

# SUPPLY CHAIN PERFORMANCE ENHANCEMENT USING TOC-ENTROPY-GP APPLICATION

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## Abstract

*Many foundries are operating at lower levels than the installed capacities. A study has been conducted across 56 foundries in India and found that only 68% of installed capacities are being utilized. This is mainly because of lack of co-ordination among the supply chain partners. This study is an effort in identifying these gaps using TOC approach, which will help in the supply chain performance enhancement.*

*Field of Supply Chain Management witnessed rapid growth in the recent past and proved to be a successful tool for the organization's growth. Success of supply chain improvement initiative lies in the selection of appropriate Key Performance Indicators (KPI's) using appropriate supply chain framework. These performance indicators are to be measured, monitored and controlled with proper review mechanism. Know what to measure and what targets to set as critical first steps in improving Supply Chain performance, it is very difficult to identify what is to be measured from the list of supply chain metrics. It becomes more important to identify and measure the relevant KPI's related to the area which we want to improve. KPI's should be simple, easy to measure and intuitive.*

*This research work starts with defining of supply chain, selection of SCOR framework for supply chain performance measurement, defining set of KPI's under SCOR framework, measuring of these KPI's and comparing with benchmark data's. This comparison leads to the gaps which are due to the constraints in the system. These constraints are identified using the principles of TOC. Entropy, AHP and GP are used as mathematical aids in solving this multi criteria decision making problem.*

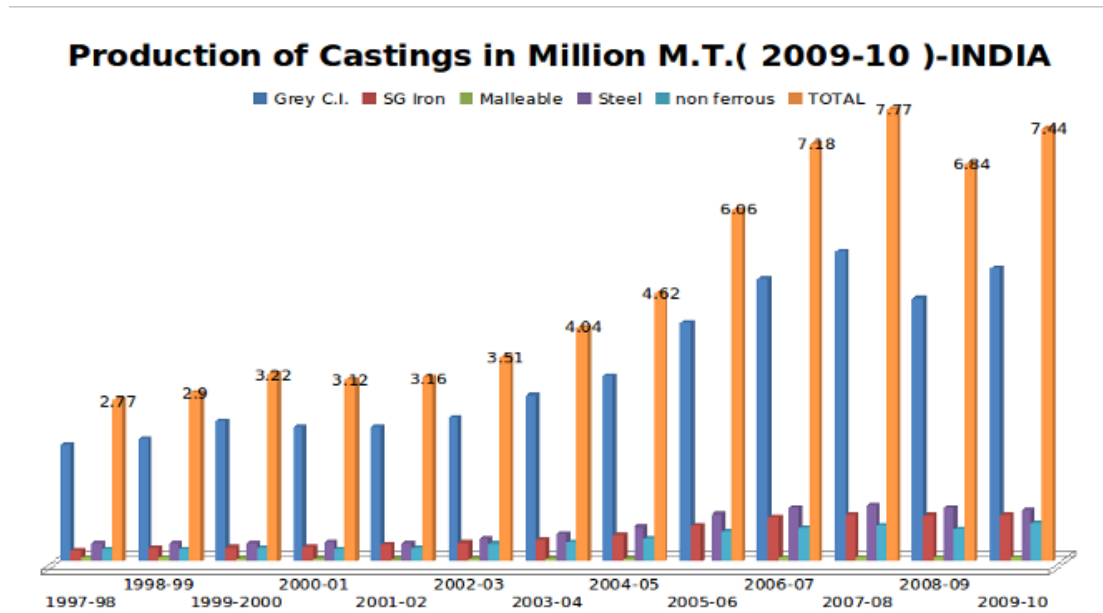
**Key Words:** SCOR, KPI, TOC, AHP, GP, Entropy

## 1. Introduction

The aim of this research work is to devise a methodology which will help in supply chain performance enhancement in Indian Iron and Steel foundries. Foundry is an industry where metal is melted and casted. Casting is the process of producing shaped articles by pouring metal into moulds.

Indian foundry industry's growth in the last decade is at a faster pace when compared to the global growth of the foundry industry. The Indian foundry industry showed Compounded Annual Growth Rate (CAGR) of 20% over the last five years (12% CAGR for passenger cars, 4.4% CAGR-Commercial Vehicles, 11% CAGR-Two Wheelers, 9% CAGR-Three wheeler vehicles).

India is the second largest producer of castings in the world led by China. India's production of castings has reached 7.44 Million tonnes during 2009-10 when compared to 2.77 Million tonnes during 1997-98, which shows a phenomenal growth of over 168% in last 12 years. Growth trends in production of castings in India from 1997 till 2010 is shown in FIGURE 1. This sudden increase in foundry castings requirement is mainly because of two reasons, one increase in domestic castings requirement mainly from the automobile manufactures and the second from the export market because of closure of foundries mainly in USA and Europe in the last 7-8 years because of stringent pollution control norms and high labour costs. As foundry is labour intensive industry, China and India were looked as the first destination by the international castings buyers. Both these countries are in a position to offer best castings at a competitive price.



