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A contemporary TOC innovative thinking process in the backdrop of leagile supply chain

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Abstract

Purpose – The purpose of this paper is to propose a fresh perspective to effectively adopt leagility in supply chain. The research adopts Theory of Constraints (TOC) methodology and amalgamates it with design thinking process, people's opinion and mathematical approach to help achieve supply chain leagility.
Design/methodology/approach – The proposed framework is a seven stepped approach to achieve supply chain leagility combination analytical and mathematical procedures. Data enveloping analysis (DEA) is used to identify high level constraint. The new designed thinking process is used to further evaluate the constraints. Nominal group technique (NGT) is used to help build the current reality tree and identify detail level constraints.
Findings – The framework application on a case supply chain improves various parameters of leanness and agility over a period of one year. Improvements include reduced rework, improved cash flow, reduced operating cost, reduced order backlog and better customer interaction.
Research limitations/implications – This research opens up TOC application in a totally new area of leagility adoption in supply chain. The framework needs to be explored with more implementation in various business scenarios.
Practical implications – The proposed framework is extremely intuitive and pragmatic in approach. The case application demonstrates the framework can be easily adopted by supply chain managers to improve leagility.
Social implications – The current study attempts to diversify the TOC application. Using thinking process, DEA and NGT in TOC parlance brings in objectivity and employees together for improvement.
Originality/value – Amalgamating the mathematical approach of DEA, design thinking process and NGT within the TOC framework for supply chain leagility is new and novel.

Keywords Lean, Theory of Constraints, Supply chain management, Agile, Design thinking, Thinking process

Paper type Research paper

1. Introduction

The twenty-first century enterprises needs to be lean while being agile (leagile) (Christopher and Towill, 2000). With Naylor *et al.* (1999) introducing leagility, the trend is to adapt both lean and agile processes together to improve performance. There have been numerous ways of improving supply chain performance like decoupling point strategy, production efficiency, logistics optimization, adoption of IT and e-business, procurement process improvements, collaborations among supplier and customer, collaborative planning forecasting and replenishments. Theory of Constraints (TOC) over the years evolved not only as a production scheduling tool but also as an integrated management tool to improve supply chain (Spencer and Cox, 1995; Wu *et al.*, 2014; Costas *et al.*, 2015). Watson *et al.* (2007) while discussing the evolution of TOC concludes that TOC has gained acceptance from both practitioners and academicians alike. The current research proposes to use TOC for achieving supply chain leagility by

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integrating design thinking process. Design thinking is a discipline that uses the designer's sensibility and methods to match requirements with what is technologically feasible and a viable business strategy (Brown, 2008). Slowly design thinking is being applied in the context of supply chains to bring in a new, innovative and a human-centered design to supply chains.

The paper is divided into five sections. The first section is a review of literature in leagile supply chain, TOC and design thinking process. The second section formulates the framework. The third section is the application of the framework on a real world case. The fourth section is the results and discussion followed by the final section of concluding remarks.

2. Background review

2.1 Leagile supply chain

Leagility comprises of leanness for efficiency and agility for responsiveness. Lean philosophy is a bundle of tools and practices to reduce cost and improve quality while agility is an ability to adapt unpredicted changes in the external environment (Backhouse and Burns, 1999; Banerjee *et al.*, 2012). Adopting leagility in supply chain has always lacked two important issues firstly all these interactions are purely mathematical models (lacks empirical applications), and secondly many of them lack the holistic view for supply chain improvement as they are too focused on a specific part of a supply chain. Ifandoudas and Chapman (2009) explore supply chain agility through the TOC approach. However, achieving leagility through the implementation of TOC is quite a begging. It is important to review the TOC application in business to better understand the research gap and its background.

2.2 TOC and its application

TOC research are mostly analytical analysis as described by Blackstone (2010) and finds wide range of applications in manufacturing and supply chain. Profitability improvement (Goldratt and Cox, 1984; Chaudhari and Mukhopadhyay, 2003; Watson and Polito, 2003; Umble *et al.*, 2006; Coman and Ronen, 2007; Ifandoudas and Chapman, 2009), project and business performance improvements (Goldratt, 1997; Blackstone *et al.*, 2009; Huang *et al.*, 2014), improved marketing (Goldratt, 1994) and process performance improvement (Gattiker and Boyd, 1999).

Coman and Ronen (2007) introduced two types of constraints in an organization, namely, tactical (dynamic) and strategic (static). Tactical constraints are mostly under the responsibility of mid-management while the strategic constraints are managed by senior management. TOC is a methodology for identifying the limiting factor (i.e. constraint) that stands in the way of achieving a goal. The progression of the research is based on a simple fact that adoption of lean or agile systems separately may not always lead to overall leagility as it may not be alleviating the constraints.

2.3 Design thinking process

Design Thinking Process is widely used to solve socially ambiguous design problems. Design thinking refers to the methods and processes of investigating problems, acquiring information, analyzing knowledge, and positioning solutions in the design field. Design thinking can be described as a discipline that uses the designer's sensibility and methods to match needs with what is technologically feasible and strategically viable (Wall, 2010). In TOC parlance the design thinking can help discover hidden constraints of a business problem and help design a solution which is technologically feasible and strategically viable to overcome constraints. A classical design thinking process as described by Plattner (2012) consists of five steps, namely, empathize; define; ideate; prototype; and test.

3. Research approach and framework

This research uses the existing TOC principals and innovatively tweaks a bit to elevate constraints for leagility adoption in supply chain. The research approach is to innovatively use the TOC framework and improve it further so that it can be used to help adopt leagility in the supply chain. This research approach was needed as classical TOC steps alone cannot expose and exploit the constraints of a broad level supply chain. Two key factors for success of supply chain are people and technology (Helour and Caddy, 2006). So it was imperative to consider peoples aspect in elevating constraint and adopting leagility. Leagility is all about seamless contribution from teams and technology. So it is important to involve employees in every aspect of decision making. All these attributes were considered to develop the research approach and framework.

The paper develops a stepped approach to analyze, identify and elevate bottlenecks for leagility. The approach is conceived as per the framework of Coman and Ronen (1995), driven by design thinking and is powered by the tools of Jonah process to elevate constraints for a leagile supply chain. The highlights of the proposed structure is the mathematical analysis using data enveloping analysis (DEA) to identify the constraint from the broad area of functional limitation and the use of nominal group technique (NGT) to identify undesirable effects (UDEs) to help draw the current reality tree (CRT).

3.1 Need for a new TOC approach with design thinking process

Existing TOC process lacks three things, first it does not have any mathematical approach to help identify high level constraints, secondly the thinking process in TOC misses the softer issues like empathy and critical observation and thirdly there are limited scopes to involve employees and people in decision making. These are essential not only from business point of view but also from people and design perspective. In certain areas of application (like in leagility for supply chain) it was deemed necessary that the TOC approach needs to be tweaked so as to have a mathematical approach to identify high level constraints and also inculcate empathy, observation and rational thoughts. Empathy and observation becomes predominantly important when the change impacts not only processes but also the way humans interact and work.

3.2 Proposed framework for leagility through TOC

The framework proposed by Coman and Ronen (1995) for constraint management consisted of seven steps. The Jonah thinking process consists of five steps, namely, CRT; future reality tree (FRT); evaporating clouds; prerequisite tree; and transition tree (TT). The design thinking process as proposed by Plattner (2012) consists of 5 basic steps as discussed in previous section. Inspired by these frameworks the new proposed approach consists of seven steps. Figure 1 represents the proposed framework along with certain details of the process.

The first step in the approach is defining the broad factors which impacts the leanness and agility of supply chain. This step also identifies the strategic and tactical constraints of leagility. The output of first step results is a broad array of options, as constraints of leagility can exists in every aspect of business. Thus it is necessary to channelize the constraint and identify high level constraints based on factor analysis. This is to identify focus areas to concentrate and apply a thinking process for detailed analysis.

