Supply Chain Simulation of Manufacturing Process of Women's Solid Cotton Knit T-Shirt Using System Dynamics Modeling Software

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Introduction: This project simulates the manufacturing process of a women's solid cotton knit t-shirt using a system dynamics modeling software (SDM) called STELLA (Systems Thinking, Experimental Learning Laboratory with Animation). SDM is a computer-aided approach to analysis and design and offers a mathematical modeling method to frame, understand, and discuss complicated issues. SDM was originally developed in the 1950s to help managers improve their understanding of industrial processes and is currently being used throughout the public and private sectors (Bala, Arshad, & Noh, 2017; Radzicki & Taylor, 1997). It first specifies the scope and boundary of the problem, and then maps the problem in a visual environment as an interacting systems model that, through a visual programming protocol, can be used to execute quantitative simulations of different scenarios. The primary elements of SDM diagrams are feedback, accumulation of flows into stocks, and time delays. The approach allows the relationships between different factors (cause, effect, impact, outcomes) to be explored over different time periods and geographical areas (Richardson, 2020).

STELLA is an SDM that uses four building blocks: stocks, flows, converters, and connectors (Figure 1). A stock is the measurable quantity of something (e.g., a material, a product, currency, people, etc.) that either grows or depletes over time. A flow is the mechanismby which the stock increases or decreases over time (by adding or removing from the stock). A converter takes input data and manipulates or converts it into an output signal that modulates thestocks and flows in each simulated scenario. A connector allows information to pass between converters, stocks and flows in order to modify parameters in each scenario. The "cloud" in Figure 1 indicates and marks the boundary of the system and identifies the scope of the model. Simulations only consider changes within the system boundary of the model (systems, 2015).

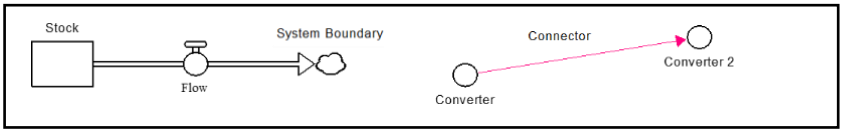

Figure 1. Four building blocks

The steps involved in building an SDM model are:

1) Define the goal: the supply chain of the product.
2) Define the scope: identify the boundaries, inputs, and outputs of the system.
3) Define the functional unit: production of X numbers of goods/day.
4) Build the STELLA model using all four building blocks.
5) Add equations: conditional statements like "if_then_else" to the flows.
6) Add initial conditions to each stock and converter.
7) Run the model and monitor the stocks and flows for the given set of inputs (i.e., a givenscenario)
8) Change inputs and re-run the model for different scenarios

Literature Review: SDM has recently reemerged in supply chain management. Supply chain management research on SDM focuses on developing inventory decisions and policies, manufacturing, compressing time, amplifying demand, designing and integrating supply chains, and managing international supply chains (Angerhofer & Angelides, 2000; Jahangirian, Eldabi, Naseer, Stergioulas, & Young, 2010). Recent research indicates an increasing interest in SDM as an approach to complex systems (Jahangirian et al., 2010).

Problem statement: Manufacturing companies fear losing valuable time and assets in the manufacturing process on a daily basis. Determining total raw material to order, number of human resources to produce order quantity, and days to meet the delivery date are some of theissues that garment manufacturing units face every day. Inaccurate estimation in terms of rawmaterial or days required to produce a quantity leads not only to monetary loss for the manufacturing unit and for brands/retailers but also affects their relationship with other participants in the product supply chain.

Purpose: The purpose of this paper is to demonstrate how STELLA can help a manufacturing unit make better decisions when confronted with dynamic systems. We chose t-shirt manufacturing to demonstrate the model because of its relatively simple manufacturing process. The example model simulates the manufacturing of 95 pieces of women's solid cotton knit t- shirts that are to be manufactured and shipped in 10 days. The model (Figure 2) was used to simulate various scenarios by changing equations and stock quantities in the model. The model can assist manufacturing companies to (a) understand the supply chain of a t-shirt, its various inputs, and their impact on the required final output; (b) understand the material flow within the supply chain; and (c) determine actions needed to minimize waste and improve sustainability in the supply chain. The same basic methodology demonstrated here can be applied to a wide rangeof garment production processes, regardless of the complexity.

Findings and Conclusion: Our results suggest that STELLA is a reliable modeling and simulation tool and that the specific simulation provided here is an efficient way to assist t-shirt manufacturing companies in making business decisions without fear of losing valuable time andassets, as the model simulates different manufacturing supply chain scenarios in a risk-free environment. Upon running the model, material flow equilibrium can be achieved depending on the units of production, thereby reducing waste and saving costs and resources. Figure 3 shows the optimum (equilibrium) result for a scenario in which 95 t-shirts are manufactured and shipped in 10 days. In comparison, Figure 4 shows an unbalanced, non-equilibrium result for thesame scenario. The supply chain is not stable in Figure 4 because of non-optimal inflows of fabric and an insufficient packaging rate.

For future research, material flow within the supply chain can be coupled with a life cycle assessment (using LCA software such as openLCA or SimaPro) to study the environmental impact of the equilibrium material flows on the overall supply chain's environmental impact.

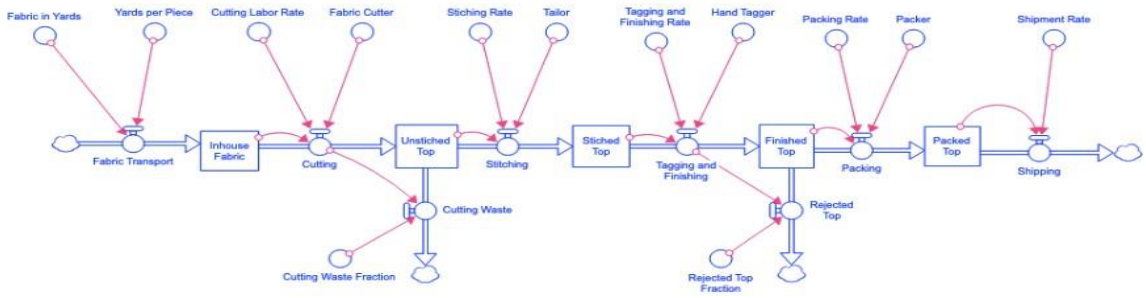

Figure 2. Simplified women's solid cotton knit t-shirt manufacturing SDM model

STOCK

	Inhouse Fabric	Unstiched Top	Stiched Top	Finished Top	Packed Top	Shipping
1	1	1	1	1	1	1
2	100	0.95	1	1	1	1
3	100	95	0.95	1	1	1
4	100	95	95	0.95	1	1
5	100	95	95	95	0.95	0.95
6	100	95	95	95	95	95
7	100	95	95	95	95	95
8	100	95	95	95	95	95
9	100	95	95	95	95	95
Final	100	95	95	95	95	95

Figure 3. Equilibrium stock

STOCK

	Inhouse Fabric	Unstiched Top	Stiched Top	Finished Top	Packed Top
1	1	1	1	1	1
2	250	0.9	1	0.95	1
3	372	115	0.9	0.95	0.95
4	494	134	96	0.855	0.95
5	616	154	96	91.2	0.855
6	738	173	96	181	1
7	860	192	96	272	1
8	982	211	96	362	1
9	1.1k	230	96	452	1
10	1.23k	250	96	542	1

Figure 4. Disequilibrium stock

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