*Figure 1: production trend in indian foundries*  
 Source: foundry informatics centre, assessed on 30.04.2011

## 2. Supply Chains

Last few decades have witnessed rapid growth in the globalization of industries, where interdependence between each supply chain partner has increased and failure of any partner member affects the performance of the entire supply chain. Toyota India has cut down its production levels by 70% for 5-6 weeks when Earthquake and Tsunami effected in Japan during Apr'11.

89 literature reviews has suggested improving supply chain performance by concentrating only on one aspect of supply chain, supplier selection / inventory management / cost reduction / logistics / Demand forecasting or asset management. Reduction in inventory levels at manufacturing stage by aggressive marketing approach will increase inventories at distributors and retailers. It has also observed that many companies buy raw materials more than the required capacities when the raw material price falls. This adds up raw material inventory. But supply chain is not one specific process improvement, entire chain has to have benefit of reducing inventories, cost advantage and return on investment. We cannot ask our suppliers to hold safety stock at their end and dump our goods at distributors and claim our inventory levels are low. Supply chain excellence cannot be achieved in isolation.

Though supply chain performance improvement depends on external factors, most of the times it lies within the measuring system itself. This is explained with a specific example of British Telecom. British Telecom wanted to measure the effectiveness of their customer service representatives who attends the customer complaints over the telephone. Initially they fixed customer satisfaction as the performance measure and each caller has to rate in 1-10 scale, 10 being the best. Everyone tried to solve the customer query and they took the maximum time for clearing each caller queries. This made other callers wait in the queue for longer times and most often they fail to get their lines connected. In order to solve this British Telecom changed the performance measurement as a number of callers attended per day. Now every representative started answering fast and tried to cut the calls without clearing the queries. This necessities the urgency in formulating a methodology in identifying the appropriate supply chain performance (SCP) metrics Douglas et al. (2001).

Business horizons are growing beyond the earlier set boundaries and most of the business activities are entering into global markets either for procurement of raw materials or manufacturing activities or for sales of the end products. Many foundries import raw materials such as steel scrap, steel shots and alloys like Ferro silicon magnesium because of the competitive pricing and quality. Castings are exported to many global players like Volvo, Ford, Arvin Meritor, MAN etc. to fit into their end components. These necessities the proper co-ordination between all the team members, suppliers-manufacturing-logistics and distribution networks, which is termed as supply chain.

It is not only important to start the supply chain networks but to establish these supply chain networks, what is important is performance measures and planning contingencies. This section is completely dedicated to

explaining the concepts of supply chains, followed by few definitions given by different researchers and authors, supply chain management strategies and at the end it explains the need for performance measurement of the supply chains. Flow of supply chain and its activities are shown in FIGURE 2. Supply Chain Management helps in managing the supply chains. In order to manage supply chains, we need to monitor and control the chain performance which is done by measuring the performance of the supply chain. In order measure performance we need a set of guidelines like what is to be measured and at what frequency? These set of guidelines are given by supply chain frameworks. Frameworks gives the broader perspective of measurement ideas. In order measure the quantifiable performances, each frame work will recommend a set of metrics which are termed as Key Performance Indicators (KPI). Consistent measuring, monitoring and controlling of these KPI's will give enhanced performance of the supply chains.

