the Lead Time affects the optimal Cash Conversion Cycle and accordingly the financial management of the supply chain in two ways:

- When the Lead Time is reduced, first it reduces the inventory levels and inventory conversion period, and
- It enables the company to deliver the products or services sooner; thus the receivable collection period starts earlier.

However Lead Time reduction has a considerable cost, that is modeled for a manufacturing company by Ben-Daya and Raouf (1994) in their study as follows;

$$R(L) = c_i(L_{i-1} - L) + \sum_{j=1}^{i-1} c_j (b_j - a_j)$$

They first state that Lead Time, which is the time elapsed after the firm orders raw materials until the customer receives the final product, consist of components such as transportation and production processes. According to their model in parallel with project scheduling methods, Lead Time compression starts with the processes that have the least cost and continues on to the ones with higher costs; see the Ford-Fulkerson algorithm (1954). The firm must first deplete all of the available crash time on the least cost activity before jumping to the one with the next smallest cost. So if the parameters in the model are examined in detail; $R(L)$ denotes the crashing cost for a given Lead Time L . L_i denotes the length of the Lead Time with components $1, 2, \dots, i$ crashed to their minimum, a_i denotes the minimum and b_i denotes the maximum duration of the i^{th} component, and c_i is the crashing cost per unit time of the component i . So the second part of the formula shows how much it cost to crash lower cost activities to their minimum before jumping to the new cost level. And the first part shows the partial cost of crashing in the last cost level in order to achieve the desired Lead Time.

Thus according to Ben-Daya and Raouf total cost is defined as;

$$K(Q, L) = \text{ordering cost} + \text{inventory holding cost} + \text{leadtime crashing cost}$$
$$= A \frac{D}{Q} + h \left(\frac{Q}{2} + k\sigma\sqrt{L} \right) + \frac{D}{Q} R(L)$$

Where A denotes the fixed ordering cost, D denotes the yearly demand, and Q denotes ordering quantity. Thus the first component of the formula represents annual ordering cost. And the second component is the inventory holding cost where h is the yearly holding cost per unit and k is the safety factor; consequently, $k\sigma\sqrt{L}$ shows the safety stock and the term in the parenthesis represents average amount of inventory at any given time. Finally last component shows the Lead Time crashing cost for the current Lead Time L. As seen from the equation the firm incurs Lead Time reduction cost for each replenishment cycle.

In our model we are using the Ben-Daya and Raouf's model to calculate total cost including the Lead Time crashing cost and find out the optimal Lead Time and ordering quantity. They drive the following equation by improving the classical Economic Order Quantity (EOQ) model, which intrinsically assumes that there is no Lead Time.

$$Q = \sqrt{\frac{2D[A + R(L)]}{h}}$$

On the other hand if the accounts payable component of the CCC is examined, Gupta and Dutta (2011)'s model for optimal accounts payable flow suggests that the payments of the debts should be done during the period that minimizes the present value of cash outflows given that in the current period the accumulated cash inflow from the downstream partners are sufficient to pay the

debt. Thus in their study L_k denotes invoice amount for invoice k , and $A_k(t)$ denotes the amount paid for invoice k if it is paid at time t ;

$$A_k(t) = \begin{cases} L_k(1 - u_k) & \text{if, } s_k \leq t \leq b_k \\ L_k & \text{if, } b_k \leq t \leq d_k \\ L_k(1 + v_k) & \text{if, } d_k \leq t \end{cases}$$

Where;

u_k : Discount that is granted for invoice k in case of early payment

v_k : Punishment that is charged for invoice k due to late payment

b_k : Due date for the firm to get early payment discount for invoice k

d_k : Due date for the firm not to be charged punishment for invoice k

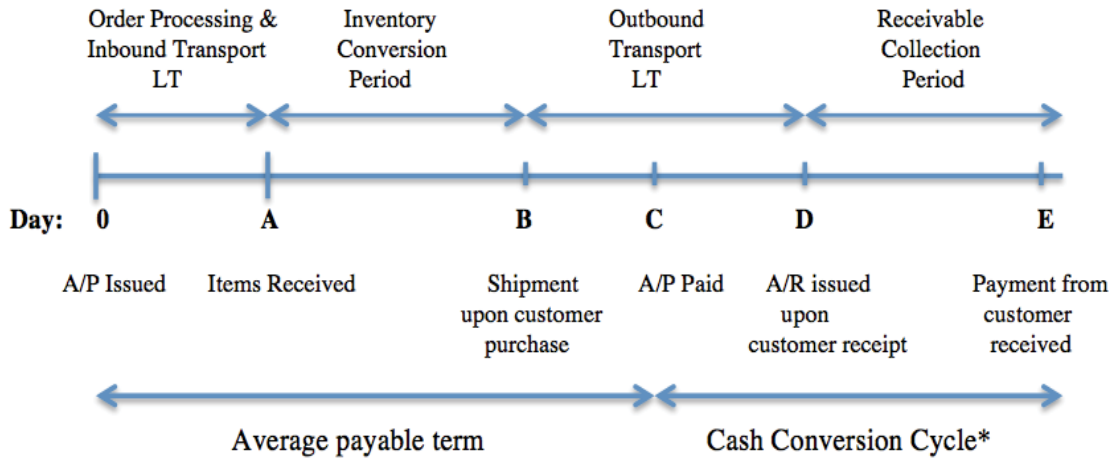
s_k : Time at which invoice k was generated.

