A System Dynamics Model of Apparel Supply Chain Under Mass Customization

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Abstract

Mass customization could be considered as a new trend in the apparel industry. Not only, the fashion industry has limitations of the short life cycle and low predictability market but its supply chain also faces many obstacles to achieve this customization with a high level of customer satisfaction and more flexibility at low cost. The present study aims to address the factors affecting the performance of supply chain. That's why a survey and individual interviews have held with apparel supply chain professionals in order to focus on these factors and construct the relationship among them through simulation and modeling using a system dynamic approach. The results have revealed that the product variety, lead time, return policy and quality levels affected dramatically the supply chain profit under mass customization. Moreover, some potential areas have been suggested for further studies in order to enhance the supply chain profitability whenever mass customization system is applied within the apparel industry.

Keywords
Apparel Industry, Supply chain management, mass customization, System Dynamics

Introduction

The fashion industry is distinguished by the short life cycle, high volatility and low predictability due to the growing level revolution which put great pressure on its supply chain management [Chan Alan TL, Eric WT Ngai, and Karen KL Moon, 2017]. That's why a garment variety can be presented to the apparel market with minimum cost and short the time through mass production [Mehrjoo and Pasek, 2014]. Nevertheless, it can be achieved at high lot sizes, while the consumer demand has recently focused on functioned garments towards mass customization (MC) [Satam D., Liu, Y. and Lee, H.J., 2011]. So, it is the current trend to meet individual customer requirements in which the supply chain should be flexible. [Roy, N., Komma, V.R. and Kumar, J., 2013]. The Made-to-Measure (MTM) is considered as a customized approach where digital patterns are used to fit the garment exactly to the customer size using different software like Gerber, Lectra, Optitex, and PAD [Gill , S., 2015]. These systems were developed to obtain the pattern using different methods of body measurements, namely direct entry, 3D body scanning, and 2D digital camera that can achieve the optimum fitting [Lu and Wang, 2011]. Therefore, the basic block to achieve the fashion MC is through different stages; garment design, production, customer demand, the information flow, and management risk.[Wen , X., Choi, T.M. and Chung, S.H., 2018]. This supply chain is a sophisticated and inflexible cycle [Martino , G., Fera, M., Iannone, R. and Miranda, S., 2017]. Therefore, it faces a great challenge in balancing the demand and the supply with a quick response to the market [Ambe, Intaher Marcus, 2009] where the manufacturer prefers to deliver the consumer the required product at the exact time in which the lead time and cost should be minimized [Lu and Wang, 2011].

The MC supply chain deals with single product flow focusing on the customer demand instead of sales forecasting [Peterson, J., 2015]. Therefore, the supply chain should adopt the MC trend so that a complete apparel technology can provide the decreasing of the lead time, fast delivery and customer satisfaction [Peterson, J., 2016]. The lead time reduction causes the sales and supply chain to be improved [Asgari Behrooz, and MdAynulHoque, 2013]. Charnsirisakskul (2006), created a model and found that the more lead time flexibility, the more profitability could be gained as well as the product quality dramatically affects the long term profitability cause it is the main element of accomplishing customer satisfaction.

The apparel industry strength has shifted from the retailer to the consumer in which the stakeholders can pay their attention to the MC [Pookulangara and Shephard, 2013]. Several trials have been handled to let fashion companies ensure high quality and sustainability. [Turker and Altuntas, 2014].There is approach is to let the customer decide which yarn convenient for producing the garment design itself. This results in zero-inventory as the apparel has been sold before the production [Peterson, J., 2011]. Moreover, a simulation process highlighted that the manufacturing stage is preferred to be in the retail store itself as it reduces the lead time [Peterson, J., 2015]. This knit-on-Demand provides a leagillity supply chain because it achieves both concepts of lean and agile through eliminating the waste by direct knitting and delivering the goods just in time [Larsson, Peterson and Mattila, 2012].