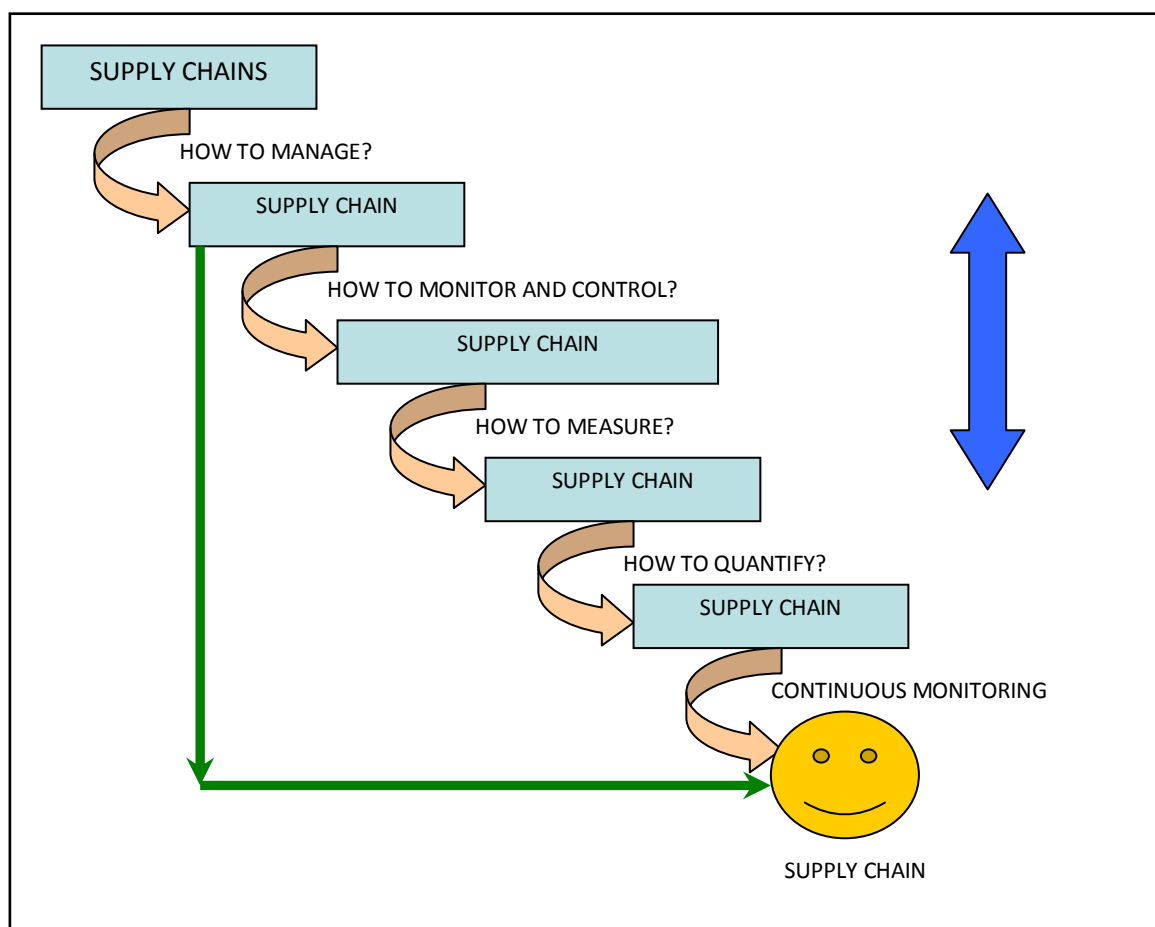


Figure 2: supply chain flow

There are many definitions on supply chains. Some of the prominent definitions are explained in the next section.

### 3. Definitions of Supply Chains

There are n-number of definitions to define supply chains, but at the end all the definitions boils down to Jim Ayer's, (2000) most basic definition and shown in FIGURE 3.

“Supply Chain is all that happens to a product from dirt to dust”, we can slightly modify this and define, “Supply chain is all that converts concepts into cash and customer satisfaction”.

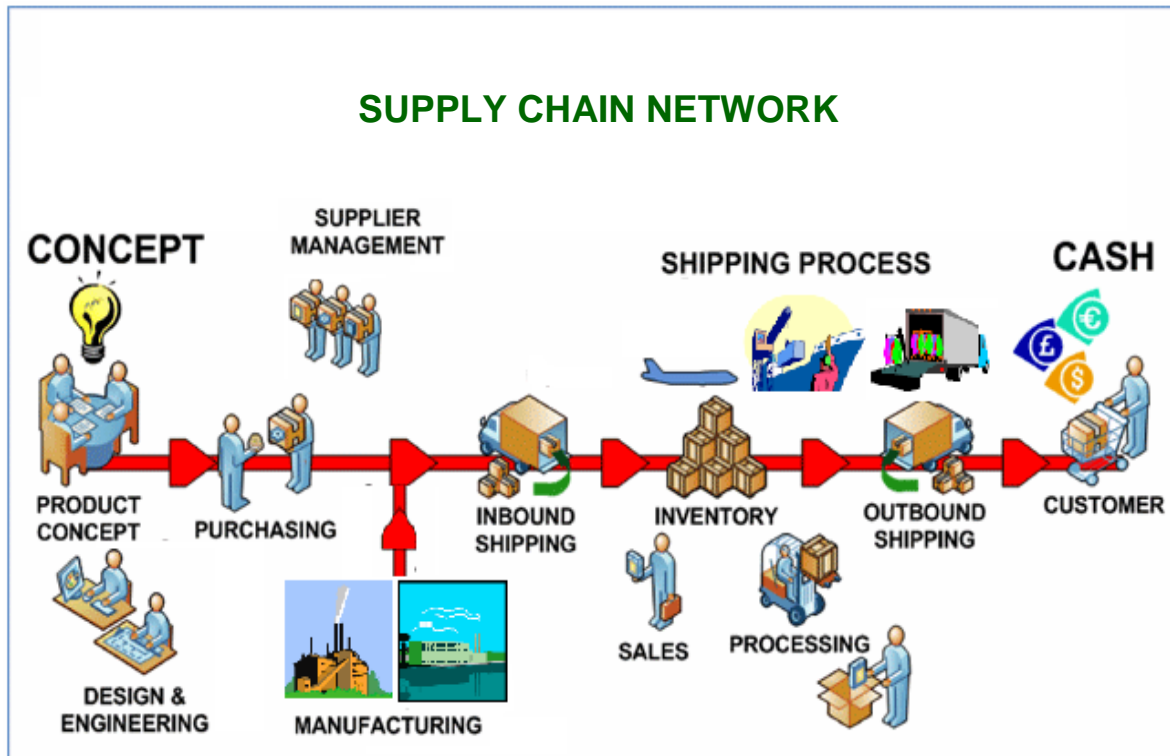


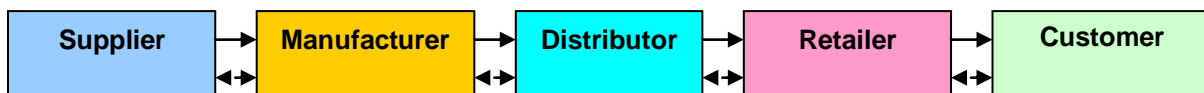
Figure 3: supply chain network

Let us see some of the definitions given by various authors and researchers on the supply chain.

