I J C T A, 9(11) 2016, pp. 5467-5486

TRADE-OFF BETWEEN TIME, COST, QUALITY, SAFETY, ENVIRONMENT – STAR OPTIMIZATION MODEL

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Abstract: The quality, cost, time, safety and environment are the vital parameters in a manufacturing industry. It is a challenging task for the leaders to optimize the above contradictive objectives. From the literature review, it is evident that most researchers talked about quality, cost, time and trade-offs between quality-cost, quality-cost-time. But there is no model that included both safety and environment along with the traditional parameters time, cost and quality. It is necessary to have an efficient tool that could optimize all the above said five parameters. This paper proposes a "Star Optimization Model" (SOM) based on work and resource breakdown structure considering all five parameters in a production project. The model developed is generic and could be applied to any manufacturing industry.

Key Words: Trade-off, Time, Cost, Quality, Safety, Environment, Green Manufacturing, Star Optimization Model, Manufacturing, Work and Resource Breakdown Structure.

1. INTRODUCTION

Manufacturing Leadership strives for excellence in every project, every day through continuous improvement and innovation. The primary objective of any organization involved in business is "profit". There may be other objectives that determine what the organization is competing for. To maximize one objective or to achieve satisfactory level of the objective, the leadership decides to give up something.

1.1 Importance of Green Manufacturing

Green Manufacturing process slows down the diminution of natural wealth and the amount of litter that go into landfills. It enables economic growth. Research work in the field of green design includes energy and environment, waste reduction, sustainable infrastructure, environmental management, design of cleaner products, pollution prevention etc.,

The global survey conducted by the World Bank Group on the biggest obstacles faced by private manufacturing companies indicated that electricity is one of the top 10 business environment constraints. With plenty of resources the manufacturing and research and development should go full stream into the renewable energy. Adopting it in full swing would change the business environment constraints.

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There is a misnomer that green manufacturing increases the cost of production. The following case studies indicate that applying green manufacturing principles in their production process resulted in cost savings. Ford Australia Ltd., implemented eco-friendly cleaning process in their automotive industry. The process change involved high pressure water jet cleaning instead of hot caustic cleaning method. Bharath Heavy Electricals Limited (BHEL) implemented various measures for water conservation, energy conservation and control of air pollution.

Implementing green manufacturing technology and processes has economic, social and environmental benefits that includes energy security, employment impact, safety, job satisfaction and better working conditions, competitiveness and efficiency in production, health impact through reduced pollution, water conservation, ecological impact through less fossil, fuel extraction etc.,

2.2 Importance of Safety

Manufacturing organization can never take safety as granted. All employees should ensure

(i) Workplace Safety

(ii) Monitor the employees to make sure they follow safety in manufacturing

(iii) Test all finished goods for compliance with product safety requirements

(iv) Provide safety certification

In April 2014, Industry week - A Magazine that helps to advance the business of manufacturing reported that "More than 90 percent of the business managers surveyed said managing health and safety had become an integrated part of their corporate culture. A company's culture and ethics, not money ultimately determines safety performance."

The announcement of Toyota recalling 3.8 million cars in October 2009 was due to the safety issue. It was cited that the poorly placed floor mats under the driver seat could lead to wild acceleration resulting in accidents.

Machinery production is facing lots of occupational illness and injuries. Machinery production workers are at higher risks of death or disability injury than most other workers. The philosophy behind safety and environment management systems are accepted by most of the workers.

2. LITERATURE REVIEW

The work carried out by various researchers and organizations relating to time, cost, quality, safety, environment, trade-off models, surveys with respect to production, that are reported in the literature are surveyed and presented.

J. Stacy Adams [1] in his work stated that increase in productivity declines the quality of work produced. Genichi Taguchi [2, 3, 4, 5, 6] developed a statistical technique to enhance the quality of manufactured products. The work of J. V. Saraph Et Al., [7] implies that the administration team contribute to manufacturing quality and consume a considerable cost, even though they hardly impact on production. In 1990, Kasra Ferdows and Arnoud De Meyer [8] suggested a model and pointed out that management should focus on quality first, followed by dependability, flexibility & finally cost efficiency. Their new theory revealed that in order to have lasting improvement in manufacturing we should evade trading off one capability to another.

A. J. G. Babu and N. Suresh [9] proposed a framework using linear programming model to study cost, time and quality trade-off problem. Selden [10] applied Taguchi Method to advertising and marketing. H. R. Thomas and K. A. Raynar [11] revealed that overtime decrease the productivity and increases the cost rate per hour.

James V. Camahan and Deborah L. Thurston [12] designed a trade-off model that integrates environmental factors with product and process design in a manufacturing setup. Further Deborah L. Thurston Et. Al., [13] gave a decision model to trade-off between quality, cost and environmental impact. In this study, the willingness of customers to pay for eco-friendly products is assessed.

In 2001, Huang [14] introduced a model to calculate the optimum mean and standard deviation taking both quality and cost into account. Vincent K. Omachonu Et. Al., [15] revealed that there exists a strong correlation between the cost of appraisal plus the cost of prevention and quality of input for machine and material. Richard H. Barden [16] stated that companies should not aim at minimizing the cost at the expense of quality, safety & environment.