As seen from the equations above, the amount paid for any invoice depends on the time it is paid according to the contract terms between the firm and the manufacturers. Late payments are punished with a certain percentage of the invoice amount whereas early payments are rewarded with a discount.

The last component of the CCC requires managing the account receivables in the most efficient way. Although the early receipt of payments is worthy for the firm, customers usually look for a motivator to do so knowing that they can pay later if they buy from a competitor. As a result, in order to encourage customers for early payment firms are usually forced to offer discounts (Farris and Hutchison, 2002)

IV. MODEL

In our model, working on a three tier supply chain consisting of a manufacturer, retailer and a customer, we are examining the financial effects of any change made in the components of Cash Conversion Cycle on the retailer. Our retailer bases its inventory planning on forecast of demand so places order to the manufacturer in advance by using Economic Order Quantity (EOQ) Model. The retailer issues accounts payable upon placing the order to the manufacturer. The shipment of the items occurs after the manufacturer's order-processing time. So it takes order processing time plus inbound transportation time for the retailer to receive the items which is initially 20 days in our model. The items wait in retailer's warehouse until customer inquiry. The sale transaction is completed when the customer receives the item upon which the accounts receivable is issued and the receivable period started. Thus for the retailer average time to convert an order with the manufacturer to a final sale takes total Lead Time (order processing & inbound transportation and outbound transportation Lead Times) plus the time period that the inventory stays in warehouse (Inventory Conversion Period). So by taking into account the Lead Times in our model, Figure 1 can be improved as follows;



*Cash Conversion Cycle: Total Lead Time + Inventory Conversion Period + Receivable Collection Period- Average Payment Term

Figure 4. Cash Conversion Cycle considering Lead Time Factor

Through the paper for practical purposes Order Processing and Inbound Transportation Lead Time is called Lead Time 1, and Outbound Transportation Lead Time is called Lead Time 2.

We assume that contract terms for both accounts payable and accounts receivable are not changed for the one-year period. In the model the pattern of collection from customers is probabilistic, whereas the pattern of payment to manufacturer depends on the payment received from customers. This is the case to assure that the cash in hand is sufficient to pay the current debt.

The retailer offers a credit term to its customers; a discount of u_r if payment is received within 3 days upon delivery or the full amount must be paid after the 3th day. On the other hand for each day after the 8th day a delay penalty is charged; v_r . We assume that the customers wait until the last day of each payment term to earn interest. The pattern of customer payment is probabilistic where p_e is the probability of early payment, p_n is the probability of normal payment and p_l is the probability of late payment. Also for practical purposes, it is assumed that if customers pay

after the due date they always pay on the 10th day. Similarly, there is a credit term allowed by the manufacturer to the retailer.

The firm's objective is to maximize the cash available at the end of a one-year period after paying the annual inventory holding, ordering and crashing costs by proper selection of the decision variables that composes the Cash Conversion Cycle.

In our model total Lead Time is deterministic whereas the Inventory Conversion Period depends on the Lead Times. Lead Time 1 affects Reorder Point by changing the required safety stock level and demand during Lead Time; what is more, total Lead Time affects optimal ordering quantity by changing the crashing cost. Thus Inventory Conversion Period is a dependent variable in the model. And since the receivable collection period is probabilistic, we are left with two decision variables; Total Lead Time and the Payment schedule. So our purpose is to find the optimal payment period and optimal total Lead Time, which gives the optimal CCC for the retailer.

Customer Demand: Customer daily demand, D , is normally distributed with mean μ , and standard deviation σ_D , estimated by \bar{D} during each period (one day). D_{L1} on the other hand is the mean demand during Lead Time 1; with standard deviation $\sigma_{L1} = \sqrt{L_1} * \sigma_D$.

Inventory Policy: Since it takes Lead Time 1 for retailer to receive items from manufacturer, SS denotes the safety stock that allows the system to meet the demand during Lead Time 1. In order to find the safety stock, we first need to determine the cycle service level (CSL) as defined by Chopra and Meindl (2001); “the probability of not having a stock out in a replenishment cycle”. It is assumed that CSL equal to 0.75 and stable in our model in order to compare the results across different levels of Cash Conversion Cycle whereas providing the same service level to the customers. So, Reorder Point is determined by D_{L1} and SS .

Order Quantity: Optimal ordering quantity is calculated by using EOQ model taking into account the total Lead Time crashing cost as presented by Ben Daya and Raouf (1994).