Product design is the spine of the fashion industry as it has a great influence on its supply chain management [Shen B., Li, Q., Dong, C. and Quan, V., 2016]. In addition, its development increases the customer willing to purchase the product within the season instead of waiting for the discount [Caro Felipe, and JérémieGallien , 2007]. At the same time, the apparel variety could give rise to costs of the logistics, inventory, design and manufacturing stage [Huang , S.M. and Su, J.C., 2013]. This diversity could be found in three essential components fabric, color, and silhouette [Pan, 2013]. However, such creative product design has various limitations when it is linked to its supply chain, the integration of the product design with the supply chain gives the company the chance to adopt such a volatile market [Khan O., Stolte, T., Creazza, A. and Hansen, 2016].

On the other hand, this achievement requires the commitment of all staff levels to ensure the information flow smoothness [Choi Tsan Ming, PuiSze Chow, and ShukChing Liu, 2013]. Researchers found that this kind of flow could be accomplished by using Information Technology (IT) [Ngai E.W.T., Peng, S., Alexander, P. and Moon, K.K, 2014]. Dual channel is also commonly preferred in recent years where the retailer sells garments through online services direct to the customer. That's why it causes the sales to be increased and the cost to be decreased [Chen Jing, Hui Zhang, and Ying Sun, 2012]. On the other hand, management should also pay their attention to restrict the return policy during online shopping as it has a negative effect on customer reliability and companies' profitability [Hua Z., Hou, H. and Bian, Y., 2017].

Furthermore, the right choice of firm suppliers is a crucial element for improving the value chain [Hussien and Abdelsalam, 2015]. The sustainable supplier with a convenient channel is so critical to market the products efficiently [Wen X., Choi, T.M. and Chung, S.H., 2018]. That's why the time is an essential factor provided by the suppliers because the firm can only respond to the customer using its capacity if the raw material arrives on time [Sirovetnukul, Chutima, P. and Kritchanchai, D., 2007]. The customer will only satisfy when the shipment arrives at the right time, place and the required quality [Dong, B., Jia, H., Li, Z. and Dong, K., 2012].

However, there are systems' developments for enhancing the simulation process; it has not been obvious yet whether consumers are ready to share their measurements through 3D body scanning with retailers, while athletes accept this customization even with a higher cost to get better performance [Vandaele and Decouttere, 2012]. Despite that the higher stock of yarns and raw material decreases the lead time needed for customizing the garment, it is required to manage the stock of these resources efficiently [Peterson, 2015]. So, the trust between the supplier and the manufacturer is an effective element in the MC supply chain. This trust is found to be in the information flow of product design, logistics, and quality management [Liao. K., Ma, Z., Jiung-Yee Lee, J. and Ke, K.,. 2011].

1.1 System Dynamics Modeling for MC fashion Supply chain

System Dynamics (SD) is an approach to simulate a complex system with dynamic motions as well as qualitative and quantitative methods [Feng , Y., 2012]. Nevertheless, it doesn't predict the whole supply chain cost but highlights the area of interest under certain scenarios. In addition, it could provide stakeholders with a framework for a complex system in the long term [Rebs , Y., 2018]. SD maps out the model structure through causal loops in

order to highlight the interactions between the system variables and understand the behavior and the feedback of the system in which a critical strategy could be developed [Haraldsson, 2004]. It also concludes stock, flow and control variables. A stock variable represents the accumulations and the flow variables are the elements causing the variation in the stock. The other variables, control, are the rest components [Asgari , Behrooz, and MdAynulHoque, 2013]. SD modeling is the most appropriate system for fashion supply chain than the traditional methods as it gives the right link between the real and model behaviors [Mehrjoo and Pasek, 2016].

Şen, 2008, a created SD model for apparel industry using three different variables, the stock flow variation, the inventory level and the lead time; so that the dynamics between product variety, revenue, cost, and profit can be investigated. It has been found that the supply chain profit is much more sensitive to the product variety and lead time in such a way that apparel companies should offer an optimum variety level to their customers. Furthermore, a causal loop model of the fashion supply chain was created to optimize the return and to control the delays in the refurbishment cycle. It was found that the companies could decide the convenient strategy and if it is better to sell the products as a second quality or to follow a refurbishment certain activity. In addition, the online business was the most sectors that could create high and late returns [Difrancesco, Rita Maria, ArndHuchzermeier, 2018]. Another study highlighted a causal loop model which facilitates the decision making for the management level to choose the best strategy for determining and balancing the different requirements in the retailer complex network [Iannone , R., Martino, G., Miranda, S. and Riemma, S., 2015].On the other hand, Kim (2018), created a closed loop supply chain planning model to control the reverse logistics follow of uncertainty material by applying the robust optimizing approach. The model provided its budget and the advantages of avoiding collectors fail.