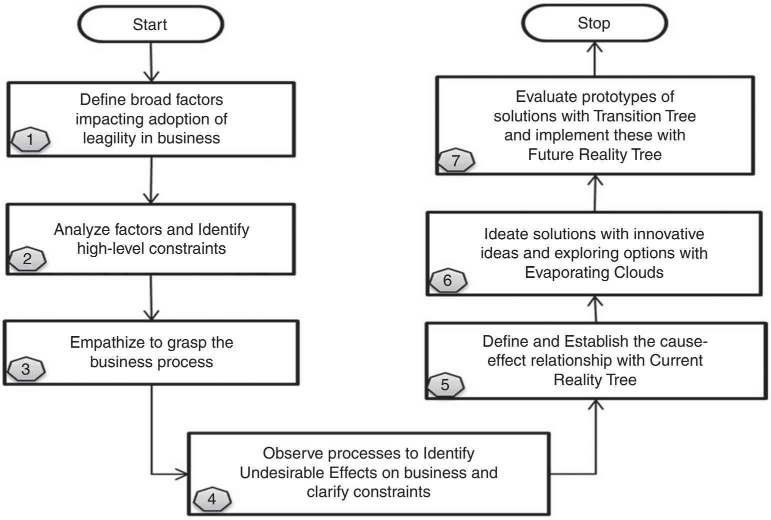

Figure 1.
Theory of constraint framework for leagility constraints

The subsequent step is to empathize and observe business to identify and define the actual business constraints which are acting as bottlenecks. This is followed by solution ideation, solution exploration leading to elevation of constraint and meeting business objectives. The Figure 1 provides the proposed framework details and its five steps.

3.3 Framework step details

The detailed steps of the framework are enumerated below.

Step 1: define broad factors impacting supply chain: this step identifies the strategic or tactical level factors impacting the lean and agile processes. Few generic broad level factors are mentioned below. But there can be many other factors depending on business scenario and federal and local regulations:

- generate revenue and margin of operations;
- available skilled professionals in the area of lean and agile system;
- develop culture of innovation and improvement in the company;
- accomplish level of engagement of employee;
- embedded saving and reward as a culture;
- use conscious efforts to bring in flexibility in planning and execution; and
- promote ability of a company to plan and use information technology (IT) effectively

Step 2: analyze factors to channelize the constraint: in order to identify the most eminent channel having common influence on all the factors mentioned in step 1 various options were explored. These included analysis of cost/ revenues, operating parameters, employee skills, work processes but none of them were common across the company. This forces to an innovative way of analyzing constraints of an organization through the department functions. Departments at a broad level could provide insight into detailed operations as well as ability to have common criteria across the board. To identify the weakest link the departments were studied with common parameters across and compared. In order for further analysis to be held it was important to identify what kind of data is needed to compare departments.

3.3.1 Exploring options to channelize constraints. As department data availability is sensitive so a non-parametric approach of statistical modeling and analysis was designed as it can work with smaller data. As the need here was to compare the departments across common parameters it was considered tests of differences between independent sample groups. There were quite a few options explored but none could possible fit the requirement as most of these tests were non-parametric tests of hypothesis and not comparing data efficiency. Example:

(1) Wald-Wolfowitz test – not applicable as it is for a two-valued data sequence

(2) Mann-Whitney *U*-test is a non-parametric test of the null hypothesis that two populations are the same against an alternative hypothesis, especially when a particular population tends to have larger values than the other.

(3) Kruskal-Wallis test – it is a non-parametric test for testing hypothesis and variance.

The need was to identify a method that can be used to compare performance of data or efficiency. DEA has been regularly used to determine the efficiency of many organizations, e.g. hospitals (Kuntz *et al.*, 2007), police forces (Aristovnik *et al.*, 2013), education institutes (Johnes, 2006). This helped provide a clue as to a possible use of DEA for the current research problem also.

In the current research data envelopment analysis is used to compare the departments. The comparison helps identify the bottleneck department/business function in adopting leanness and agility. It is possible that the constraint for leanness and constraint for agility can be in two different depart/business function for two separate reasons. The research will look at each business function of the department and identify the efficacy scores

3.3.2 DEA modeling for channelizing constraint. DEA is a data-oriented method for measuring and benchmarking the relative efficiency of peer decision making units (DMUs) with multiple inputs and multiple outputs. DEA was initiated in 1978 when Charnes, Cooper and Rhodes (CCR) (Charnes *et al.*, 1978) demonstrated how to change a fractional linear measure of efficiency into a linear programming format. DEA is widely used for measuring the relative performance of organizational units where the presence of multiple inputs and outputs prove comparison to be difficult.

In this paper the DEA approach will consider many factors for manufacturing/supply chain departmental efficiency measurement and will thus significantly enhance the depth and the value of performance analysis. Initially, DMUs help in evaluating the efficiency based on common Inputs and Outputs. The DMUs being the basic step required to be identified; the various departments were clubbed together on the similarity of functions. For a normal supply chain business operation all functions were evaluated and their respective departments were identified. Functions not directly impacting supply chain like finance, HR, legal, IT, etc. were ignored. The business functions were then grouped into some departments as shown in Table I.

For these identified business functions key indicators are identified like number of employees in a department or expenses and budgets, etc. These indicators are carefully identified as either input oriented or output oriented. Input oriented means these are values/numbers that are key to the functioning of the business function like number of employees. Output oriented means these are values/numbers that directly or indirectly

Functional departments of business	Decision making units
Manufacturing design Operations/Shop floor Repair and maintenance Quality	Shop Floor Department Functions: manufacturing, inbound and in-process and outbound quality testing
Demand planning Production and procurement planning Inventory, stores and materials management Outbound and inbound warehousing Sourcing and procurement Shipment, packaging, transportation planning and logistics	Supply Chain Department Functions: planning of demand and supply, procurement, supply scheduling, fulfillment, warehouse functions, and logistics planning
Order capture After market sales team Repair orders team	Sales, Customer Order and Customer Service Department Functions: customer ordering and also interfaces with manufacturing and production as well as customer management

Table I. Grouping of departments for identifying DMUs

measures the output of the business function. These key indicators are termed in DEA as DMUs. In this research both input and output DMUs has to be common for all from lean and agile aspects. The inputs and outputs are decided based on the strategic and tactical factors determined in step 1. Each of the strategic and tactical factors is analyzed and the corresponding leagility tools/processes are considered. Based on careful analysis and thoughtful decisions the following inputs and outputs are decided for leanness and agility adoption measurement as shown in Table II.

After the input, output and DMUs are identified, the next it to decide on the type of DEA model to be applied. For departmental efficiency calculation Input oriented DEA model is deemed suitable as the attempt was more towards achieving the same efficiency with lesser inputs. Careful analysis revealed that it was possible to adjust the inputs rather than adjusting outputs and thus resulting in Input based DEA model. In this practical scenario constant return to scale is not applicable as the input and

	Input				Output			
DEA calculation to identify departmental efficiency for adopting leanness								
DMU name for leanness	Number of employees in department	Total number of identified steps in the departmental value stream mapping process	Department expenses/ Budget in last 1 year. Figures in 100,000	Total productive man hours of service in department	Total number of value adding steps in department function	Number of continuous improvement initiatives	Departmental cost savings. Figures in 100,000's	Productivity improvement
DEA calculation to identify departmental efficiency for adopting agility								
DMU name for agility	Number of employees involved in S&OP process	Department expenses/ Budget in last 1 year. Figures in 100,000	Number of customer and supplier feedback received in last 1 year	Total number of IT users	Number of customer and supplier feedback adopted into business process	Number of business process automated in last 1 year	Number of new business process introduced in last 1 year	Service/ Work stoppage

Table II. DMU, input and output modeling for leanness and agility measure output are not a function of any common factor. So Variable Return to Scale is considered for all calculation purposes.

3.3.3 DEA calculation details. CCR DEA model (Charnes *et al.*, 1978) is adopted for the DEA analysis. The linear program model for CCR is represented as in the following equation:

$$\text{Maximize } f_0 = \frac{\sum_{\mathrm{i}} u_i \times Y_{iq}}{\sum_{\mathrm{j}} v_j \times X_{jq}},$$

Subject to:

$$\frac{\sum_{\mathrm{i}} u_i \times Y_{ik}}{\sum_{\mathrm{j}} v_j \times X_{jk}} \leqslant 1; \quad k = 1, \ \ldots, \ n, \ \ V_{\mathrm{i}}, \quad u_i \geqslant 0 \tag{1}$$

where f_0 represents the efficiency score; Y represents the outputs; X represents the Inputs.