Crashing Cost: Again, Ben Daya and Raouf's equation for Lead Time crashing cost is used in the model. Lead Time reduction comprises two components in our model; inbound transportation & order processing and, outbound transportation. These components have different crashing costs with varying available crash times. The firm in our model issues accounts payable for the first crashing cost it has to pay since there is no accumulated cash at the beginning of the simulation; however, the following crashing costs are paid by the accumulated cash on the same day that it incurred the crashing cost. Crashing cost is incurred once per replenishment cycle and issued upon placing an order to the manufacturer.

Model Parameters:

L : Total Lead Time

L_1 : Inbound Transportation & Order Processing Lead Time

L_2 : Outbound Transportation Lead Time

C : Unit cost of a component

P : Price of finished product

D : Mean daily demand

\bar{D}_t : Random demand on day t

σ_D : Daily demand standard deviation

D_{L1} : Demand during Lead Time 1.

σ_{L1} : Standard deviation of demand during Lead Time 1

h : Yearly holding cost as percentage of unit purchasing cost of one component

H : Cost of holding 1 unit in inventory for 1 year.

p_e : Probability that the customer pays in early payment period.

p_n : Probability that the customer pays in normal payment period.

p_l : Probability that the customer pays in late payment period.

u_r : Discount that is granted to customers in case of early payment

v_r : Penalty that is charged to customer due to late payment

u_p : Discount that is granted to manufacturer by manufacturer in case of early payment

v_p : Penalty that is charged to retailer due to late payment

d_u : Due date for the retailer to get early payment discount

d_v : Due date for the retailer not to be charged with delay penalty

a_j : Shortest possible Lead Time for component j

b_j Normal Lead Time for component j

c_j : Unit crashing cost of component j where

$j=1$ is outbound transportation component

$j=2$ is inbound transportation & order processing component

F : Fixed cost of ordering from supplier

Independent and Dependent Variables:

ICP: Inventory Conversion Period

ROP_{L_1} : Reorder Point with L_1

Q_L : Optimal Ordering Quantity when total Lead Time is L

BI_t : Beginning inventory at day t

EI_t : Ending inventory on day t

S_t : Sales (in units) on day t

AP_t : Accounts payable that is generated on day t.

A_{t+n} : Amount to be paid, if the Accounts Payable that is generated on day t is paid n days later.

n: Payable Term (in days)

X_e : 1 if Accounts Payable is paid in early payment period 0 otherwise.

X_n : 1 if Accounts Payable is paid in normal payment period, 0 otherwise

X_l : 1 if Accounts Payable is paid in late payment period, 0 otherwise

AR_t : Accounts receivable that is generated on day t

$B_{t,m}$: Amount to be collected on day t for the Accounts Receivable that is generated m days earlier.

m: Receivable Term (in days)

Xo_t : 1 if order placed at the end of day t, 0 otherwise.

Xp_t : 1 if the outstanding accounts payable is paid on day t, 0 otherwise.

CI_t : Cash inflow on day t

CO_t : Cash outflow in day t

CA_t : Cash available at the end of day t

Cr_L : Crashing cost when total Lead Time is L

Cash Conversion cycle when the Accounts Payable term is n , Accounts Receivable Term is m and total Lead Time is L is calculated by the following formula; see Figure 4.

$$CCC = L + ICP + m - n \quad (1)$$

Constraints

Inventory Conversion Period;

$$ICP = \frac{\sum_{t=0}^{360} EI_t}{360} \times C \Big/ \frac{\sum_{t=0}^{360} S_t}{360} \times C \quad (2)$$

The numerator shows the average value of inventory held in hand throughout the year and denominator shows the daily Cost of Goods Sold so the Formula 2 can be rephrased as follows;

$$ICP = \sum_{t=0}^{360} EI_t / \sum_{t=0}^{360} S_t$$

So we run the simulation with 100 iterations in order to find the Inventory Conversion Period corresponding to each total Lead Time level.

Demand during Lead Time 1;

$$D_{L1} = L_1 * D \quad (3)$$

Standard Deviation of demand during Lead Time 1;

$$\sigma_{L1} = \sqrt{L_1} * \sigma_D. \quad (4)$$

Total Lead Time is 45 days normally and it can be compressed to 15 days when all the components are crashed to their minimum so;

$$15 \leq L_T \leq 45 \quad (5)$$

Safety Stock;

$$SS = \sigma_L * z_{1-CSL} \quad (6)$$

Where z_{1-CSL} denotes the z value for the standard normal distribution with the probability 1-CSL

Sales during day t (in units);

$$S_t = \min(D_t, BI_t) \quad (7)$$

Crashing cost when total Lead Time is L_T ;

$$CR_{LT} = c_j(L_{j-1} - L) + \sum_{j=i}^{i-1} c_j (b_j - a_j) \quad (8)$$

Optimal order quantity Q_{L1}^* , when Lead Time1 is L_1 ;

$$Q_{L1} = \sqrt{\frac{2 \times D \times 360 \times (F + Cr_{LT})}{H}} \quad (9)$$