Carlos W. Moreno [17] in his white paper talks about 3 drivers - market demand, economics and safety. These drivers have impact on profit and loss statement of production unit. Emre Kazancioglu and Kazuhiro Saitou [18] presented an optimized method for multi period production capacity planning that traded-off production cost and quality.

Rao Et. Al., [19] applied Taguchi model to Biotechnology. Chung - Ho Chen [20] modified the Huang's Cost Model using process capability index value to determine the optimum mean and standard deviation for the process. J. L. Rosa Et. Al., [21] applied Taguchi model to engineering. A new model to trade-off time, cost and quality of a project is proposed by Reza Ghodsi Et. Al., [22]. This paper addresses the research gap that an activity with best quality can be carried out in least possible duration.

Hadi Mokhtari Et. Al., [23] developed a technique for stochastic time-cost trade-off problem. Monte Carlo Simulation and Cutting Plane Method were used to develop this model. The results showed that the project completion probability improved. Joseph Berk [24] presented cost reduction techniques for industrial and manufacturing organizations. He presented that cost reduction can be applied to labour, design, process, material and overhead.

Moneer Helu Et. Al., [25] in his study evaluated the tradeoffs between environmental, performance and the cost involved in green manufacturing technologies. The results indicated that the method may not give good results for smaller machines and may give significant benefit to larger machines.

Hadi Zaklouta [26] stated that improvement in manufacturing process and inspection strategy should go hand in hand. Further Hadi along with Roth R. [27] proposed a cost of quality framework and applied it to welded automotive assemblies. He proved that the welding process improvement and the choice of inspection strategy are to be made together.

Stefanie Lynn Robinson [28] in his dissertation work proposed a method to assess and quantify the usage of resource along with environmental and financial impacts linked with distinct manufacturing practices.

Vasilliki Kostami and Sampath Rajagopalan [29] considered Speed Quality Trade-off in a Dynamic Model. Roya H. Ahari and S. T. A. Naiki [30] proposed a fuzzy optimization model to simultaneously handle cost, time and quality. In this work, quality is represented as a function of cost and time. The model is derived using Fuzzy rule Base.

Vikash Agarwal Et. Al., [31] studied trade-off problems considering time and cost between 1990 to 2012. It is reported that between 1990 to 2002 major work was done in the construction based projects. Starting from 2003 major work has been done in areas such as construction, software, industrial, management and there is great scope in the field of industrial, management and software field.

Wisconsin Survey results [32] on Manufacturing industries revealed that Sales, Quality, Production/Output, Labour Cost, Delivery Performance, Total Cost, Material Cost, Safety, Accounting Related, Reject/Scrap, Equipment Utilization, Downtime, Total Cycle Time are the primary metrics to measure Key Performance Indicators (KPIs) in manufacturing industries. Sales being the most important KPI Metric is the result of safety, trade-off between cost, quality and time. Labour cost, total cost, material cost and equipment utilization can be grouped under one parameter Cost. Delivery performance and accounting related fall under quality parameter. Downtime, Total Cycle Time, Production/Output are grouped under time. Reject/Scrap fall under Environment parameter. Based on the above study, we deduced the following five parameters as Key Performance Indicators in a manufacturing industry.

Wenfa Hu and Xinhua He [33] proposed time, cost, quality optimization model using work breakdown structure technique that helps decision makers to optimize multiple objectives.

A white paper published by Rockwell Automation in May 2014 [34] addressed the routine challenges faced by automobile manufacturing plants. Workforce, process, equipment and safety were identified as a key areas to improve production and to reduce downtime.

3. RESEARCH GAP

Based on the above review of literature, the various parameters considered by different authors are summarized in Table 1.

Table 1: Summary of Literature Review

REF NO.	YEAR	AUTHOR NAME	PARAMETERS				
			TIME	COST	QUALITY	SAFETY	GREEN MANUFACTURING
[1]	1963	J. Stacy Adams	✘	✘	✓	✘	✘
[2]	1983	Genichi Taguchi	✘	✘	✓	✘	✘
[3]	1986	Genichi Taguchi	✘	✘	✓	✘	✘
[4]	1987	Genichi Taguchi	✘	✘	✓	✘	✘
[5]	1989	Genichi Taguchi	✘	✘	✓	✘	✘
[6]	1993	Genichi Taguchi	✘	✘	✓	✘	✘
[7]	1989	J. V. Saraph Et. Al.,	✘	✓	✓	✘	✘
[8]	1990	Kasra Ferdows Arnoud De Meyer	✘	✓	✓	✘	✘
[9]	1996	A. J. G. Babu N. Suresh	✓	✓	✓	✘	✘
[10]	1997	Paul H. Selden	✘	✘	✓	✘	✘
[11]	1997	H. R. Thomas K. A. Raynar	✓	✓	✘	✘	✘
[12]	1998	James V. Camahan Deborah L. Thurston	✘	✘	✘	✘	✓