The efficiency calculated by the CCR model resulted in unity, indicating that the DMUs are highly efficient and there was a call for super efficiency calculation model that calculates efficiency of more than unity thus differentiating the DMU performance. Specific researches were carried out to test the most suitable super efficiency model for the specific purpose, namely, Chen (2004), Tone (2001), Bogetoft and Hougaard (2004), Dula´ and Hickman (1997), Seiford and Zhu (1999), Thrall (1996) and Zhu (1996) but all of them resulted in infeasibility. The model suggested by Lovell and Rouse (2003) suited the most due to its superior result and was selected for the research. The model of Lovell and Rouse, 2003 is presented in Equation (2).

3.3.4 Super efficiency modeling and calculation. Min θ subject to constraints:

$$Y\lambda + Y_0\lambda_0 \geqslant Y_0; \quad X\lambda + \alpha X_0\lambda_0 \geqslant \alpha X_0; \quad \Sigma\lambda + \lambda_0 = 1; \quad \lambda, \lambda_0 \geqslant 0, \quad \theta \text{ free.} \tag{2}$$

Outputs $y_1, y_2, \ldots, y_s$; inputs $x_1, x_2, \ldots, x_m$; DMUs $j = 1, 2, \ldots, n$. λ is a dimensional vector of intensity variables for DMUs j, with $J \neq 0$. Y_0 and X_0 are output and input vectors for $\mathrm{DMU_o}$ being evaluated; and λ_o is the intensity variable for $\mathrm{DMU_o}$.

The super efficiency helps identify the high level constraint. The lowest score of efficiency among the departments (DMUs) indicate the weakest area. This paves way for the third step.

Step 3: empathize to grasp the business process: the third step involves working with various teams to understand existing design and create the context of the solution and its challenges. This provides tremendous engagement and value with the way the managers thinks. This paves way for the next step of defining problem.

Step 4: observe processes to Identify UDEs on business and clarify constraints: this step is to consensually decide on the UDEs on business. NGT is a weighted ranking method that enables a group to generate and prioritize a large number of issues within a structure that gives everyone an equal voice. In the current research NGT was selected to enable department members to identify and prioritize the UDEs in business with an equal opportunity to everyone. The final issues as listed may not be everyone's first priority, but they all have consensus on it. NGT is a two part process with the first part to define issues and generates ideas followed by second part of ranking and prioritizing. In the current context the NGT Part II was modified a bit and the main aim of the exercise was to develop a consensus on the ranking and priorities and its impact on leanness and agility. The third step is confirmatory step and is designed to take the activity forward. The sequential three stepped staged NGT process is shown in Figure 2. In this research NGT process clearly identifies the UDEs and helps build the CRT.

Step 5: define and establish the cause-effect relationship with CRT: the UDEs as available from NGT process are connected together to construct the CRT. CRT is built from top-down by identifying UDEs, and depicting probable causes for those effects (effect-cause).

Step 6: ideate solutions with innovative ideas and exploring options with evaporating clouds: the step is about idea generation activity and exploring its impact on the probable solutions. The ideas, that are supposed to elevate the constraints are first drawn with various options and converted to evaporating clouds. The ideas are categorized as being either primary idea or secondary idea. Primary ideas are the direct adoption of any lean or agile processes to help be more lean or agile. The secondary ideas are change in business processes that leads to leanness or agility.

Step 7: evaluate prototypes of solutions with TT and implement these with FRT: the evaporating clouds are discussed and evaluated with respect to value, sustainability, return on investments as well as comfort to department members. Based on the generated and accepted ideas the TT is developed. FRT is drawn based on the TT using primary idea, secondary idea and combination of both ideas.

4. Case of architecting a leagile supply chain – TOC framework application

The proposed framework is applied on an Asia based manufacturing plant. The plant has a global supply base with 80 percent export orders and 20 percent domestic orders. The case company had adopted some lean and agile processes with limited success. They wanted to explore further to understand what else could be done to achieve a leagile supply chain. The framework and its details were shared with the managers to get the data and related inputs. The framework, mathematical model and business relevance were explained to get a buy-in regarding the initiative, data gathering, process, results and approach. The five stepped approach is described in detail.

4.1 Step 1: identification of broad factors impacting leagility

The first step in the framework is to identify the strategic and tactical factors impacting leagility. Based on discussion with managers following factors were identified as influencing the leanness and agility of the plant supply chain:

(1) Strategic factors:
- market orientation and learning orientation;
- culture of innovation and improvement in the plant/company;

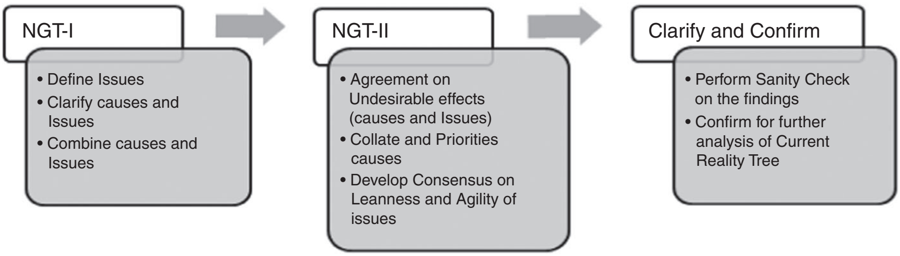

Figure 2.
Nominal group technique process flow

- saving and reward as a culture; and
- effective planning and ability to use IT effectively.

(2) Tactical factors:

- level of engagement of employee;
- intention to adopt norms of quality, productivity and value to customer;
- ability and willingness to spend on continuous improvements and wastage reduction; and
- conscious efforts to bring in flexibility in planning and execution.

These factors were analyzed to determine the decision making entities and identify constraints. Some key areas of concerns as laid down by managers were service/work stoppage, customer and supplier feedback and department expenses. These areas of concerns were mapped to the strategic/tactical factors which in turn helped understand whether it was a lean constraint or an agile constraint. The detail level mapping of the strategic and tactical factors with the areas of concern and leagility constrained in provided in Table III. This table helps decide the Input and output factors of the DMUs.

	Constraining leagility	Impacting influencers	
Strategic factors			
Market orientation and learning orientation	Agility constraint	Number of customer and supplier feedback received in last 1 year	Number of customer and supplier feedback adopted into business process
Culture of innovation and improvement in the company	Agility constraint	Service/Work stoppage	Number of new business process introduced in last 1 year
Saving and reward as a culture	Lean constraint	Department expenses/Budget in last 1 year. Figures in 100,000	Departmental cost savings. Figures in 100,000
Effective planning and ability to use information technology effectively	Agility constraint	Total number of IT users	Number of business process automated in last 1 year
Tactical factors			
Level of engagement of employee	Lean constraint	Number of employees in department	Total productive man hours of service in department
Intention to adopt norms of quality, productivity and value to customer	Lean constraint	Total number of identified steps in the departmental value stream mapping process	Productivity improvement
Ability and willingness to spend on continuous improvements and wastage reduction	Lean constraint	Total number of value adding steps in department function	Number of continuous improvement initiatives
Conscious efforts to bring in flexibility in planning and execution	Agility constraint	Number of employees involved in S&OP process	

Table III.
Factor analysis

4.2 Step 2: analyze factors to channelize the constraint

In order to channelize the constraints to a specific department data as per template of Table II were sought from supply chain managers of the case company. First CCR model is applied to calculate DEA efficiency. The calculation of the DEA efficiency is done using Joe Zhu's free DEA software (Zhu, 2012). The efficiency calculated for both lean and agile were 1. This necessitated calculation of super efficiency. Lovell and Rouse (2003) model is used as suggested in framework. The results of the super efficiency calculation are show below in Tables IV and V.

4.2.1 DEA result analysis. Tables IV and V help us conclude the following. Both in terms of leanness and agility adoption constraints the customer order/customer service department is the least efficient. While the super efficiency for leanness adoption of customer order/customer service department is 666.667, it is significantly lower than the other two departments. The super efficiency of customer order/customer service department for agility adoption is lowest at 128.425 among all departments. This result indicates that the processes of customer order/customer service department needs to be analyzed in detail to understand and identify the under lying problem and come up with granular level constraint.