Reorder point when Lead Time 1 is L_1 ;

$$ROP_{L1} = D_{L1} + SS \quad (10)$$

So after calculating the Reorder Point according to the Formula (10), a binary variable is defined regarding placing an order on a given day;

$$X_{Ot} = \begin{cases} 1, & EI_t \leq ROP_L \\ 0, & otherwise \end{cases} \quad (11)$$

The manufacturer checks the ending inventory at the end of each day and if it is less than the Reorder Point, an order of Q_L^* is placed at the end of the same day. Beginning inventory on day t , which is denoted as BI_t , includes the items that are ready to be labeled as “sold” which is the time when the customer receives the final product. So BI_t becomes;

$$BI_t = EI_{t-1} + X_{O_{t-L1}} \times Q_L \quad (12)$$

The items in amount of Q_L^* , that are ordered Lead Time ago is ready to be deducted from the inventory as “sold” only Lead Time days later which includes the production time and shipment times.

Accounts receivable generated on day t is;

$$AR_t = S_t \times P \quad (13)$$

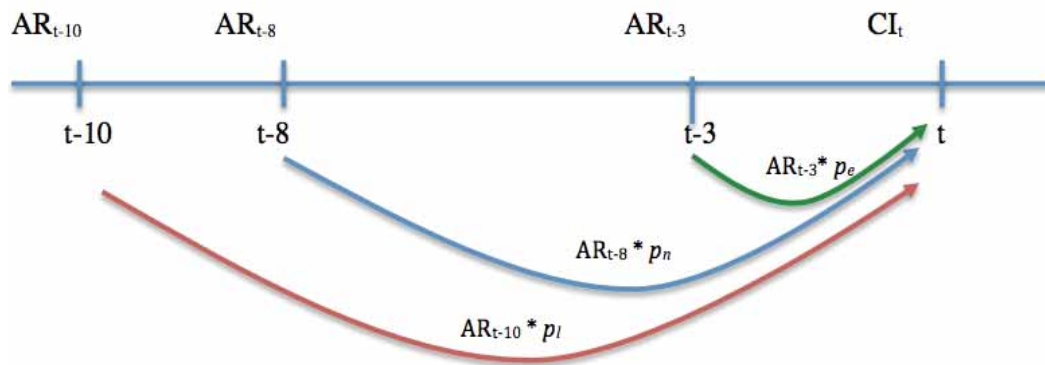


Figure 5. Cash inflow on day t

As seen from the Figure 5, Accounts Receivable generated on any day is received 10 days later with a probability of p_l , received 8 days later with a probability of p_n and received 3 days later with a probability of p_e . Thus the receivable term m is;

$$m = \begin{cases} 3, & p_e = 0.35 \\ 8, & p_n = 0.45 \\ 10, & p_l = 0.2 \end{cases} \quad (14)$$

Accordingly, amount to be collected on day t for the Accounts Receivable that is generated m -days earlier is;

$$B_{t,m} = \begin{cases} AR_{t-3} \times (1 - u_r) & \text{if, } m = 3 \\ AR_{t-8} & \text{if, } m = 8 \\ AR_{t-10} \times (1 + v_r)^2 & \text{if, } m = 10 \end{cases} \quad (15)$$

Since the retailer charges a penalty of v_r for each day after the 8th day, when the customer pays on the 10th day which is 2 days after the normal period, the penalty becomes, $(1 + v_r)^2$.

To illustrate; $B_{15,3}$ denotes the amount collected on day 15 for the accounts payable issued 3 days earlier which has a collection period of 3 days. And it is equal to $AR_{t-3} \times (1 - u_r)$.

So the Cash inflow on day t becomes;

$$CI_t = \sum_{m=3,8,10} B_{t,m} \quad (16)$$

So the cash inflow on day 15 is;

$$CI_{15} = B_{15,3} + B_{15,8} + B_{15,10}$$

And the Accounts Payable generated on day t is;

$$AP_t = Q_L \times C \times X_{0t} \quad (17)$$

On the other hand, amount to be paid, if the Accounts payable that is generated on day t is paid after n days;

$$A_{t+n} = \begin{pmatrix} AP_t(1 - u_p) & \text{if, } n \leq d_u \\ AP_t & \text{if, } u_d \leq n \leq d_v \\ AP_t (1 + v_p)^{n-v_d} & \text{if, } d_v \leq n \end{pmatrix} \quad (18)$$