Table 1 Contd…

[13]	2000	Deborah L. Thurston Et. Al.,	✗	✓	✓	✗	✓
[14]	2001	Ying-Fang Huang	✗	✓	✓	✗	✗
[15]	2004	Vincent K. Omachonu Et. Al.,	✗	✓	✓	✗	✗
[16]	2006	Richard H. Barden	✗	✓	✓	✓	✓
[17]	2006	Carlos W. Moreno	✗	✓	✓	✓	✗
[18]	2006	EmreKazancioglu	✗	✓	✓	✗	✗
		Kazuhiro Saitou					
[19]	2008	Rao RS. Et Al.,	✗	✗	✓	✗	✗
[20]	2009	Chung - Ho Chen	✗	✓	✓	✗	✗
[21]	2009	J. L. Rosa Et Al.,	✗	✗	✓	✗	✗
[22]	2009	Reza Ghodsi Et Al.,	✓	✓	✓	✗	✗
[23]	2010	HadiMokhtari Et. Al.,	✓	✓	✗	✗	✗
[24]	2010	Joseph Berk	✗	✓	✗	✗	✗
[25]	2011	MoneerHelu Et. Al.,	✗	✓	✗	✗	✓
[27]	2012	HadiZaklouta	✗	✓	✓	✗	✗
		Roth R.					
[28]	2013	Stefanie Lynn Robinson	✓	✓	✓	✗	✓
[29]	2013	VasillikiKostami	✓	✗	✓	✗	✗
		Sampath Rajagopalan					
[30]	2013	Roya H. Ahari	✓	✓	✓	✗	✗
		S. T. A. Naiki					
[31]	2013	VikashAgarwal Et. Al.,	✓	✓	✗	✗	✗
[33]	2014	Wenfa Hu	✓	✓	✓	✗	✗
		Xinhua He					
[34]	2014	Rockwell Automation	✓	✓	✓	✓	✗

Based on the above summary of literature it is evident that none of the trade-off model considered all five parameters - time, cost, quality, safety and environment. This thesis will address the above research gap.

3.1 Star Optimization Model

A simple five pointed star comprises of five lines, the center representing a pentagon. It is drawn in a continuous loop i.e unicursal. In a manufacturing process, the five important parameters time, cost, quality, safety and environment each representing one point contributes to the success. Hence the model proposed in this paper to tradeoff the above said parameters is called “Star Optimization Model” (SOM).

The quality, cost, time, safety and environment are the vital parameters in a manufacturing industry. It is a challenging task for the leaders to optimize the above contradictive objectives. Hence it is necessary to have an efficient tool that could optimize the above said parameters.

The parameter decided are competing. The manufacturing industries can compete on cost by producing high volume, offer limited range of products, offer little customization, develop automation systems to decrease unit cost, use less skilled labour.

Industries that focus on quality develop high performance design, maintains product and service consistency which means the product developed has superior, highly durable, meets exact design specification, error free product release and excellent service.

Industries that are competing on time focus on fast delivery, on time delivery, use parallel processes to reduce product development time. For example, Blue Dart, Dominos competes on speed.

Industries that value human life and health, take action to keep up the safety of work places, their products and services. They do not compromise on safety in order to meet the goals of quality, cost and time.

Industries that focus on sustainable development follow green manufacturing technologies. Sustainable Development is a long term objective that meets the requirements of present generation and develop systems that do not affect the requirements of future generations.

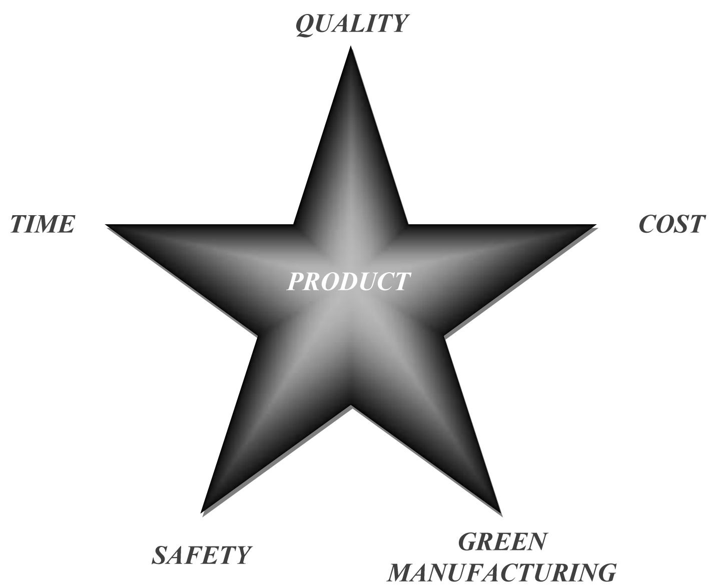

Figure 1: Star Optimization Model

4. WORK & RESOURCE BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) is a process to divide a project to number of activities (Work Breakdown) and for each activity resources are identified. The Work Breakdown Structure (WBS) is drawn by identifying various activities in a particular function.

Let us consider the case of a machinery production unit. A machinery production project is divided into various activities A1, A2...An, where 'n' represents the number of activities. Each activity requires various resources. In this example, the resources are production labour, materials, tools and equipments, administration and consumables (Resource Breakdown).Time, Cost, Quality and Safety are the vital parameters for all the resources. It is important to pay attention to the safety of labourers. Safety aspect in materials, tools and equipments and consumables are to be ensured. The materials and consumables used in the process are selected in such a way that the system is eco - friendly and aid in the sustainable development.