4.3 Step 3: empathize to grasp the business process

With the identification of the constraining department it was deemed necessary to bring in the empathy aspect as further analysis were more people, process and practice oriented. It was necessary to empathize with business managers, understand their concern, and get business overview with their valuable offerings. The focus on customer order/customer service department and order booking/shipping processes revealed some recurring problems related to mismatch of address, price, date-related problems, shipment -related problems, export- related issues, customer payment-related issues and change orders-related issues. After a comprehensive understanding of the processes the current state process flows were developed. While a customer books orders, there are change orders as well. Change orders are handled slightly differently and are depicted in a separate flow. The current order booking and processing flow is shown in Appendix (Figure A1). The change order process is shown in Appendix (Figure A2).

4.4 Step 4: observe processes to identify UDEs on business and clarify constraints

In order to gain an insight into the processes aligned with the ordering process, meetings were held with the supervisors, managers, lean champions, business analysts and senior executives with the agenda to better understand the problems. The teams were briefed about the NGT process and the objective of identifying a consensus on UDEs on business. The members performed NGT Part I and a combination of issues were developed. As all groups put forward their views on the issues a quick analysis helped develop a structure of issues as shown in Figure 3. The UDEs were segregated into 5 different headings as faced by the department.

NGT Part II was held to rank and prioritize issues. This step helped develop a consensus on priority and rank of the causes followed by consensus on the impact of leagility.

It is important to derive the paradigms of leanness or agility constraints at the end of this step. The team composition was such that some opinionated members thought they know the most important problems, while several members were not vocalizing their opinion. The NGT Part II helped solve this problem. 14 members participated in

Table IV.
Results of DMUs for leanness measure

DMU name	Number of employees in department	Total number of identified steps in the departmental value stream mapping process	Department expenses/ Budget in last 1 year. Figures in 100,000	Total productive man hours of service in department	Total number of value adding steps in department function	Number of continuous improvement initiatives	Departmental cost savings. Figures in 100,000's	Productivity Improvement	α	θ_0	Final Efficiency Score
	DEA calculation to identify departmental efficinecy for adopting leanness using the model of Lovell and Rouse (2003)										
	Input					Output			Results		
Shop floor manufacturing (production) and quality department SFMD	128	50	10	26,6240	40	40	200.00	6	22.33	0.5155	1151.112
Purchasing, materials (store), logistics, warehousing supply chain department (SCMD)	40	25	9	83,200	19	25	250.00	10	22.33	0.5253	1173.333
Customer 0rder/ Customer service department (CSD)	6	8	7	12,480	4	8	1	2	22.33	0.2985	666.667

Table V. Results of DMUs for agility measure

	DEA calculation to identify departmental efficinecy for adopting agility using the model of Lovell and Rouse (2003)										
	Input				Output				Results		
DMU name	Number of employees involved in S&OP process	Department expenses/ Budget in last 1 year. Figures in 100,000	Number of customer and supplier feedback received in last 1 year	Total number of IT users	Number of customer and supplier feedback adopted into business process	Number of business process automated in last 1 year	Number of new business process introduced in last 1 year	Service/ Work stoppage	α	θ_0	Final efficiency score
Shop floor manufacturing (production) and quality department SFMD	7	10.00	12	6	12	12	39.00	4	2.75	1.34	368.5
Purchasing, materials (store), logistics, warehousing supply chain Department (SCMD)	4	9	8	9	10	9	4.00	2	2.75	0.545	149.875
Customer order/ Customer service department (CSD)	5	7	10	7	8	6	3.00	2	2.75	0.467	128.425

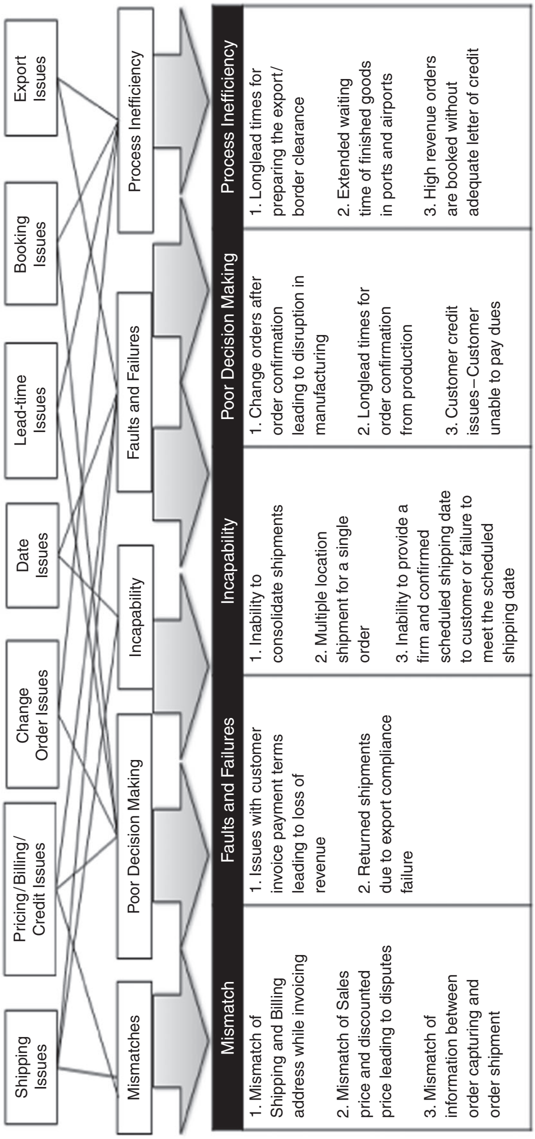

Figure 3.
Findings of NGT process part I

the exercise and each member was asked to rank the causes. Even with 14 members the finding of the step was that the total points earned were same for all. The details of the member participation exercise for NGT-II is provided in Appendix (Table AI). There were no clear winners and it was difficult to priorities one cause over the other. It was consensually decided to consider all the causes/effects together for impact analysis and constraint evaluation. The next step in the NGT Part II was to develop a consensus on the leanness and agility impacts of these causes. For the leanness and agility evaluation the effects were evaluated in detail and the result of the analysis is shown in Table VI and is used to draw the CRT.

Pricing/Billing/ credit issues	Dates and shipping issues	Export and lead time issues	Booking issues			
1. Mismatch of shipping and billing address while invoicing	1. Inability to provide a firm and confirmed scheduled shipping date to customer	1. Returned shipments due to export compliance failure	1. Change orders after order booking leading to disruption in manufacturing			
2. Mismatch of sales price and discounted price leading to disputes	2. Failure to meet the scheduled shipping date	2. Long lead times for preparing the export/ border clearance	2. High revenue orders are booked without adequate letter of credit			
3. Customer credit issues – customer unable to pay dues	3. Inability to consolidate shipments	3. Extended waiting time of finished goods in ports and airports				
4. Issues with customer invoice payment terms leading to loss of revenue.	4. Multiple location shipment for a single order	4. Long lead times for order confirmation from production				
	5. Mismatch of information between order capturing and order shipment					
Paradigms of leanness or agility constraints						
Mismatches leading to rework /effort wastage	Inability to understand customer	Inability to consolidate and also rework during shipment	Inability to understand and meet customer requirements	Rework /effort wastage/ Longer lead time	Rework /effort wastage	Customer credibility issue
Constraint for leanness and agility		Constraint for leanness and agility		Constraint for leanness	Constraint for leanness and agility	

Table VI. Categorization and confirmation of issues faced by the customer service department

4.5 Step 5: define and establish the cause-effect relationship with CRT

It was important to understand which cause was leading to what effect in order to identify an effective solution. This analysis was facilitated by the CRT in conjunction with NGT output. CRT analysis was a suitable option as it is constructed from the top-down by analyzing the UDEs and depicting probable causes for those effects (effect-cause). The UDEs in Table VI are converted to logical figures and connected together to arrive at the CRT. Figure 4 represents the CRT. CRT analysis laid down the constraints as rework, long lead times, inability to accommodate change order, unable to consolidate shipment, credit issues and customer trust. All these put together are leading to reduced leanness and agility.

4.6 Step 6: ideate solutions with innovative ideas and exploring options with evaporating clouds

The next step was to ideate solutions for the constraints. Brain storming sessions were held to club the issues and come up with solution options. With adequate pragmatic solution options available the evaporating clouds were drawn. IT adoption facilitated better utilization and scheduling of resources, prioritizing, appropriate decision making with cost/utilization analysis and simulations. The three ECs are referred to in Figures 5-7.