Cash outflow on day t is sum of Accounts Payable if it is paid on that day and, Fixed Ordering Cost and Crashing Cost if an order is placed on day t. Crashing Cost is paid once in every replenishment cycle upon order placement since each order placement is the beginning of a new cycle. Thus the cash outflow on day t can be formulated by;

$$CO_t = A_t \times Xp_t + F \times Xo_t + CR_L \times Xo_t \quad (19)$$

And cash available at the end of period t is;

$$CA_t = (CA_{t-1}) + CI_t - CO_t \quad (20)$$

In order to assure that the cash outflow on any day does not exceed the available cash on the same day we have the following constraint;

$$(CA_{t-1}) + CI_t \geq CO_t \quad (21)$$

in other words, $CA_t \geq 0$

Cost of holding one unit in inventory for one year;

$$H = h \times C \quad (22)$$

Total Lead Time L;

$$L = L_1 + L_2 \quad (23)$$

Inventory holding cost for one year period;

$$\frac{\sum_{t=0}^{t=360} EI_t}{360} \times H \quad (24)$$

Objective function

$$\text{Max } CA_{360} - \frac{\sum_{t=0}^{t=360} EI_t}{360} \times H \quad (25)$$

Where CA_{360} refers to the ending cash balance and $\frac{\sum_{t=0}^{360} EI_t}{360}$ refers to the average inventory

level. The formula can be rephrased as follows;

$$= \sum_{t=1}^{360} CI_t - \sum_{t=1}^{360} CO_t - \frac{\sum_{t=0}^{360} EI_t}{360} \times H$$

$$= \sum_{t=1}^{360} CI_t - \sum_{t=1}^{360} (A_t \times X_{p_t} + F \times X_{o_t} + CR_{LT} \times X_{o_t}) - \frac{\sum_{t=0}^{360} EI_t}{360} \times H$$

The objective function as seen from the above formula depends on the Lead Time, Accounts Payable and Accounts Receivable Terms. Lead Time Affects Crashing Cost, CR_L , and also since Crashing Cost changes the optimal ordering quantity Q_L , it affects the amount to be paid to manufacturer, A_t . Accounts Payable Term affects whether any payment is made on a particular day t or not, X_{o_t} and finally Accounts Receivable Term affects cash inflow on any day, CI_t . Thus CCC is a good metric that incorporates all three factors that affect the Accumulated Cash.

Optimal Payment Period: In order to find optimal Payment Period, we use Gupta and Dutta's (2011) model. So we developed the following integer linear programming;

Decision variable;

n: Payment Term (number of days passed since the accounts payable was generated)

Objective Function;

PVA_{t+n} : Present Value of the amount paid for the accounts payable generated on day t and paid n days after.

$$\text{Min } PVA_{t+n} = \frac{AP_t(1-u_p)}{(1+r)^n} X_e + \frac{AP_t}{(1+r)^n} X_n + \frac{AP_t(1+v_p)^{n-v_d}}{(1+r)^n} X_l$$

Constraints;

X_e, X_n and X_l are binary

X_e : 1 if $n \leq 10$, 0 otherwise

X_n : 1 if $11 \leq n \leq 20$, 0 otherwise

X_l : 1 if $n > 20$, 0 otherwise

$X_e + X_n + X_l = 1$

The discount factor $r=0.05\%$.

Average Collection Period: To find the average Collection Period we simulate the payment day for each Accounts Receivable by using discrete probability distribution function and finally take the average over one year period.

Assumptions

Backordering is not allowed.

Crashing cost CR_L is paid at the beginning of each replenishment cycle.

Ordering cost is paid on the day of order.

Inventory Holding Cost is paid at the end of the year in terms of cash.

First crashing cost is added to the accounts payable but the others are paid cash on the period the cost was generated.

One year is 360 days.

V. COMPUTATIONAL EXPERIENCES

To solve the above problem a Monte Carlo simulation program via Microsoft Excel is developed.

The inputs of the simulation model are given in the following tables:

Table 1. Demand Distribution, Unit Cost, Sales Price and CSL

Parameters			
Mean daily demand	500 units	Purchasing Cost	\$250
Standard deviation of daily demand	50 units	Sales price	\$450
CSL	0.75	Fixed ordering cost	\$5000
Inventory holding costs	0.25		

Table 2. Retailer's Contract Terms with Customer and Manufacturer

Accounts Payable Terms		Accounts Receivable Terms	
u_p ; discount that is granted for early payment	1%	u_r ; discount that is granted for early payment	1%
v_p ; penalty charged for late payment	2%	v_r ; penalty charged for late payment	2%
d_u ; due date to get early payment discount	10	p_e Probability of early payment	0.35
d_v ; due date not to be charged punishment	20	p_n : Probability of normal payment	0.45
		p_l : Probability of late payment	0.2

Table 3. Lead Time Crashing Parameters

Crashing	Normal Days	Minimum Days (Crash Duration)	Daily Crashing Cost	Available Crash Time
inbound transport & Order Processing	20	6	\$20000	14 Days
outbound transport	10	4	\$15000	6 Days
Total	30	10		30 Days

In our model, Optimal Ordering Quantity for each Lead Time level is calculated according to Ben-Daya and Raouf's (1994) EOQ equation. Reorder Point on the other hand is calculated by the formula (10), which determines the reorder point such that demand is satisfied with a certain probability level (CSL) during the Lead Time. Thus, the system automatically places order to the

manufacturer once the inventory in hand falls below that reorder point. And it takes Lead Time 1 for the order to be received by the retailer.