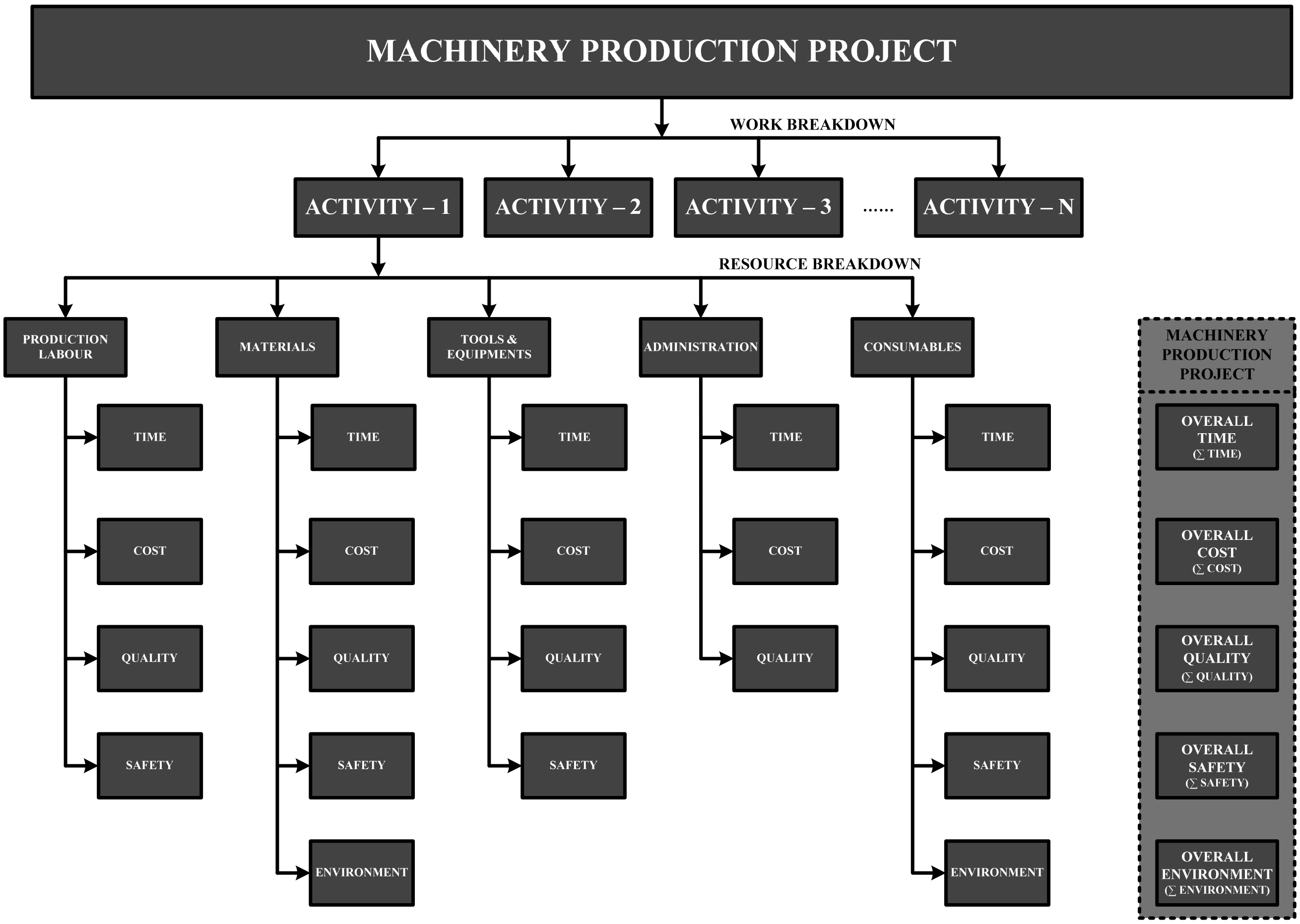

Figure 2: Work & Resource Breakdown Structure

Deriving Relationship between various parameters defined under each activity

Considering activity 1 as per the above work and resource breakdown structure in figure 2, the following relationships are derived.

Relationship between Productivity of Labour and Quality of Labour

There is a linear relationship between productivity of labour and the quality of labour.

$$PRL = PRL^{MAX} - QLF\,(QL - QL^{MIN})$$

$$QLF = \frac{PRL^{MAX} - PRL^{MIN}}{QL^{MAX} - QL^{MIN}}$$

Where

PRL = Productivity of labour;

PRL^{MAX} = Maximum Labour Productivity;

PRL^{MIN} = Minimum Labour Productivity;

QLF = Labour Quality Factor;

QL = Labour Quality;

QL^{MIN} = Minimum Labour Quality;

QL^{MAX} = Maximum Labour Quality.

Relationship between Cost of Labour and the Time taken to complete Activity 1

$$Time = \frac{QTA}{APR * OTF}$$

Where

QTA = Quantity of a production;

APR = Actual Productivity;

OTF = Overtime Factor.

Table 2
Overtime Factor

No. of Hours	*Overtime Factor*
8 Hours	1.0
10 Hours	1.25
12 Hours	1.5
16 Hours	2.0

Normal working period is 8 hours per day; if overtime work is planned the working period may extend up to 16 hours. OTF = 1, if no overtime work is planned; OTF = 1.25 or 1.5 or 2, depending upon the overtime work assigned as per the above table 2.