The three ECs are:

(1) evaporating cloud for rework and long lead-times depicted in Figure 5;

(2) evaporating cloud for reduced agility in customer response depicted in Figure 6; and

(3) evaporating cloud for Poor understanding of Customer Requirements depicted in Figure 7.

As all the evaporating clouds are independent to each other so a generic evaporating cloud was not deemed suitable. The objective of all the three EC is to improve the leagility of the department.

4.7 Step 7: evaluate prototypes of solutions with TT and implement these with FRT

4.7.1 Evaluating solutions with TTs. The ideas generated through the thinking process are translated into primary ideas and secondary ideas. Though the primary and secondary ideas are interrelated, but are clearly distinguishable. Table VII shows the details of the ideas which is used to develop the TTs. The TT is drawn for few of the major constraints in the department which needed improvements.

Referring to Table VII the most common and prominent solution is the IT adoption. The application of the IT is needed in the area of business process automation, analysis and simulation. In terms of IT, enterprise resource planning (ERP) seemed to be the best fit technology adoption possible for the department as well as the company to achieve leagility. Figure 8 shows the TT and how the technology enablement is helping elevate the constraints with the showcase of effect-cause-effect. All the effects are not shown in the figure.

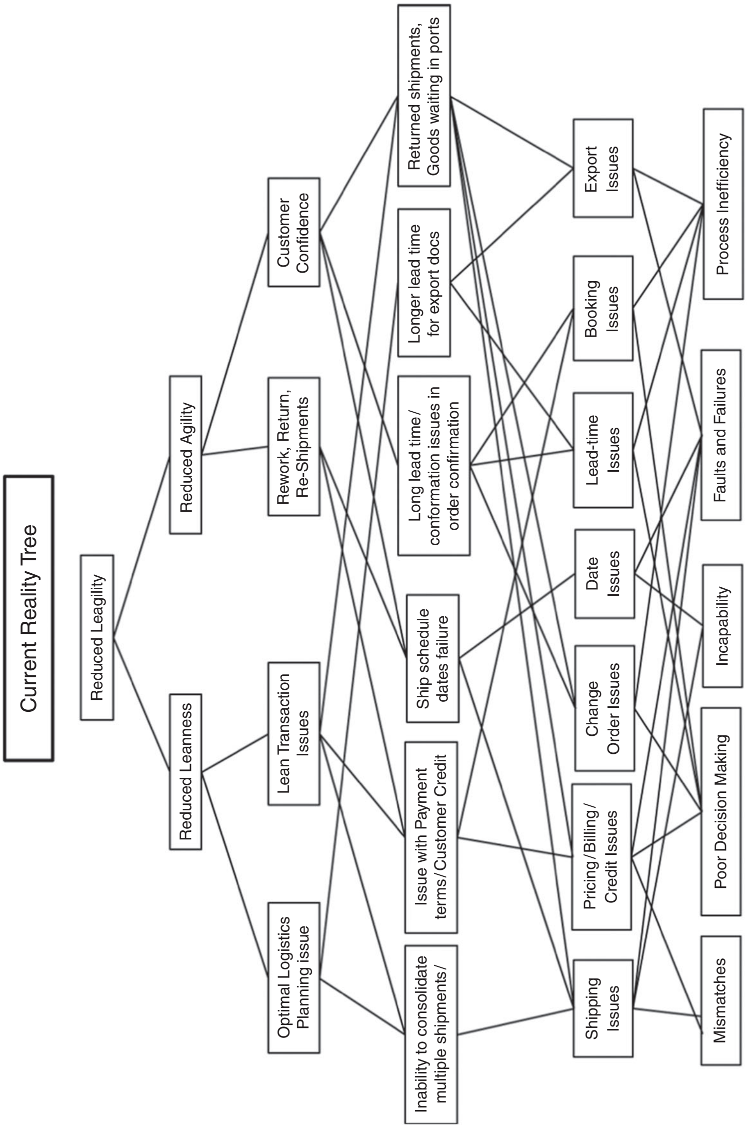

Figure 4.
Current reality tree

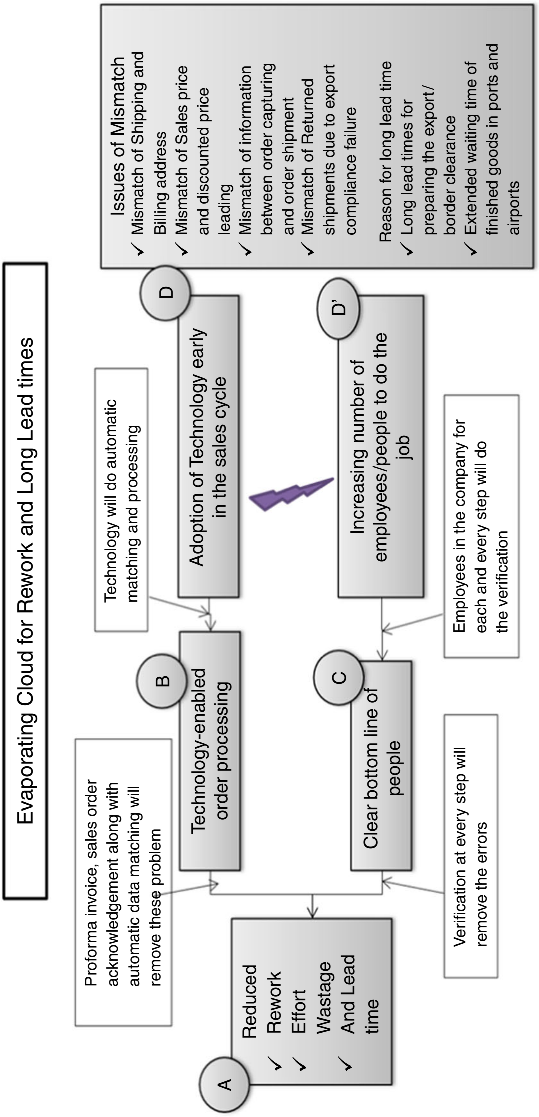

Figure 5.
Evaporating cloud for rework and long lead times

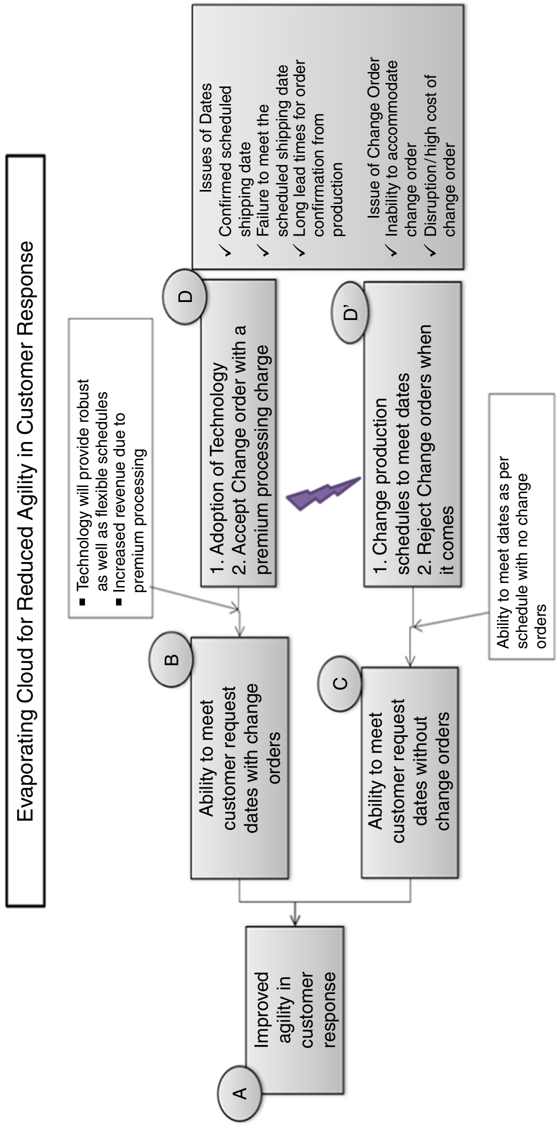

Figure 6.
Evaporating cloud for reduced agility in customer response

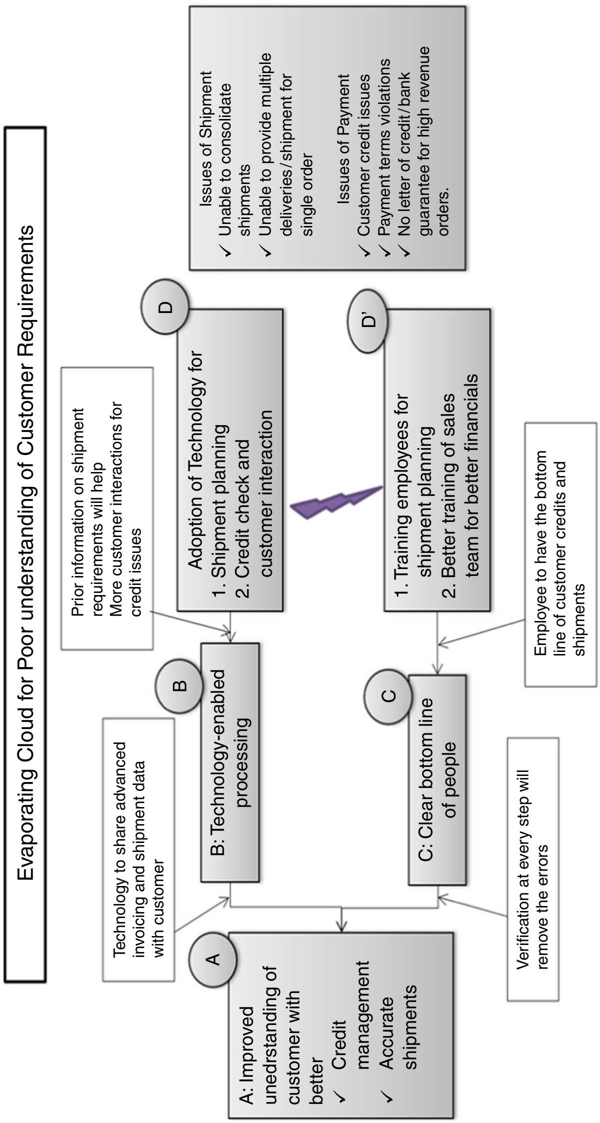

Figure 7.
Evaporating cloud for poor understanding of customer requirements

Table VII. Thinking process ideas for transition trees

S.No.	Improvements needs	Solutions	TP idea
1	Reduction of lead times for many of the activities	Training and through technology adoption	Primary +Secondary idea
2	Agile change order process	Making sure the change order is financially viable, feasibility check and necessary approvals	Primary idea
3	Reduced rework and return shipments	Possible through necessary approvals and technology adoption	Primary +Secondary idea
4	Reduced payment issues	Better communication and technology adoption	Primary +Secondary idea
5	Better understanding of customers	Possible through better planning and technology adoption	Primary +Secondary Idea

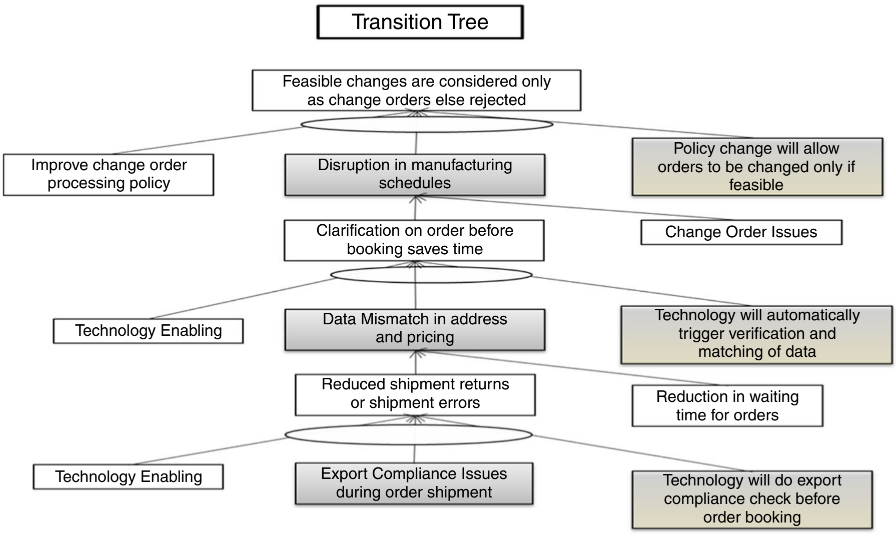

Figure 8. Transition tree

Few examples where technology adoption is greatly helping the business improve leagility in the current case are being provided below:

(1) technology will facilitate sharing of special instruction from customers related to packaging, processing, labeling, tagging or shipping to be carried till order shipment reducing mismatch;

(2) technology can be automatically programmed to trigger verification and matching of shipping and billing address, sales price and discounted price during order booking process helping reduce mismatch;

(3) with ERP scheduling tools, reliable scheduled shipping date can be calculated improving order reliability;

(4) confirmation of order from production will be lot quicker due to seamless integration and advanced material planning;