- “A supply chain consists of all stages involved, directly or indirectly, in filling a customer request”, Peter Meindl and Sunil Chopra, (2002).
- “A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products to customers”, Mohanty and Desmukh, (2005).
- “Supply Chain encompasses all the activities associated with moving goods from the raw material stage through to the end-user”, Peter C Brewer, (2000).
- “Supply chain is life cycle processes supporting physical, information, financial and knowledge flows for moving products and services from suppliers to end users”. James Ayer, (2004).

- “Supply Chain is a process which connects all the links involved in the customer order fulfillment, viz., supplier, transporter, manufacturer, wholesaler, retailer, consumer and the business processes that bring products and services to the market place”, B.S.Sahay, (2006).

By going through all these definitions, the supply chain can be defined with a single line diagram as shown in FIGURE 4



*Figure 4 : single line diagram of supply chain*

- Consists of all parties involved, directly or indirectly, in fulfilling a customer request.
- Consists of all the processes involved in converting customer request into customer delight.
- All the activities involved in converting raw material into finished goods and supplying to customers.
- Supply chain is all that converts concepts into cash and customer satisfaction.

#### **4. Supply Chain Management**

Many optimization techniques started pouring in during 1980's. Strategies such as just-in-time (JIT), kanban, lean manufacturing, total quality management (TQM), total productive management (TPM) gained momentum and organizations spent vast amounts of resources in effectively implementing these techniques. However all these techniques aimed mainly at optimizing the manufacturing facility both in terms of productivity and cost, but overall supply chain network management has not been considered. So, organizations started thinking over next step to take in order to increase profit and market share. Many companies spend to the tune of 15-20% of their turnover on logistics. Survey results by supply chain council shows that though the U.S economy slowed down in 2005, logistics costs increased by about 15%. This throws a light into the potential areas where avenues exist for increasing profits. Supply Chain Management is not only managing manufacturing units but also the associated chain members from suppliers to customers. A couple of definitions on SCM are:

- “SCM is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses and stores, so that merchandise is produced and distributed in the right quantities, to the right locations,

and at the right time, in order to minimize system wide costs while satisfying service level requirements”, David Philip et al. (2008).

- “SCM deals with managing all the activities which have direct or indirect impact on cash generation and play a role in making converting the concepts into cash and customer satisfaction”.
- “SCM is a process whereby our company and yours agree to work as partners to consistently provide a part that has 100% Quality , 100% On-Time Delivery and 100% correct quantities .” – Peter L Grieco Jr, (1995)
- “SCM is the systematic strategic co-ordination of the traditional business functions within a particular company and across businesses within the supply chain for the purposes of improving the long term performance of the individual companies and the supply chain as a whole”. – Mentzer, (2001)

More simple form of all these definitions is “ SCM is design, maintenance and operation of supply chain processes for satisfaction of end user needs”.-James Ayer (2004)

The objective of SCM is to be efficient and cost-effective across the entire system. SCM aims at global optimization then the local optimization of the activity or process. There are various techniques available to manage these supply chains, but any thing we want to manage requires a measurement method which is effective. Supply Chain performance measurement is a basic step in order to have an effective supply chain management in place. These aspects are discussed in section 5

### ***5. Supply Chain Performance Measurement***

It is crucial that the measurement of Supply Chain performance indicators are synchronized with the overall supply chain strategy. Often the measurement of performance indicators begins at a functional level and with the formation of supply chain these do not change much. The organizations continue to measure the same old performance indicators while implement the new initiatives in the supply chain for better coordination. A number of early supply chain adopters have recently been left bewildered by their failure to demonstrate what they have achieved. The explanation may lie in the failure of these companies to measure what they ought to measure. ([www.decisioncraft.com/dmdirect/measure.htm](http://www.decisioncraft.com/dmdirect/measure.htm), accessed on 12.08.2012).

Performance evaluation is extremely important for the survival and growth of any organisation. In order to know where we stand in the present global competitive environment, we should have measurable parameters to compare- “you can’t improve what you can’t measure”. Performance measurement is very vital aspect in improving the organization performance. These measures should be inclined towards the growth of the organization and should enable the organization to achieve its goals.