Cash inflows are probabilistic in the system; the firm grants a 1% discount if the customers pay the amount within 3 days, and charges 2% penalty if the amount is paid after 8 days. So with the given accounts receivable terms we assume that:

- 35% of the customers are paying within 3 days,
- 45% of the customers are paying between 4th and 8th day, and finally
- 20% of the customers are paying after 8th day.

What is more the manufacturer is following a similar reward-punishment mechanism regarding the retailer's purchases; if the firm pays its debt within 10 days it gets a 1% discount but if it pays after 20th day it has to pay 2% more for each day passed after the 20th day. However as stated in Gupta and Dutta's (2011) study, the optimal payment days within early or late payment periods are the last days of those periods since the company should keep the money in hand as long as possible given that the cash outflow is going to be the same. Thus, in our study we assume that the 35% of the customers are paying on the 3rd day (last day of the early period), and similarly 45% of the customers are paying on the 8th day (last day of the normal period) and for the late payments for practical purposes we assume that 20% of the customers are paying on the 10th day.

Although Accounts Payable Term has no effect on inventory policy, Lead Time Compression has. The formula (3) indicates that when the Lead Time is reduced by crashing, demand during Lead Time (D_L) decreases. Also from the equation (4), when Lead Time is reduced, standard deviation of demand during Lead Time decreases which in turn according to formula (6) causes a decrease in required Safety Stock. Thus when Lead Time is compressed since both the Safety

stock and the Demand during Lead Time decreases reorder point decreases. However the EOQ equation indicates that when Lead Time is reduced since the crashing cost is increasing, optimal order quantity increases, thus the firm is forced to order higher amounts, but less frequently which increases the inventory holding cost while decreasing the fixed ordering costs.

Using the parameters above we first solve the integer liner programming problem regarding the optimal payment period. And then simulate a one year period by Monte Carlo Simulation over 100 iterations of the cash available at the end after deducting the annual inventory holding costs. All in all, our simulation results give us the average Collection Period, Optimal Lead Time Level and corresponding Inventory Conversion Period. Also the integer linear programming that we developed to minimize present value of accounts payable gives the optimal payment period. Thus, according to Formula 1 we find the optimal Cash Conversion Cycle for the firm by combining the optimal values of its components.

Figure 6 graphs the change in Accumulated Cash and Total cost consisting material purchase, Lead Time crashing, Fixed Ordering and lost profit due to stock outs that is calculated by the following formula;

$$Total\ Cost = \sum_{t=1}^{360} A_t \times Xp_t + \sum_{t=1}^{360} (CR_L + F +) \times Xo_t + \sum_{t=1}^{360} Max(\bar{D}_t - BI_t, 0) \times (P - C)$$

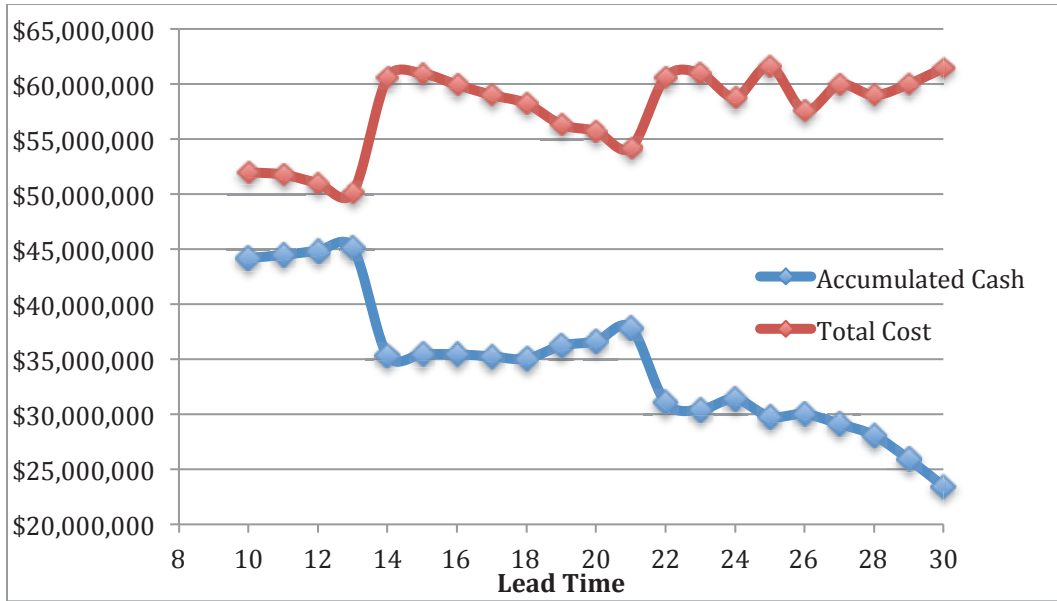


Figure 6. Accumulated Cash and Total Cost vs. Lead Time

As seen from Figure 6, the optimal Total Lead Time for the retailer is 13 days, which maximizes the accumulated cash value.