2. Methodology

There are three different approaches to analyze the data, qualitative, quantitative and combination of both [Creswell, , John W., and J. David Creswell, 2017]. In this research, a mixing of both methods has been carried out in which the qualitative way measures quality variables such as garment virtualization as well as the quantitative measures the variables in number such as the cost and revenue. A system dynamic is used for measuring the behavior of such variables. There are several simulation programs for system dynamics modeling such as i-Think ®, Stella®, and Vensim®. In this study, Vensim® is used to develop a stock and flow diagram.
There are two ways for analyzing any system dynamics. The inter-relations among different variables could be found in polarities where the (+) sign means that by increasing the independent variable the dependent variable will be increased; and the (-) sign means the dependent variable will decrease. The stock and flow diagram provides the stock represents the accumulation such as the raw material and return inventory while it changes over time by inflow and outflow. There are other variables called Auxiliary variables which are used for connecting the stock variables with the flow variables. All these three variables are used to identify the dynamics of the system.

2.1 The SD Model Characteristics and Variables

The model shows the key parameters affecting the apparel supply chain cost in terms of mass customization considering that the raw material is available all the time. In addition, the customer first chooses the style, size, color, fabric type and fabric properties which are simulated using garment visualization software so that the manufacturing process can be started according to the sample approval, however; the manufacturer should be flexible enough to adapt the customer changes. Furthermore, the product quality should be acceptable to the customer in which the customer satisfaction and acquisition could be achieved at a convenient manufacturing cost. This satisfaction increases the sales rate and could be accomplished by increasing the product variety but the manufacturer has to optimize its level to maintain the profit. In addition, this variety is also affected by the manufacturer flexibility and capacity, where there is a rearrangement of the production process according to the customization level or not, in which skilled workers are needed for decreasing the lead time that positively affects the manufacturing cost. The return products are considered in this model as it definitely affects the chain cost; however, a return policy has to be followed to avoid the negative impact. With respect to mass customization, there is zero warehouse inventory as the products have been solved before the production. All of these variables are classified as per table (1).

The simulation occurs over one year (48 weeks) to investigate the behavior of such variables. The manufacturing capacity is 10,000 garments for 2 weeks lead time and one day for delivery. The total cost included the raw material

price (fabric, accessories, labels …etc), the administration cost which is equal 2% from the production cost, the workmanship that it depends on the style and its time study or standard mints, finally other production costs like print or embroidery or washing and the transportation cost. There are two scenarios, first, the profitability is calculated neglecting the return percentage and the other is taking into consideration its percentage so that net and gross profitability can be obtained.

Table 1: Variables Definition and its Associated Factors in this Study

Variables	Remarks (Associated factors)	References
MC Supply Chain Profit (orders and performance)	Includes lead time, quality level and cost minimization variables are attained by the following activities.	Agarwal, Ashish, and Ravi Shankar 2005.
Lead Time Reduction (Production flexibility, manufacturing capacity, skilled labor)	It is the time from receiving the order to the product shipment and its reduction allow the manufacturing cost to be more competitive.	Asgari , Behrooz, and MdAynulHoque 2013
Product Variety (Size, design, and color)	The increment of the product variety increases the supply chain profitability up to a certain limit and then it starts to be decreased in case of lead time is not neglected and the product price doesn't exceed the optimal market level. It also affects various sectors such as marketing, manufacturing, logistics and customer preferences so that there is a wide range of product diversity which causes the sales to be increased too.	Mehrjoo and Pasek 2014
Raw material stock and availability	To customize the product, the raw material has to be available always so that the lead time could be reduced; however, the stock should be managed well.	Peterson 2015
Supplier Selection and sustainability	The supplier selections are so important that the customize orders needs the raw material to be ready for decreasing the time and increasing customer satisfaction. These build the trust between the supplier and the manufacturer that let the firm to sustain the relationship with certain suppliers.	Hussien and Abdelsalam, 2015 Sirovetnukul ., Chutima, P. and Kritchanchai, D., 2007
Return products and sales	The return products are high at online shopping because of different customer expectations. Unfortunately, This causes the firm profit to be reduced as well as the company has to sell the returned product as a second quality or follow a refurbishment certain activity	Hua , Z., Hou, H. and Bian, Y.,2017 Difrancesco , Rita Maria, ArndHuchzermeier 2018
Product Quality Level	Customer satisfaction could be achieved by their acceptance of the product quality. In addition, it affects the product cost, lead and delivery times.	Macchion, , L., Marchiori, I., Vinelli, 2019
Production Flexibility	The sustainable customer could be achieved by the manufacturing flexibility that should be enough to adapt the customer changes. The integration of customer, supplier, process/ product technology and marketing can gain manufacturing flexibility.	Mishra R.,Pundir, A.K. and Ganapathy, 2018
Garment Virtualization (fabric characteristics, sample approval, customer changes)	The Garment Simulation is the behavior in which the fabric drapes on the model's body depending on its mechanical and physical properties. It reduces the time consumed while sample making and be flexible with customer changes. It can prevent product returns due to improper fitting. It also a good opportunity to gain customers because of exact measurements with the advantage of 3D body scanning techniques.	Power 2013 Cichocka, Bruniaux and Frydrych, 2014