Relationship between Safety of Labour and Cost of Labour

There is a linear relationship between safety of labour and cost of labour.

$$CL = CL^{MIN} - SLF\ (SL - SL^{MIN})$$

$$SLF = \frac{CL^{MAX} - CL^{MIN}}{SL^{MAX} - SL^{MIN}}$$

Where

CL = Cost of Labour;

CLMAX = Maximum Cost of Labour;

CLMIN = Minimum Cost of Labour;

SLF = Labour of Safety Factor;

SL = Labour of Safety;

SLMIN = Minimum Safety of Labour.

SLMAX = Maximum Safety of Labour.

Relationship between Cost of Labour and Quality of Labour

$$CL = CL^{MIN} - QLF\ (QL - QL^{MIN})$$

Where

CL = Cost of Labour;

CLMIN = Minimum Cost of Labour;

QLF = Quality Labour Factor;

QL = Quality Labour;

QLMIN = Minimum Quality of Labour.

Relationship between Safety of Labour and Quality of Labour

From the above two relationships

$$CL^{MIN} - SLF\ (SL - SL^{MIN}) = CL^{MIN} - QLF\ (QL - QL^{MIN})$$

$$SLF\ (SL - SL^{MIN}) = QLF\ (QL - QL^{MIN})$$

Where

SLF = Safety Labour Factor;

SL = Safety Labour;

SLMIN = Minimum Labour Safety;

QLF = Quality Labour Factor;

QL = Quality Labour;

QLMIN = Minimum Quality of Labour.

Relationship between Cost of Material and Quality of Material

$$CM = CM^{MIN} - QMF\ (QM - QM^{MIN})$$

Where

CM = Cost of Material;

CMMIN = Minimum Cost of Material;

QMF = Quality of Material Factor;

QM = Quality of Material;

QMMIN = Minimum Material Quality.

Relationship between Safety of Material and Cost of Material

$$CM = CM^{MIN} - SMF\ (SM - SM^{MIN})$$

Where

CM = Cost of Material;

CMMIN = Minimum Cost of Material;

SMF = Material Safety Factor;

SM = Safety of Material;

SMMIN = Minimum Material Safety.

Relationship between Safety of Material and Quality of Material

From the above two relationships

$$CM^{MIN} - QMF\,(QM - QM^{MIN}) = CM^{MIN} - SMF\,(SM - SM^{MIN})$$

$$QMF\,(QM - QM^{MIN}) = SMF\,(SM - SM^{MIN})$$

Where

QMF = Quality Material Factor;

QM = Quality of Material;

QMMIN = Minimum Quality of Material;

SMF = Material Safety Factor;

SM = Safety of Material;

SMMIN = Minimum Material Safety.

Influence of Equipment in Productivity

$$EPA = PRL * MFL$$

$$MFL = MFL^{MIN} + DQF\,(QE - QE^{MIN})$$

$$DQF = \frac{MFL^{MAX} - MFL^{MIN}}{QE^{MAX} - QE^{MIN}}$$

Where

EPA = Equipment Productivity of an Activity;

PRL = Production Labour;

MFL = Modified Factor to Labour;

MFLMIN = Minimum Labour Factor;

QE = Equipment Quality;

QEMIN = Minimum Quality of Equipment;

MFLMAX = Maximum Labour Factor;

QEMAX = Maximum Quality of Equipment.

Relationship between Cost of Equipment and Quality of Equipment

$$CE = CE^{MIN} + QEF\,(QE - QE^{MIN})$$

$$QEF = \frac{CE^{MAX} - CE^{MIN}}{QE^{MAX} - QE^{MIN}}$$

Where

CE = Cost of Equipment;

CEMIN = Minimum Cost of Equipment;

QEF = Quality of Equipment Factor;

QE = Equipment Quality;

QEMIN = Minimum Equipment Quality;

CEMAX = Maximum Cost of Equipment;

CEMIN = Minimum Cost of Equipment.

Relationship between Productivity of Equipment and Safety of Equipment

$$PRE = PRE^{MAX} - SEF\,(SE - SE^{MIN})$$

Where

PRE = Equipment Productivity;

PREMAX = Maximum Equipment Productivity;

SEF = Equipment Safety Factor;

SE = Equipment Safety;

SEMIN = Minimum Equipment Safety.

Relationship between Administration Cost and Administration Quality

$$CA = CA^{MIN} - QAF\,(QA - QA^{MIN})$$

Where

CA = Administration Cost;

CAMIN = Minimum Administration Cost;

QAF = Administration Quality Factor;

QA = Administration Quality;

QAMIN = Minimum Administration Quality.

Relationship between Cost of Consumables and Quality of Consumables

$$CC = CC^{MIN} - QCF\,(QC - QC^{MIN})$$

Where

CC = Consumables Cost;

CCMIN = Minimum Consumables Cost;

QCF = Consumables Quality Factor;

QC = Consumables Quality;

QCMIN = Minimum Consumables Quality.

Relationship between Cost of Consumables and Safety of Consumables

$$CC = CC^{MIN} - SCF\,(SC - SC^{MIN})$$

Where

CC = Cost of Consumables;
CCMIN = Minimum Cost of Consumables;
CLMIN = Minimum Cost of Labour;
SCF = Safety Factorin Consumables;
SC = Safety in Consumables;
SCMIN = Minimum Safety of Consumables.