(5) automatic generation of export/border clearance documents reducing lead-time and mismatches;

(6) proforma invoice, sales order acknowledgment during confirmation and advanced shipment notice will strengthen customer interaction in the order cycle; and

(7) payment terms can be shared with customer with sales order acknowledgment while booking of order, thus removing ambiguity on terms.

4.7.2 Solution presentation in the form of FRT. Based on the analysis of Table VII and the TT, the FRT is drawn as shown in Figure 9. The FRT depicts the amalgamation of the primary and secondary ideas indicating the improvement in leagility of the department. The more important point in the journey towards leagility is the business processes which have to be in line with the FRT. With FRT clearly drawn (primary idea) the modified business process flows (secondary idea) are also redesigned so as to help the department and company become more leagile.

4.7.3 Future process flows. Based on the secondary idea the future process flows are drawn. Two future process flow is drawn one for order booking and execution while the other is for change order process. These changed processes bring in required approvals and checks which enables leanness and agility of department functioning. The revised order booking and processing flow which will be the future process state is shown in Appendix (Figure A3). The revised change order process which will be the future process state is shown in Appendix (Figure A4).

The case exemplifies how the framework can be adopted in a real life scenario. The future process flows were shared with the company executives and management agreed to the changes. The management expressed satisfaction with the modified processes and decided to carry out the changes in business processes and IT enablement in phases over a period of time. Benefits accrued due to the change in the processes are discussed subsequently.

5. Results and discussion

The case clearly demonstrates that TOC can help realize leagility in supply chain. Following are the benefits of the changes.

Shipping and billing address mismatch while invoicing, Sales price and discounted price mismatch, information mismatch between order capturing and shipment were considerably reduced with the use of an ERP system and processes. These problems in a month typically led to an average 5-7 customer shipment returns prior to the exercise, which came down drastically to an average of 1-2 over a period of six months. These 1-2 causes of return were mostly related to quality issues pointing to a new area of concern (constraint). The net customer receivables after six months of exercise improved to 364 K USD from an average of 380 K-390 K USD a reduction of approximately 4-6 percent leading to improved bottom line as well improved cash flow. With the ability to consolidate shipment over similar locations (regions), opening up cross-docking opportunities and reducing multiple deliveries of same order, there was a reduction of 3.7 percent in logistics transportation cost for customer shipment. The details of the calculation are provided in Appendix (Table AII). This saving was in addition to the savings in logistics cost due to lesser number of shipments owing to lesser customer returns. The combined reduction in logistics cost was one of the biggest advocacies of leagility through the new TOC approach.