Customer demand and acquisition	Customers' demand could be increased by garment virtualization as they can get the required measurements. It also affected by the return rate as it causes a lack of trust between them and manufactures. The product modularity could also raise the customer acquisition rate while excessive modularity causes a negative influence on operational performance like manufacturing cost and delivery speed. That's why, the higher customer satisfaction, the higher firm profitability could be gained.	Power 2013 Difrancesco , Rita Maria, ArndHuchzermeier, 2018 HwangandSuh 2018
Variables	**Remarks (Associated factors)**	**References**
Cost reduction	It is considered as one of the main criteria affects the profitability and could be achieved by the lean and integrated supply chain.	Iannone , R., Martino, G., Miranda, S. and Riemma, S.,2015
Delivery Speed	The fast delivery speed attracts more customers and improves the supply chain agility this can be associated with the response flexibility	Chan Alan TL, Eric WT Ngai, and Karen KL Moon, 2017

Table 1: Variables Definition and its Associated Factors in this Study

Results and Discussion

In this paper, Vensim® is used to develop a stock and flow diagram according to the interview with supply chain professionals as shown in figure (1). The model variables have been discussed on the previous section and the next one is going to discuss the interaction flow among them as per figure (1). The MC supply chain profitability is depending on the difference between the total cost and the total revenue as well as the return rate. Therefore, the higher revenue at low cost and return rate, the more profit could be gained. Besides these assumptions, there are another factors affecting on their performance that absolutely has a great influence on the profitability increment. The Vensim software could provide how these variables interrelations are dynamically connecting. Consequently, the total cost should be reducing through manufacturing cost and shipment cost. The manufacturing cost depends on several factors including product variety, the lead time and product quality along with other cost parameters that have been discussed in the previous section. The mass customization depends on the increasing of the product variety according to the customer requirements that positively increases the sales and customer acquisition rate. Such variety can be found on the diversity of size, design and color. That's why it certainly has an impact on the lead time in which the complex design manufacturing takes longer production time comparing to a standard style. In addition, the lead time is affected by the raw material availability which is the heart of implementing the mass customization. The raw material availability depends on the supplier selection where the cost and delivery time play important roles on selecting the right choice. Moreover, these varieties affect the garment simulation because it is affected by the sample approval that depends on the achievement of customer product characteristics. On the other hand, in the case of mass customization, the customer preferences are high and focus on their requirements details including product quality that is considered as an important element of the return products rate.