There are many management jargons related to performance measurement, few prominent among them are

- Anything which is not measured, cannot be monitored
- Anything which is not monitored, cannot be controlled
- Anything which is not controlled, cannot be improved
- Anything measured improves
- You can't manage what you do not measure

The key to continuous improvement is to measure, measure and measure Larry Lapide (2008). Unless the organization can define, track and measure the critical outcomes that signify the achievement of supply chain goals, it will be unable to determine the effectiveness of its supply chain practices or make any necessary adjustments". Peter C Brewer, (2000). In order to know the present status of any business activity , it is of prime most thing to measure its performance through a set of well structured metrics. Performance measures are the mirrors reflecting the actual status of the business entity.

SCPM is the basic foundation step required for effectively managing the supply chains, performance of the supply chain has to be measured on accountable parameters than just measuring on non-accountable parameters. Ex: It gives a sense to measure dispatch tonnage rather than measuring the number of employees attended to work. Though the employee's presence is required but its effect on supply chain should not be significant if part of the employees are absent. It is always better not to measure than measuring a wrong parameter. British Telecom wanted to measure the effectiveness of their customer service representatives who attends the customer complaints over the telephone. Initially they fixed customer satisfaction as the performance measure and each caller has to rate in 1-10 scale , 10 being the best. Everyone tried to solve the customer query and they took the maximum time for clearing each caller queries. This made other callers wait in the queue for longer times and most often they fail to get their lines connected. In order to solve this British Telecom changed the performance measurement as a number of callers attended per day. Now every representative started answering fast and tried to cut the calls without clearing the queries. It is very much important to identify right performance measures to effectively handle the supply chains, often these are termed as Key Performance Indicators (KPI). There are different ways and strategies to identify the KPI required for SCPM. Prominent among them are SCC-SCOR model, Kaplan Nortan's Balance Score Card (BSC).

#### ***6. Supply Chain Framework And KPI Selection***

Optimizing supply chain activities are critical to all industries since it saves money, increases throughput, decreases inventory levels and increase revenues, thereby improving the organization's financial status. There are many frameworks which are given in the literature for managing the supply chains, prominent among them are



1. Global Supply Chain Forum (GSCF) framework, Douglas Lambert et al.(2005)
2. Supply Chain Operations References (SCOR) framework from Supply Chain Council (SCC) , Douglas Lambert et al.(2005)
3. Three Development Stage framework ,Krisztina Demeter et al. (2004)
4. Three Levels Model – Strategic , Tactical and Operational, Gunashekar et al.(2006)
5. Supply Chain based on Corporate Culture Compatibility , Khalid Al-Mutawah and Vincent Lee (2008)
6. Process Classification Framework (PCF) ,The American Productivity & Quality Center (APQC) (2010)

All these frameworks utilize a set of performance metrics to measure the present state of performance of the supply chains. These sets of metrics are termed as Key Performance Indicators (KPI) of the supply chain.

Anything which we want to monitor or improve needs a measurement system. Supply chain performance is measured using KPI's, often referred as Key Success Indicators (KSI). KPI's are quantifiable measurements and helps an organization to define and measure progress towards achieving goals John Reh, (2011). Many organizations identify the KPI's which are internal to the organization and does not include the performance of the supply chain members. Performance measures of the supply chain which are traditional, concentrating on the individual performance are irrelevant to the maximization of the supply chain profit Simatupang et al. (2002). Supply chain performance is measured in an oversimplified manner focusing mainly on the cost reduction method. By this, Supply chain limits itself to local measures of performance, which does not work together in an integrated manner. There is a need for identifying the performance metrics which measure the overall supply chain performance rather than the performance of the individual members. Co-relating to this many foundries found measuring local metrics as their performance measures rather than concentrating on the entire stretch of the supply chain. Commonly used performance metrics in foundries are Liquid Metal Tonnage per Day, Good Castings Tonnage per Day, Internal Rejections %, Units per Ton of Good Castings, Customer End Rejections and Dispatch Tonnage per Day.

KPI must be quantifiable and should reflect the organizational goals. KPI determines the success of supply chains, it is better not to measure than measuring wrong KPI. This necessitates the urgency in formulating a methodology in identifying the appropriate supply chain performance (SCP) metrics Douglas et al. (2001). Lack of proper metrics for a SCP measurement will result in failure to meet consumer/end user expectations & there is no evidence that meaningful performance measures that span the supply chain actually exists. Measurement system helps in identifying the Metrics which are not performing to the desired levels , this is termed as "Constraint KPI".

### 7. Theory Of Constraints (TOC)

All organizations are systems consisting of resources, which are closely linked with the processes they perform. The vision, mission and goal of the organisation serve as the primary judge of success. Within this system, a “constraint” is defined as anything that limits the system to reach this performance level and acts as a resistance for the success.

From the principle of TOC, in order to identify the constraint in the system, we have to isolate each activity and find the performance levels. Each time performance levels are measured by isolating one process from the system. Activities performed by that particular process are shared by the other team members. Other team members are stretched to share the burden of the isolated process. This procedure is extended until all the processes are isolated once and performance levels are measured. Constraint process is the one where the system performance is maximum in its absence.