Relationship between Quality of Consumables and Safety of Consumables

From the above two relationships

$$CC^{MIN} - QCF\,(QC - QC^{MIN}) = CC^{MIN} - SCF\,(SC - SC^{MIN})$$
$$QCF\,(QC - QC^{MIN}) = SCF\,(SC - SC^{MIN})$$

Where

CCMIN = Minimum Cost of Consumables;
QCF = Consumables Quality Factor;
QC = Consumables Quality;
QCMIN = Minimum Consumables Quality.
CCMIN = Minimum Cost of Consumables;
SCF = Safety Factor in Consumables;
SC = Safety in Consumables;
SCMIN = Minimum Safety of Consumables.

Further, overall quality, cost, time, safety and environment for activity 1 are calculated as follows:

Overall Quality

Overall Quality (OQ_1) = LQ + MQ + EQ + AQ

Where

OQ = Overall Quality;
LQ = Labour Quality;
MQ = Material Quality;
EQ = Equipment Quality;
AQ = Administration Quality.

Overall Cost

Overall Cost (OC_1) = LC + MC + EC + AC + CC

Where

LC = Labour Cost;
MC = Material Cost;

EC = Equipment Cost;

AC = Administration Cost.

Overall Time

$$\text{Overall Time } (OTE_1) = \text{Duration of the activity}$$

Overall Safety

$$\text{Overall Safety } (OS_1) = MS + ES$$

Where

OS = Overall Safety;

MS = Material Safety;

ES = Equipment Safety

Overall Environment

$$\text{Overall Environment}(OG_1) = ME + CE$$

Where

ME = Material Environment

CE = Consumables Environment

Similarly the relationships can be derived for all the activities. Based on the above five equations, overall quality, cost, time, safety and environment of the project are calculated as follows:

Overall Quality of the Project Q = OQ1 + OQ2 + OQ3 + ……. + OQN

Overall Cost of the Project C = OC1 + OC2 + OC3 + ……. + OCN

Overall Time of the Project TE = OTE1 + OTE2 + OTE3 + ……. + OTEN

Overall Safety of the Project S = OS1 + OS2 + OS3 + ……. + OSN

Overall Environment of the Project G = OG1 + OG2 + OG3 + ……. + OGN

5. CASE STUDY OF A MANUFACTURING INDUSTRY

In a manufacturing unit, the activities are identified and the sequences of activities are shown below in figure 3.

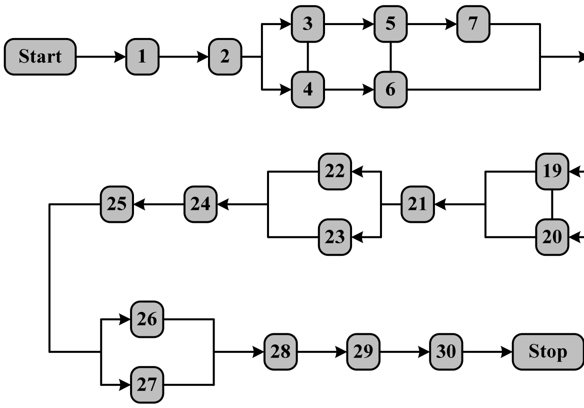

Figure 3: Sequence of Activities

(1) Mechanical Design; (2) Electrical Design; (3)Mechanical Planning; (4) Electrical Planning; (5) Mechanical Purchase (Local and Import); (6) Electrical Purchase (Local and Import); (7) Subcontract; (8) Fabrication; (9) Quality Control and Assurance; (10) Material Co-ordination; (11) Material Transfer; (12) Material Issue; (13) Material Assembling; (14) Control Panel Wiring; (15) Machine (Field) Wiring; (16) Programming; (17) Electrical Testing; (18) Mechanical Testing; (19) Co-ordination with Customer (Electrical); (20) Co-ordination with Customer (Mechanical); (21) Inspection; (22) Electrical Packaging; (23) Mechanical Packaging; (24) Documentation (User Manual, Electrical and Mechanical Drawings); (25) Machine Dispatch; (26) Installation; (27) Commissioning; (28) Customer Report; (29) Modification at Customer Site; (30) Customer Feedback and Corrective Actions.

The input parameters were assigned as Cost, time, quality, safety and green manufacturing. The outputs are obtained on the basis of planned rule base. The rule base is given below in table 3.

VL=Very Low = 0.6; L = Low = 0.7; M = Medium = 0.8;