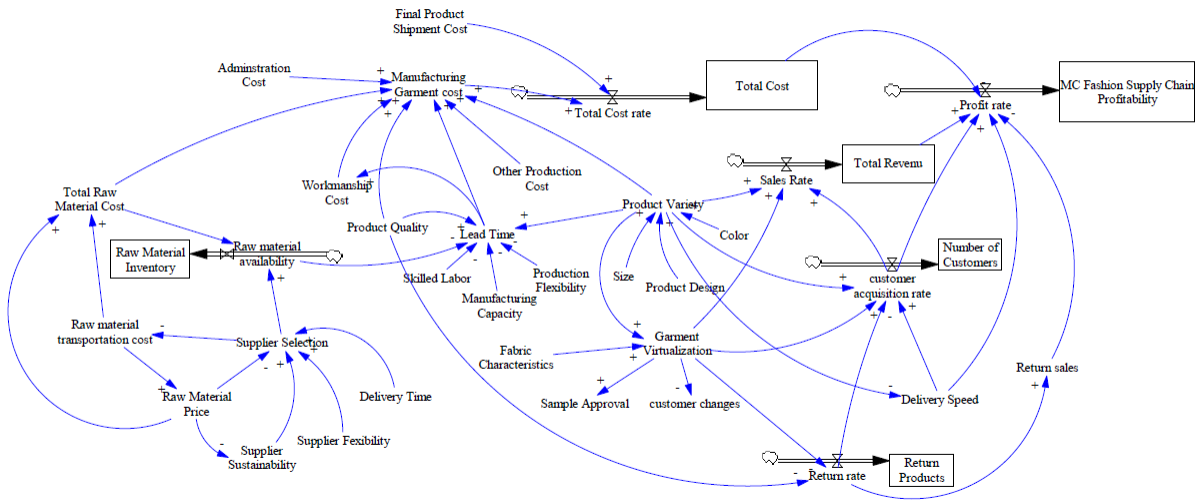

Figure (1): the Stock and Flow Diagram of MC Fashion Supply Chain using Vensim Software

Based on discussion with apparel supply chain professionals, Lead time has a direct relation with the style production difficulty. The more complicity of the design, the more time is consumed and higher cost is reached. In case of zero-return policy, Figure 2 shows that the increase of product variety leads to the increment of the profitability up to a certain limit (17 weeks lead time) after which it starts to decrease until there is no profit. The manufacturing cost is increasing due to different styles of production while the price has some kind of stability as the manufacturer must sell the product within a limited duration and price. On the other hand, if the price increases during the increasing of product variety, the profit will be increased definitely over the time period.

Other case provides a return allowance policy which causes the cost to be increased by 1%. Figure 3 shows that the profit has the same behavior of previous figures but with a dramatically reduction in case of fixed price where the changeable price has seen an increment but lower than before because of the negative impact of the return.

In the third case, the customer could return the product after the delivery because of many reasons particularly the quality is under the expectations. Most apparel companies follow Accepted Quality Level (AQL) system for optimizing the quality level towards customer satisfaction [Keist, C.N., 2015]. It is the maximum average defective product in a lot so that the higher AQL percentage, the lower quality, and low price garments. Figure (4) shows that the increasing of AQL percentage leads to decreasing the return refund as the product is at a low-quality level in which the customer accepts the defects and don't return the product. On the other hand, the low AQL % the higher return refund because the customer here requires high-quality garments and has high expectations. That's why another behavior has been studied containing the return percentage in which net profitability could be got.

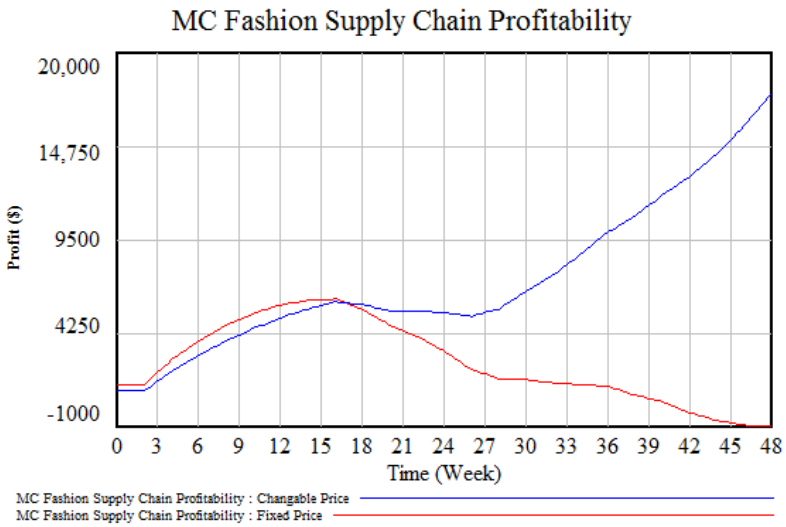

Figure (2): The Effect of Product Variety on MC Fashion Supply Chain Profitability At fixed and changeable price.