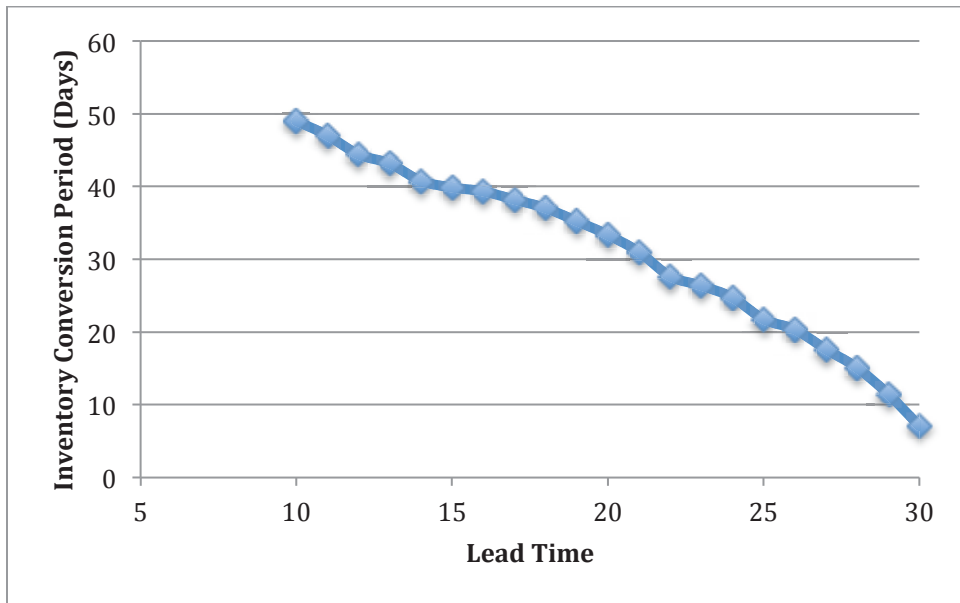


Figure 7 Lead Time vs. Inventory Conversion Period

From Figure 7 it is seen that Inventory Conversion Period is increasing as Lead Time decreases. The reason is that: when Lead time is crashed according to EOQ model considering Lead Time crashing cost, the optimal order quantity increases, so it takes longer for the company to turn this high amount of inventory into sale. The change in ROP and Optimal Order Quantity is depicted in Figure 8. And from Figure 7, it is seen that summation of Total Lead Time and Inventory Conversion Period is increasing which means that the CCC is increasing as the Lead Time is getting shorter. Thus from Figure 7, we find that the Inventory Conversion Period corresponding our optimal Lead Time of 13 days is; 43.2 days.

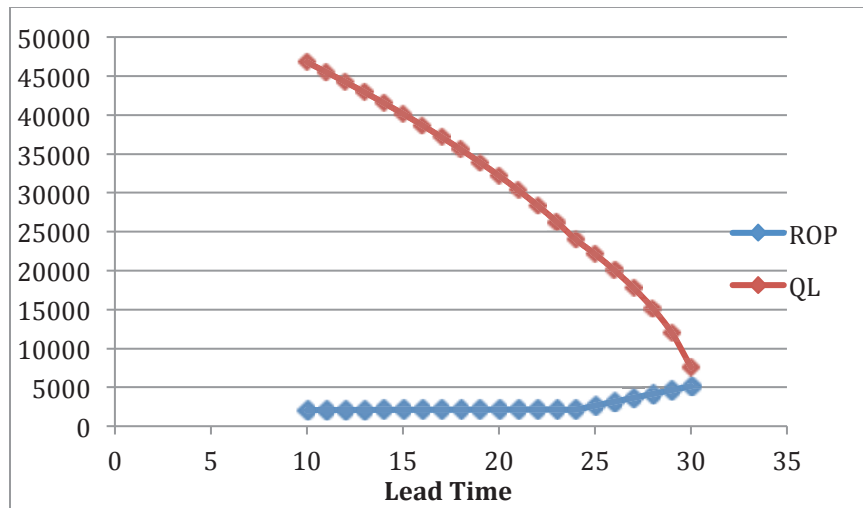


Figure 8. Change in Reorder Point and Optimal Order Quantity vs. Lead Time

According to the Linear Integer Programming that we developed to find the optimal payment time; we found that $n=10$ minimizes the present value of payment so the optimal time for the retailer to pay its debt 10 days after the invoice issuance, which is the last day of early payment period.

And finally the Monte Carlo Simulation gives the average collection period as 6.5 days, which is very close to its theoretical calculation;

$$3 \times p_e + 8 \times p_n + 10 \times p_l = 3 \times 0.35 + 8 \times 0.45 + 10 \times 0.2 = 6.65$$

The optimal values for the CCC components are shown in the following table.