TOC recommends following 5 steps in order to improve the system performance

The Five-Focusing Steps:

- a. **IDENTIFY** the system’s constraint.
- b. Decide how to **EXPLOIT** the system’s constraint.
- c. **SUBORDINATE** everything else to the above decisions.
- d. **ELEVATE** the system’s constraint.
- e. Don’t allow **INERTIA** to become the system’s constraint. When a constraint is broken, go back to step one.

### 8. Weights Calculations

The weights of the attributes plays very significant role in the process of decision making, therefore weight determination and selection of method becomes very crucial in Multi Attribute Decision Making (MADM).

There are number of methods for weights calculation given in the literature which can be clubbed under three categories, Subjective, Objective and Integrated, Ying Ming Wang et al. (2010). Decision makers subjective preferences are used in subjective weights calculation, Direct Rating Method, AHP, Eigen Vector Method, LP are few to name. In Objective methods weights are determined by objective decision making matrix information, entropy method and standard deviation methods falls under this category. Integrated methods uses both the subjective and objective decision making matrix.

Entropy method was first found its application in thermodynamics and later introduced into information theory by Shannon during 1948, now it widely used in engineering, economics, finance etc., when the

difference of the value among the evaluating objects on the same indicator is high, while the entropy is small, it indicates that this indicator is more important and accordingly weight of this indicator is set as high. On the other hand if the difference small and entropy is higher, weight set will be smaller. That's the reason why the entropy method is called as an objective method of determining weights.

Entropy method of weights calculations follows three steps

1. Normalising of the survey ratings using equation

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^n x_{ij}}, \text{ where } i=1, \dots, 56 ; j \in \Omega_b$$

Where  $\Omega_b$  is the index set of all the KPI's

2. Calculating the entropy value using equation

$$E_j = -\left(\sum_{i=1}^n p_{ij} \ln p_{ij}\right) / \ln(n)$$

Where  $i=1, \dots, n$  (number of attributes)

$j=1, \dots, m$  (number of KPI's under each attribute)

3. Calculation of entropy weights using equation

$$w_j = (1 - E_j) / \sum_{k=1}^m (1 - E_k)$$

Weights calculated from these methods are used directly to analyse the results or used as pre-emptive weights in optimizing using mathematical models such as linear programming. Goal Programming is one of the optimization technique used widely which is explained in the next section.

## 9. Goal Programming (GP)

Goal Programming attempts to combine the logic of optimization in mathematical programming with the decision maker's desire to satisfy several goals. GP results are most indicative of most optimal results when compared to other methods of optimization.

Goal Programming is linear programming method, but what distinguishes GP from normal LP is

“LP identifies from the set of feasible solutions, the point that optimizes a single objective.....GP determines the point that best satisfies the set of goals in the decision problem , GP attempts to minimize the deviations from the goals”, Mike Strager, (2008).

Now a days GP is acknowledged as the most effective strategies used in MCDM, GP attempts to reach all the goals at the same time, which may affect each other negatively. When one goal reaches the targeted value, another one may move away from its own target, therefore objective function in GP models is usually minimizing the deficiencies from the aimed values. Some priorities can be put for the goals, so that the deficiencies that should be minimized have a sequence to be satisfied, this type of goal programming models are called preemptive goal programming models, Yeliz Ekinici, (2007)

This study is intended to help the Managers to identify the set of Key Performance Indicators(KPI’s) for supply chain performance measurement and to find out the constraint KPI from this set, so that Managers can focus more on this constraint KPI to improve the overall system performance. The intent of finding the constraint KPI is not for eliminating but for improving. In order to arrive at these decisions, Theory of Constraints approach supported with strong mathematical tool Goal Programming is used to find the optimal solution in each stage. Entropy method is utilized for converting the survey ratings of each KPI into weights for Goal Programming.