H = High = 0.9; VH = Very High = 1

Safety = Yes = 0.05; Safety = No = 0; Green = Yes = 0.05; Green = No = 0

Table 3
Rule Table

Rule Base					*Corresponding values*				
Cost	Time	Safety	*Green*	*Quality*	*Cost*	*Time*	*Safety*	*Green*	*Quality*
VL	VL	YES	YES	L	0.6	0.6	0.05	0.05	1.3
VL	L	YES	YES	L	0.6	0.7	0.05	0.05	1.4
VL	M	YES	YES	M	0.6	0.8	0.05	0.05	1.5
VL	H	YES	YES	M	0.6	0.9	0.05	0.05	1.6
VL	VH	YES	YES	M	0.6	1	0.05	0.05	1.7
L	VL	YES	YES	L	0.7	0.6	0.05	0.05	1.4
L	L	YES	YES	M	0.7	0.7	0.05	0.05	1.5
L	M	YES	YES	M	0.7	0.8	0.05	0.05	1.6
L	H	YES	YES	M	0.7	0.9	0.05	0.05	1.7
L	VH	YES	YES	M	0.7	1	0.05	0.05	1.8
M	VL	YES	YES	M	0.8	0.6	0.05	0.05	1.5
M	L	YES	YES	M	0.8	0.7	0.05	0.05	1.6
M	M	YES	YES	M	0.8	0.8	0.05	0.05	1.7
M	H	YES	YES	M	0.8	0.9	0.05	0.05	1.8
M	VH	YES	YES	H	0.8	1	0.05	0.05	1.9
H	VL	YES	YES	M	0.9	0.6	0.05	0.05	1.6
H	L	YES	YES	M	0.9	0.7	0.05	0.05	1.7
H	M	YES	YES	M	0.9	0.8	0.05	0.05	1.8
H	H	YES	YES	H	0.9	0.9	0.05	0.05	1.9
H	VH	YES	YES	H	0.9	1	0.05	0.05	2
VH	VL	YES	YES	M	1	0.6	0.05	0.05	1.7
VH	L	YES	YES	M	1	0.7	0.05	0.05	1.8
VH	M	YES	YES	H	1	0.8	0.05	0.05	1.9

Table 3 contd…

VH	H	YES	YES	H	1	0.9	0.05	0.05	2
VH	VH	YES	YES	VH	1	1	0.05	0.05	2.1
VL	VL	YES	NO	VL	0.6	0.6	0.05	0	1.25
VL	L	YES	NO	L	0.6	0.7	0.05	0	1.35
VL	M	YES	NO	L	0.6	0.8	0.05	0	1.45
VL	H	YES	NO	M	0.6	0.9	0.05	0	1.55
VL	VH	YES	NO	M	0.6	1	0.05	0	1.65
L	VL	YES	NO	L	0.7	0.6	0.05	0	1.35
L	L	YES	NO	L	0.7	0.7	0.05	0	1.45
L	M	YES	NO	M	0.7	0.8	0.05	0	1.55
L	H	YES	NO	M	0.7	0.9	0.05	0	1.65
L	VH	YES	NO	M	0.7	1	0.05	0	1.75
M	VL	YES	NO	L	0.8	0.6	0.05	0	1.45
M	L	YES	NO	M	0.8	0.7	0.05	0	1.55
M	M	YES	NO	M	0.8	0.8	0.05	0	1.65
M	H	YES	NO	M	0.8	0.9	0.05	0	1.75
M	VH	YES	NO	H	0.8	1	0.05	0	1.85
H	VL	YES	NO	M	0.9	0.6	0.05	0	1.55
H	L	YES	NO	M	0.9	0.7	0.05	0	1.65
H	M	YES	NO	M	0.9	0.8	0.05	0	1.75
H	H	YES	NO	H	0.9	0.9	0.05	0	1.85
H	VH	YES	NO	H	0.9	1	0.05	0	1.95
VH	VL	YES	NO	M	1	0.6	0.05	0	1.65
VH	L	YES	NO	M	1	0.7	0.05	0	1.75
VH	M	YES	NO	H	1	0.8	0.05	0	1.85
VH	H	YES	NO	H	1	0.9	0.05	0	1.95
VH	VH	YES	NO	VH	1	1	0.05	0	2.05
VL	VL	NO	YES	VL	0.6	0.6	0	0.05	1.25
VL	L	NO	YES	L	0.6	0.7	0	0.05	1.35
VL	M	NO	YES	L	0.6	0.8	0	0.05	1.45
VL	H	NO	YES	M	0.6	0.9	0	0.05	1.55
VL	VH	NO	YES	M	0.6	1	0	0.05	1.65
L	VL	NO	YES	L	0.7	0.6	0	0.05	1.35
L	L	NO	YES	L	0.7	0.7	0	0.05	1.45
L	M	NO	YES	M	0.7	0.8	0	0.05	1.55
L	H	NO	YES	M	0.7	0.9	0	0.05	1.65
L	VH	NO	YES	M	0.7	1	0	0.05	1.75
M	VL	NO	YES	L	0.8	0.6	0	0.05	1.45
M	L	NO	YES	M	0.8	0.7	0	0.05	1.55
M	M	NO	YES	M	0.8	0.8	0	0.05	1.65
M	H	NO	YES	M	0.8	0.9	0	0.05	1.75