Table 4. Optimal CCC components and Corresponding optimal CCC value

Total Lead Time	Inv. Conversion Period	Average Collection Period	Optimal Payment Term	CCC*
13	43.2	6.5	10	52.7

All in all, from the Formula 1, the optimal CCC for the retailer is;

$$CCC = 13 + 43 + 7 - 10 = 53 \text{ Days}$$

After examining the results for our initial values we conduct the following sensitivity analysis by changing some of the key variables.

First we change the discount rate r to see the effect on optimal payment term.

Table 5. Effect of change in r on optimal payment term

r	0.00%	0.05%	0.10%	0.15%	0.20%	0.25%	0.50%	2%	2.10%
Optimal Payment	10	10	10	10	20	20	20	20	∞

As seen from table the optimal payment period increases as the discount factor increases. When it equals to the late period payment penalty v_p which is 2%, the retailer is indifferent about paying its debt on day 20 or on any other day after it because for each day it delays the payment after day 20 it earns 2% interest but at the same time its payment due increases by 2%. And once the discount factor is above v_p , there is no upper bound for the optimal payment term. Since the

optimal payment period is deducted from CCC, we can conclude that increase in interest rates will justify shorter CCC.

Another important deduction from this table is that, the firms should fully use the incentives that the suppliers offer and pay on the last day of the contract term intervals. This can be seen from the table that the optimal payment term for the manufacturer is either 20 (last day of the normal payment period) or 10 (last day of the early payment period).

Next we examine the effect of change in outbound transportation Lead Time crashing cost.

Table 6. Effect of change in Lead Time 2 on optimal payment term and accumulated cash

L2 Crashing Cost	optimal Total LT	Accumulated Cash
7500	10	41478800.16
10000	11	41615849
12500	12	41925975
15000	13	42842713
17500	13	41160918
20000	14	41145451.51
22500	14	40411788

Optimal Lead Time follows an increasing pattern while outbound Lead Time crashing cost is increasing. However the accumulated cash at the end of one year has a curve shape that increases until crashing cost of \$15,000 and then decreases. Increasing L2 crashing cost increases the optimal order quantity Q according to EOQ model which in turn creates savings in fixed ordering cost however if Q is increased too much then the inventory holding cost increases more than the savings which causes a decrease in accumulated cash.

And finally we assess how the change in CSL affects optimal Lead Time;

Table 7. Effect of change in CSL on optimal Lead Time

CSL	Optimal LT	Accumulated Cash
0.5	13	44703378
0.6	13	45082256
0.7	13	45322701
0.8	13	45301851
0.9	13	45198873

The results show that even if the CSL is changed, optimal Cash Conversion Cycle for the company remains 13 days. However the accumulated cash corresponding to the optimal CCC is changing. From the table it is seen that accumulated cash at the end of the one year period is maximized when the CSL is 0.70. This proves that trying to satisfy every customer doesn't necessarily brings more money to firms. In order to increase the CSL the company has to increase safety stock level, which in turn increases the inventory holding cost. When the proceeds from satisfying customers are not enough to justify the corresponding inventory holding cost, company starts to lose money for each additional order it aims to fulfill. So from Table 7, it can be deduced that the optimal CSL for the manufacturer is 0.75 when the other parameters are constant.

However, even the accumulated cash is maximized when total Lead Time is 13, the difference between the maximum value and minimum value of the accumulated cash is very little; so Optimal Lead Time and accordingly the optimal CCC is not very sensitive to changes in CSL; so changing CSL from 0.50 to 0.90 (which is a big change) did very little change in the accumulated cash; so really the SS is not as significant in determining CCC or LT.

VI. CONCLUSIONS

Cash Conversion Cycle is a comprehensive financial measurement that incorporates the financial and operative considerations of a business entity. Since it is the time period between payment to

the suppliers and receipt of money from the customers, it refers to days that the company needs outside financing. In that sense many researchers promote shorter Cash Conversion Cycle; however, our study, which uses project-scheduling techniques in shortening the CCC, shows that there is an optimal value for the CCC components, that the company is generating the best financial results. So the company should not push to shorten this optimal value at the expense of losing money.

To reduce the CCC, a company can crash Lead Time, shorten collection period or prolong payable term. Nevertheless, all those there factors come with a price to company. While the receivable collection period is a function of company's general operational policy and the customers' financial considerations, in order to speed up collection, the company has to provide incentives to the customers. On the other hand, the payable term and inventory conversion period are completely under management incentive, provided that the cash is enough to make payments. However lead time crashing is a costly process and also delaying the payments to suppliers most of the time comes with a penalty. So the optimal points for these three components should be found which gives the company best financial results.

To sum up, although Cash Conversion Cycle is a comprehensive metric that the companies can use to evaluate their financial and operational policies, it makes more sense when it is calculated for consecutive time periods to see the change over time or when it is compared with several competitors. As different industries may have different practices regarding the receivable and payable contract terms, the optimal CCC will differ from industry to industry.

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