**10. Flow Diagram**

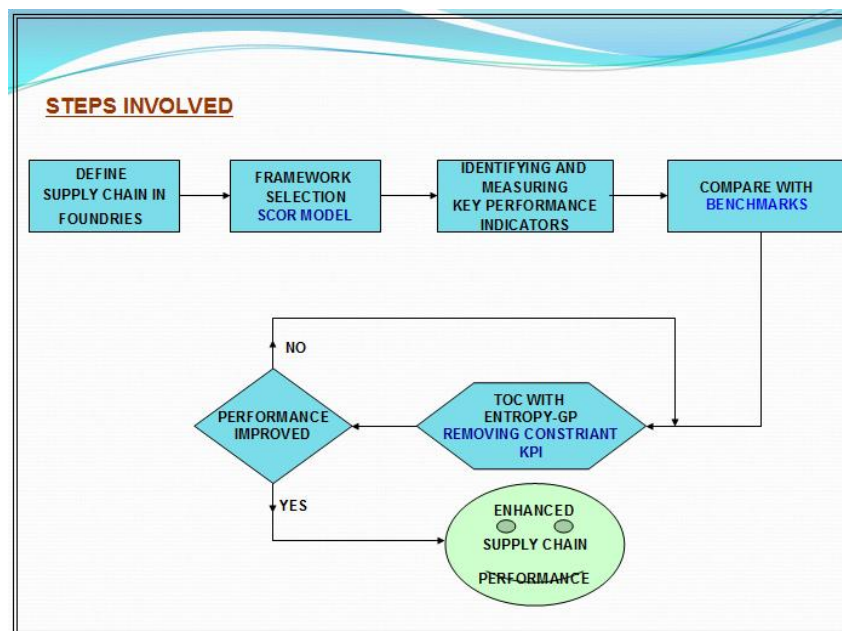


Figure 5: flow diagram for

Supply chain performance enhancement

All the above explained steps are combined in these research work to enhance the supply chain performance. Flow diagram is shown FIGURE 1.5, where first step defining the supply chain for the targeted sector / industry, followed by framework selection for performance measurement , from the selected framework measurement metrics are selected. As-is-State and benchmark levels are measured for the selected metrics set. By applying principles of TOC one KPI is removed at a time and performance levels are measured. Constraint KPI is one where the chain performance is maximum. Once the constraint KPI is identified, it has to be exploited and sub-ordinated. These steps are explained with the survey data of 56 foundries across India.

24 KPI's were identified for the performance measurement under 5 attributes of supply chain as given by SCOR model. TABLE 1 shows the performance levels of 56 foundries for 6 KPI's under reliability attribute and their corresponding benchmarks given by APQC

SL. NO	ATTRIBUTE	KPI	DIRECTI ON	UNIT	MEASURE D VALUES	BENC H MARK S
1	SUPPLY CHAIN RELIABILIT Y	PERFECT ORDER FULLFILLMENT	MAX	%	77.79	90
2		ORDERS DELIVERED IN FULL	MAX	%	82.54	80.5
3		ORDER FILL RATE	MAX	%	79.23	95
4		DELIVERY PERFORMANCE TO CUSTOMER COMMITT DATE	MAX	%	72.29	90
5		DELIVERED IN PERFECT CONDITION	MAX	%	98.23	99
6		DOCUMENT ACCURACY	MAX	%	98.95	99

Table 1: Performance levels of 6kpi's under reliability attribute

These performance levels are multiplied by entropy weights which are calculated using the ratings given by 56 foundries for these KPI's and shown in TABLE 2.

Criteria	WITH ALL KPI'S	
	Di	Wj
REL1	0.007630205	0.145
REL2	0.009694269	0.184
REL3	0.013291274	0.252
REL4	0.005812607	0.110
REL5	0.009102053	0.173
REL6	0.007186729	0.136
	<b>0.0527171</b>	<b>1</b>

Table 2: Entropy weights for reliability attribute kpi's

When these entropy weights are multiplied with the performance levels , overall reliability attribute performance is measured , which is shown in TABLE 3

SL. NO	ATTRIBUTE	KPI	UNIT	% BENCH MARK	MEASURED VALUES		% PERFORM MANCE
					KPI	ENTROPY WEIGHT	
1	SUPPLY CHAIN RELIABILITY	PERFECT ORDER FULLFILLMENT	%	90	77.79	0.145	84.84
2		ORDERS DELIVERED IN FULL	%	80.5	82.58	0.184	
3		ORDER FILL RATE	%	95	79.23	0.252	
4		DELIVERY PERFORMANCE TO CUSTOMER COMMITTED DATE	%	90	72.29	0.110	
5		DELIVERED IN PERFECT CONDITION	%	99	98.23	0.173	
6		DOCUMENT ACCURACY	%	99	98.95	0.136	

Table 3: reliability performance

Thus calculated % performance for reliability attribute shows 84.84.

Next step is applying 1<sup>st</sup> step of TOC principles. each KPI is removed at a time and corresponding Entropy weights are calculated and % performance is measured. These performance levels are calculated in the absence of one KPI at a time using goal programming, which provides near optimal solution. While using goal programming lower limit will be present measured values and upper limit will be the parity values of benchmarks. Entropy weights without KPI- REL1 are calculated as shown in TABLE 4.

		W/O REL1	
Criteria	Entropy	Di	Wj
REL1	0.992369795	0	0.000
REL2	0.990305731	0.009694269	0.215
REL3	0.986708726	0.013291274	0.295
REL4	0.994187393	0.005812607	0.129
REL5	0.990897947	0.009102053	0.202
REL6	0.992813271	0.007186729	0.159
		<b>0.0450869</b>	<b>1</b>