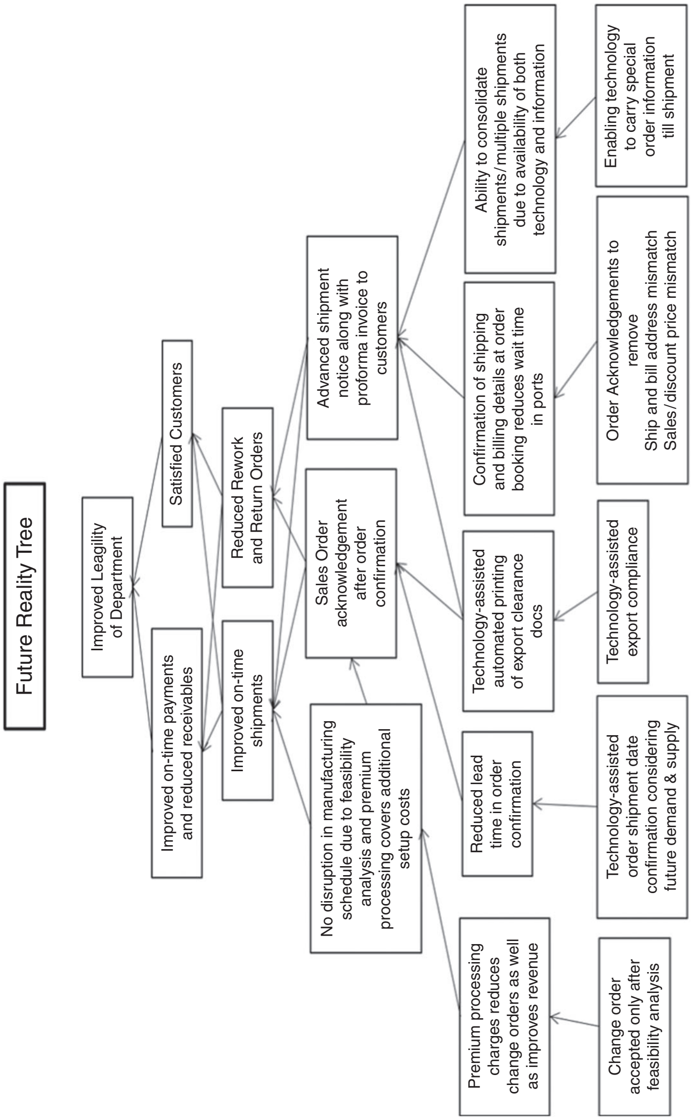

Figure 9.
Future reality tree

Over a period of one year the credibility and reliability of order shipment and customer service improved and order backlogs reduced for the company. The company was able to make an average of 2-3 more shipments per month reducing backlogs. With better visibility of planned supply based on the future demand and clearer picture of available capacity, it was possible for a more realistic order scheduling, execution and customer service. The reduction in lead time was due to the visibility of capacity and future orders. Also discipline in order scheduling provided a level load in the factory removing spots/spikes of capacity availability as well as brought consistency in material planning and availability. The built to order lead time for a customer order with a tonnage of less than three tons was around 12 days which was reduced to 10.1 days over a period of 12 months. This brought in a significant amount of agility in the business. The IT enabling of the processes and automation of export documentation preparation, the export shipment time after packaging reduced from approximately two days (due to the need for language specialist and compliance review) to three hours (including compliance check). This was a significant reduction in finished goods waiting time and improved agility.

6. Conclusion

6.1 Social implication

This research has a great social implication. Supply chain managers who are trying to improve their already implemented lean and agile processes can rely on this framework. They can use the same DMUs or can design their own DMUs as applicable to business. The framework acts like a guided TOC methodology and can easily be adopted by managers with only input required is data apart from drawing the reality trees. As it's a TOC framework it can be carried out any number of times thereby identifying a new constraint every time.

6.2 Conclusive research value

The research has three unique values; first it is an attempt to further diversify the application of TOC to a new area of improvement in supply chain. Also it introduces a mathematical approach to identify high level constraints along with establishing a new framework of TOC and its design thinking process. The suggested TOC approach will not only stream line business processes but will also improve the leanness and agility of the supply chain. The hallmark of the methodology is the analytical approach to identify the high level constraints using DEA and then utilizing the design thinking process to determine granular constraints for leagility adoption and improvement. The stepped process helps achieve the goal of Leagility through a rigorous analysis and innovative thinking process. The direct benefit of this technique is the guided TOC thinking process which will help the practitioners and objectively identifying the high level and detail level constraints. The unique methodology is applied on a real life case to prove the point that the process proposed in the research can reduce customer returns as well as improving cash flow. The process can open up opportunities like cross-docking and at the same time reduce logistics cost adding to the bottom line. This can help improve the credibility and reliability of the customer service. It can reduce order lead time as well as goods waiting time. All these aspect put together transforms the supply chain to a leagile supply chain.

6.3 Limitations and future work

This research opens up the many new opportunities of research like using this framework for identifying constraints in CPFR scenarios. This framework can be applied or tweaked to improve to better collaborative supply chain. In this research NGT is used only for developing CRT this can be further explored to other reality trees leading to greater people participation. One of the key limitations of this research is the identification of DMUs. The DMUs as identified in this research may not be applicable for every type of business scenarios.

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Appendix

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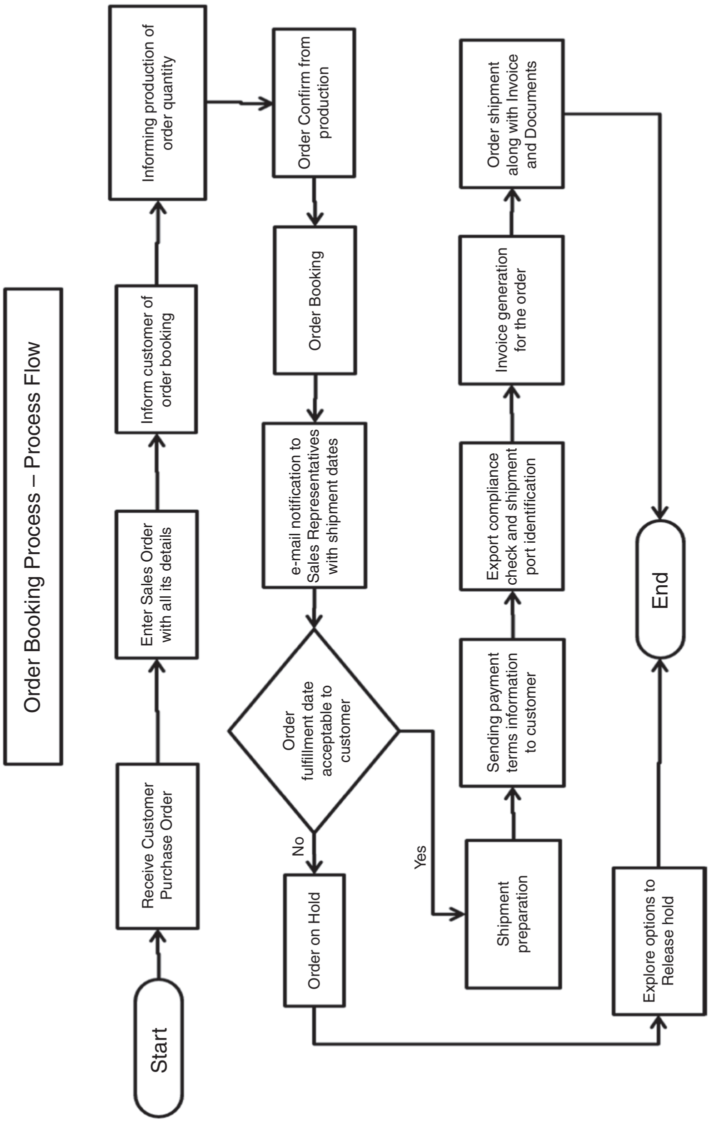