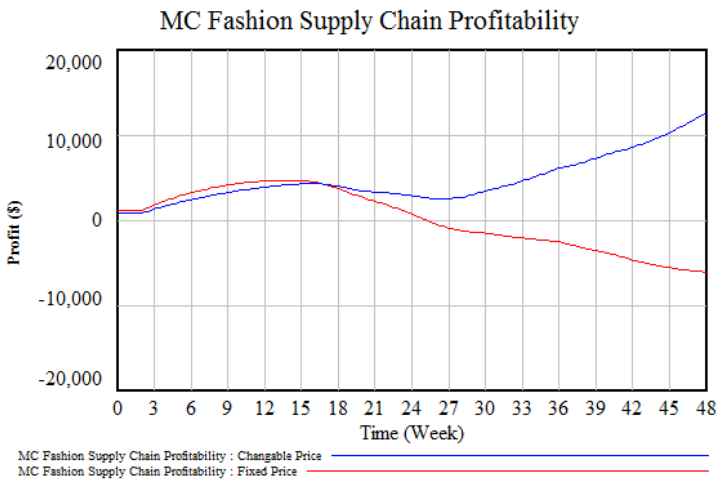

Figure (3): The Effect of Return Products on the Supply Chain Profit At Fixed and Changeable Price.

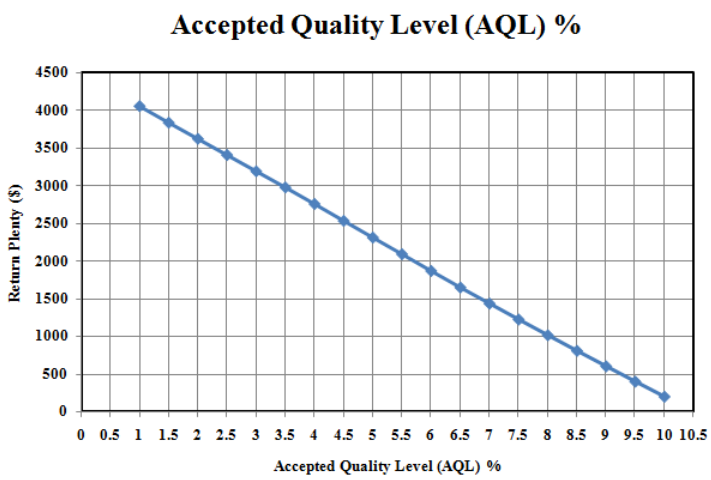

Figure (4): the Effect of Accepted Quality Level (AQL) on the Return Cost

Conclusion

This research presents a system dynamics model for the apparel supply chain under mass customization. The model could be used to investigate the relations between apparel supply chain variables under mass customization. Numerical analysis shows different ways to increase the firm profit. It can be concluded that the company should optimize the quantity of each product variety versus its market price according to the lead time consumed knowing that there is minimum quantity for each fabric color as it is strongly correlated with the ability of fabric production itself. Furthermore, the calculations of the profit should include the return percentage and the plenty or the compensation should the customer got almost overseas buyers are not able to return the products again because of return shipping cost so they don't have any option rather than accept the product as a second quality. That's why; it should set a convenient return policy so that the negative impact of the sales and customer demand could be neglected. However, this return issue is so common through online shopping; managed regulations should be put into consideration to focus on the reverse logistics that provide companies with opportunities to improve their business.

Further Studies

One of the limitations of this research is the use of a verbal source of information rather than real values from the company. That's why more studies are required to study in deep the influence of such activities on the whole profit chain including garment virtualization and the merchandising issues. In addition, there are some potential areas should be studied first before implementing the MC fashion and apparel. One of these areas of improvement is to increase the researches of the down, middle and up steam supply chain performance of the MC fashion and Apparel industry when inventory is zero as the product follow the Made – to – Order Criteria. The raw material stock level is a critical factor to accomplish such customized system; nevertheless, it needs to be well controlled. The discrepancy between online sales and customer expectations should be investigated to restrict the return and to reach their satisfaction.

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