Table 4: Entropy weights without rel1

These weights are applied in GP equation

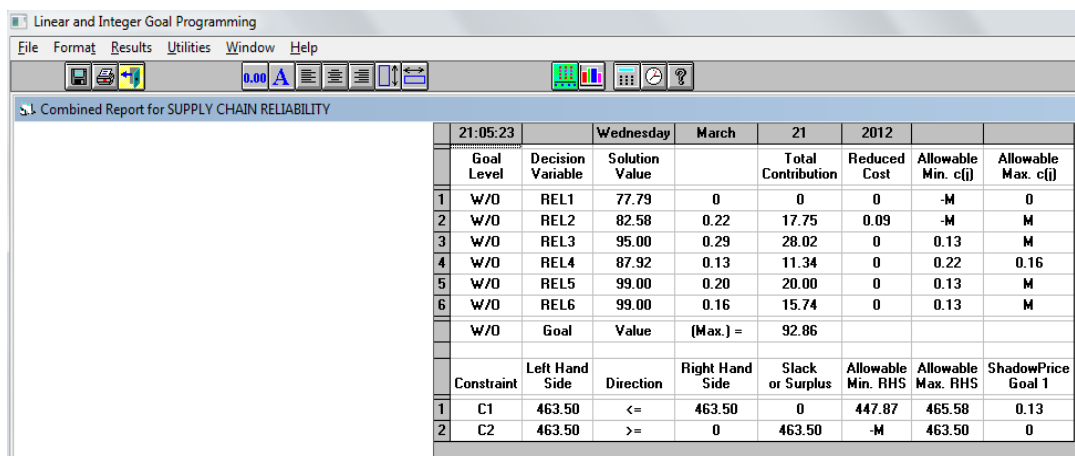
$$MAXG1 = \sum_{i=1}^6 XiRELi - E1i + U1i$$

$$MAX G1=0.215REL2+0.295REL3+0.129REL4+0.202REL5+0.159REL6$$

$$U12+U13+U14+U15+U16$$

Over Achievements E are removed because over achievement is always acceptable in efficiency.

When these values are entered in GP software WINQSB, it calculates the most optimal solution which shown in FIGURE 6.



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Goal Level	Decision Variable	Solution Value		Total Contribution	Reduced Cost	Allowable Min. c(j)	Allowable Max. c(j)	
1	W/O REL1	77.79	0	0	0	-M	0	
2	W/O REL2	82.58	0.22	17.75	0.09	-M	M	
3	W/O REL3	95.00	0.29	28.02	0	0.13	M	
4	W/O REL4	87.92	0.13	11.34	0	0.22	0.16	
5	W/O REL5	99.00	0.20	20.00	0	0.13	M	
6	W/O REL6	99.00	0.16	15.74	0	0.13	M	
	W/O Goal	Value	(Max.) =	92.86				
Constraint	Left Hand Side	Direction	Right Hand Side	Slack or Surplus	Allowable Min. RHS	Allowable Max. RHS	ShadowPrice	Goal 1
1	C1	463.50	<=	463.50	0	447.87	465.58	0.13
2	C2	463.50	>=	0	463.50	-M	463.50	0

Figure 6: GP results without rel1



Similar calculations are done by removing each KPI at a time and results are shown below in TABLE 5.

ATTRIBUTE	GOAL PROGRAM RESULTS W/O KPI						CONSTRAINT KPI
	1	2	3	4	5	6	
SUPPLY CHAIN RELIABILITY	92.86	94.61	91.59	92.66	91.09	91.50	<b>KPI 2 ORDERS DELIVERED IN FULL</b>

Table 5: Constraint identification in reliability attribute kpi's

From the TABLE 5 , it is evolved that in the absence of second KPI, REL2- Orders Delivered in Full, the supply chain reliability attribute performance is maximum – 94.96%. Supply Chain Reliability attribute performance was 84.84% when all the KPI's were present and it is improved by 9.77% in the absence of second KPI. This KPI is the constraint in the system which is holding the system from excelling. More focus is to be given to improve REL2.

Similar calculations are done for all the other 4 attributes and results are tabulated in TABLE 6

ATTRIBUTE	CONSTRAINT KPI	PERFORMANCE (%)		IMPROVEMENT (%)
		BEFORE	AFTER	
RELIABILITY	ORDERS DELIVERED IN FULL	84.84	94.61	9.77
RESPONSIVENESS	ORDER FULFILLMENT CYCLE TIME	58.56	64.07	5.51
FLEXIBILITY	UPSIDE SUPPLY CHAIN FLEXIBILITY	62.97	71.53	8.56
COSTS	COST TO RETURN FROM CUSTOMERS	53.59	57.45	3.86
ASSET MANAGEMENT	RETURN OF SUPPLY CHAIN FIXED ASSETS	60.48	72.00	11.52
<b>OVERALL IMPROVEMENT</b>		<b>63.70</b>	<b>70.70</b>	<b>7%</b>

Table 6: Summary of TOC analysis

## *11. Conclusion*

Supply Chain Performance in presence of constraint KPI's and Supply Chain Performance after eliminating the constraint KPI's are shown in TABLE 7.41. The entire supply chain performance of the system is enhanced from 63.70% to 70.70% after applying TOC principles, which means an enhancement in system performance by 7%.

This approach of finding the constraint in the measurement system was first time applied using TOC-Entropy-GP combination. In this study Managerial Decision making is supported with strong essence of mathematical tools. This makes the analysis more practical than more descriptive. This study helps managers starting from identification of KPI's and arriving at constraint KPI. Managers can focus in improving this constraint KPI, so that overall system performance of the supply chain can be enhanced. This study covers all the members in the supply chain starting from supplier to customer.

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