Figure A1.
Order processing flow

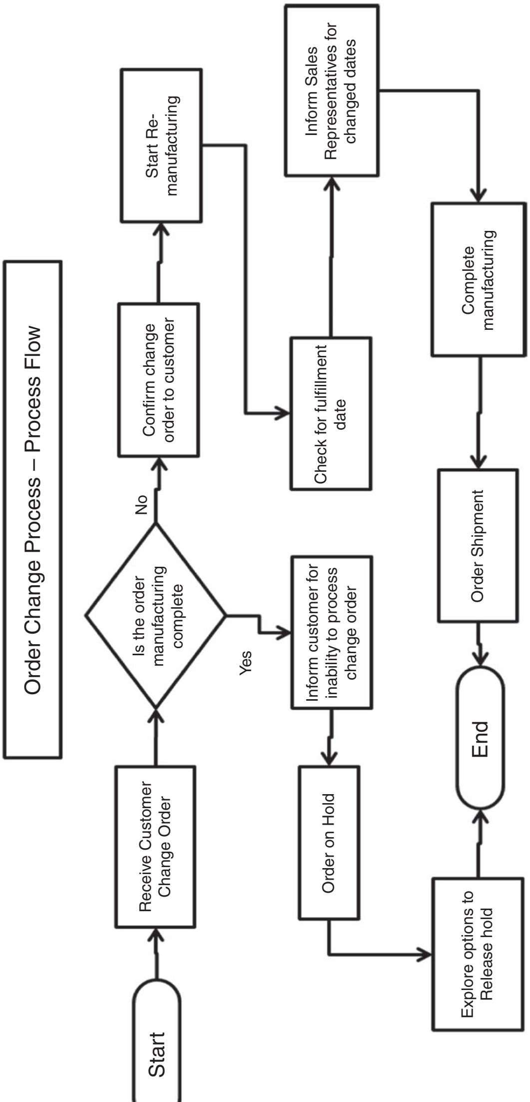

Figure A2.
Change order processing flow

Table AI.
Member participation exercise for NGT Part-II

Causes	Member 1	Member 2	Member 3	Member 4	Member 5	Member 6	Member 7	Member 8	Member 9	Member 10	Member 11	Member 12	Member 13	Member 14	Total
Mismatch	1	1	5	5	3	2	2	3	4	5	1	5	1	4	42
Faults and failures	3	5	1	4	4	3	5	1	2	1	2	4	2	5	42
Incapability	4	4	2	1	5	4	1	2	3	4	3	3	5	1	42
Poor decision making	5	3	3	2	1	5	4	5	1	2	4	1	4	2	42
Process inefficien	2	2	4	3	2	1	3	4	5	3	5	2	3	3	42

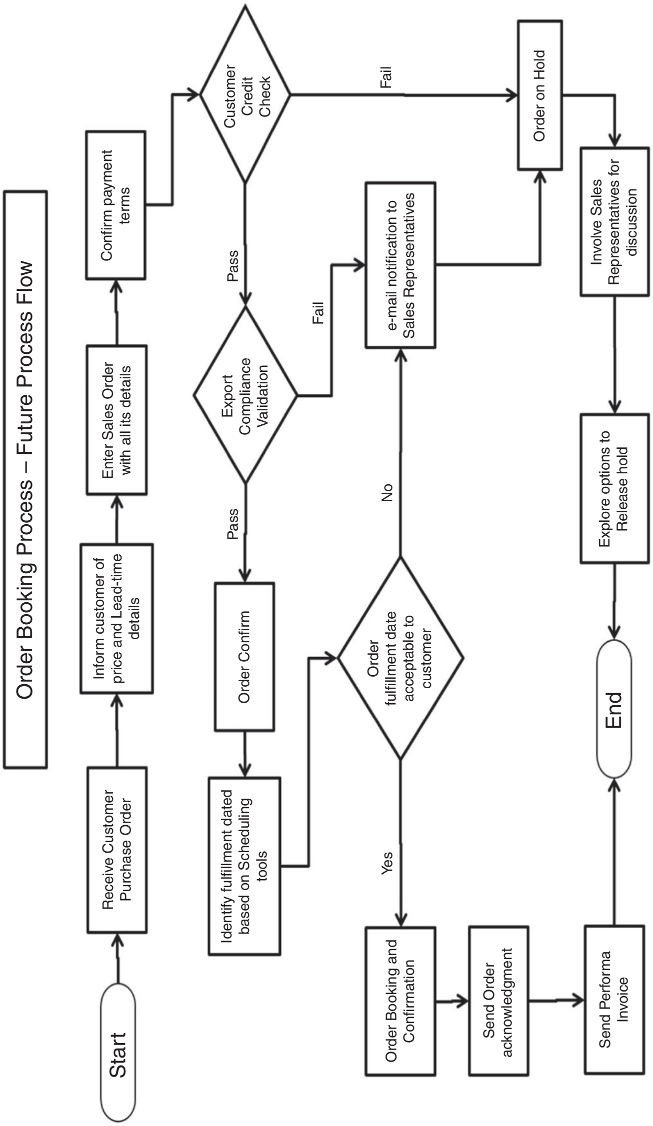

Figure A3.
Order booking process flow – future state

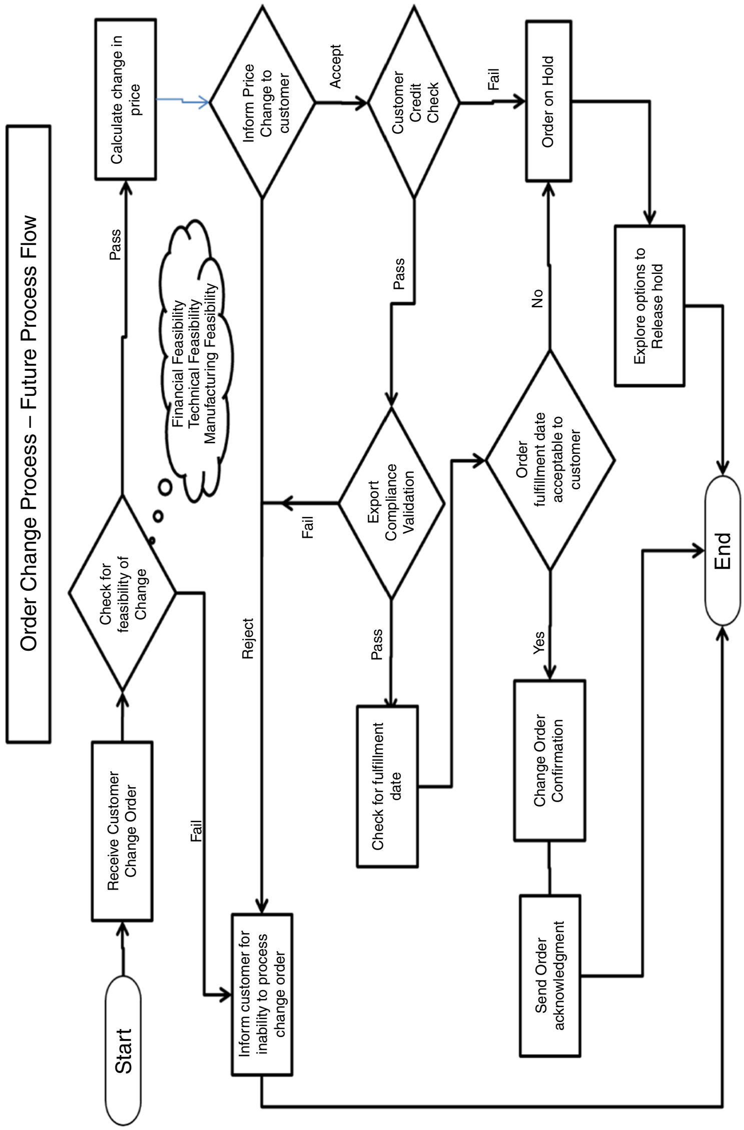

Figure A4.
Order change process flow – future state

Mode	Type of shipment	Number of shipments (previous)	Cost of shipment (USD)	Number of shipments (current)	Cost of shipment (USD)	Savings calculation
Road	Long distance	45	90,000	40	80,000	
	Intercity/local	29	43,500	25	37,500	
Air	International shipments	87	652,500	83	622,500	
Water	International shipments	206	927,000	202	909,000	
Transport cost			1,713,000		1,649,000	
Shipper-related costs	5% calculated gross on transport cost			85,650.00	82,450.00	
Logistics administration	3.5% calculated gross on transport cost			59,955.00	57,715.00	
Total transportation cost				1,858,605.00	1,789,165.00	3.7%

Table AII. Transport calculation for a period of six months

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Arnab Banerjee is currently a Principal Consultant with Infosys. Previously he was a Program Manager for Supply Chain Initiatives at the Finisar. Overall he has more than 13 years of consulting and business experience in manufacturing, supply chain and ERP domain in USA, Europe and Asia. His research interests include operations research and information technology applications in supply chain management, green/reverse supply chain, lean initiatives, theory of constraints, IT architecture, business operations, transformations and HR aspects in supply chain and humanitarian logistics. He has published articles in *International Journal of Production Research*, *International Journal of Value Chain Management* and other refereed international journals and conferences. Arnab holds a PhD in Supply Chain Management, a Master's Degree in Industrial Engineering and a Graduation Degree in Mechanical Engineering. He is a certified six sigma Black Belt Champion. He is listed in Who's who of the World 2015. Arnab Banerjee is the corresponding author and can be contacted at: arnab1979@gmail.com

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