Table 3 contd…

M	VH	NO	YES	H	0.8	1	0	0.05	1.85
H	VL	NO	YES	M	0.9	0.6	0	0.05	1.55
H	L	NO	YES	M	0.9	0.7	0	0.05	1.65
H	M	NO	YES	M	0.9	0.8	0	0.05	1.75
H	H	NO	YES	H	0.9	0.9	0	0.05	1.85
H	VH	NO	YES	H	0.9	1	0	0.05	1.95
VH	VL	NO	YES	M	1	0.6	0	0.05	1.65
VH	L	NO	YES	M	1	0.7	0	0.05	1.75
VH	M	NO	YES	H	1	0.8	0	0.05	1.85
VH	H	NO	YES	H	1	0.9	0	0.05	1.95
VH	VH	NO	YES	VH	1	1	0	0.05	2.05
VL	VL	NO	NO	VL	0.6	0.6	0	0	1.2
VL	L	NO	NO	L	0.6	0.7	0	0	1.3
VL	M	NO	NO	L	0.6	0.8	0	0	1.4
VL	H	NO	NO	M	0.6	0.9	0	0	1.5
VL	VH	NO	NO	M	0.6	1	0	0	1.6
L	VL	NO	NO	L	0.7	0.6	0	0	1.3
L	L	NO	NO	L	0.7	0.7	0	0	1.4
L	M	NO	NO	M	0.7	0.8	0	0	1.5
L	H	NO	NO	M	0.7	0.9	0	0	1.6
L	VH	NO	NO	M	0.7	1	0	0	1.7
M	VL	NO	NO	L	0.8	0.6	0	0	1.4
M	L	NO	NO	M	0.8	0.7	0	0	1.5
M	M	NO	NO	M	0.8	0.8	0	0	1.6
M	H	NO	NO	M	0.8	0.9	0	0	1.7
M	VH	NO	NO	M	0.8	1	0	0	1.8
H	VL	NO	NO	M	0.9	0.6	0	0	1.5
H	L	NO	NO	M	0.9	0.7	0	0	1.6
H	M	NO	NO	M	0.9	0.8	0	0	1.7
H	H	NO	NO	M	0.9	0.9	0	0	1.8
H	VH	NO	NO	H	0.9	1	0	0	1.9
VH	VL	NO	NO	M	1	0.6	0	0	1.6
VH	L	NO	NO	M	1	0.7	0	0	1.7
VH	M	NO	NO	M	1	0.8	0	0	1.8
VH	H	NO	NO	H	1	0.9	0	0	1.9
VH	VH	NO	NO	H	1	1	0	0	2

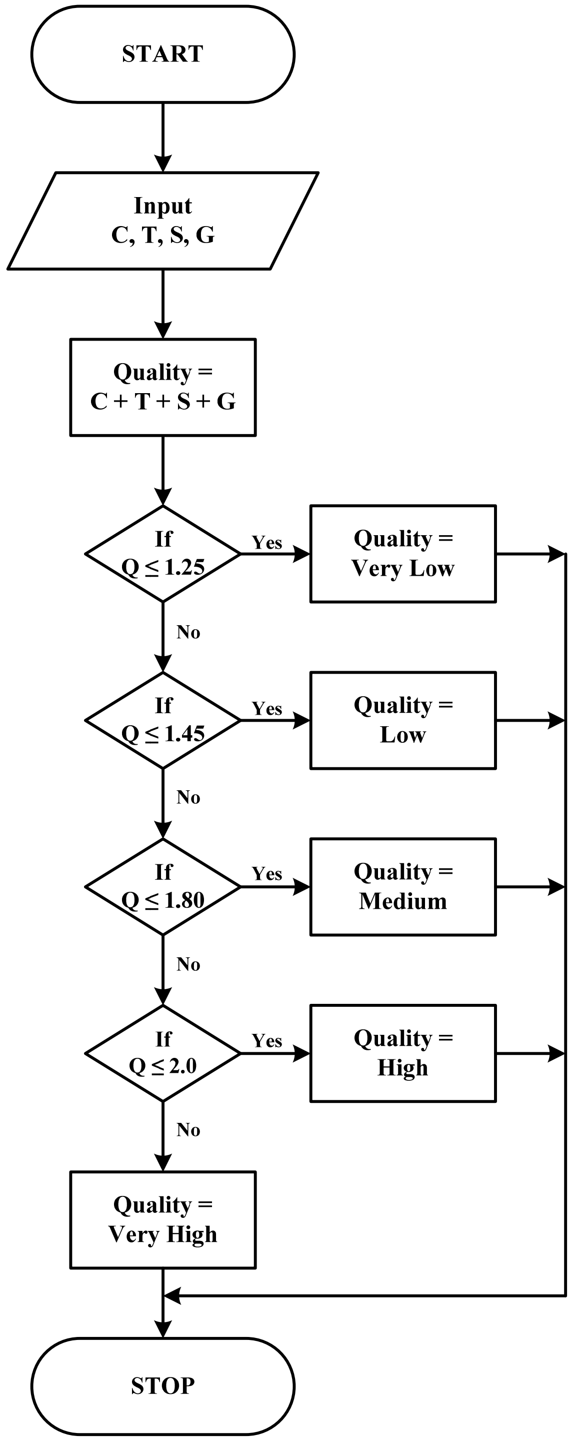

Figure 4: Flowchart for determining Quality

Based on the above rule base and its corresponding values, the following conditions are derived that are depicted in the flowchart figure 4

Quality = Cost + Time + Safety + Green

If Quality < =1.25, then Quality is Very Low,

Else If Quality < = 1.45, then Quality is Low,

Else If Quality < = 1.80, then Quality is Medium, Else If Quality < = 2.0, then Quality is High,

Else Quality is Very High.

The decisions are based on the above rule table and the manufacturing activities are listed with work and resource options. The relationships derived among various parameters are presented in the table below. All the 30 activities on the basis of sequence of activities as shown the figure 3 are presented in the template as in annexure 1.The model developed is generic and could be applied to any manufacturing industry.

6. CONCLUSION

Time, Cost and Quality were the commonly studied parameters in a business environment. Safety and environment were seldom studied even though they contribute to the sustainability of an enterprise. To bridge this gap, Star Optimization Model (SOM) is proposed. It can be used to solve Time – Cost – Quality – Safety – Environment trade-off problem. The model would be tested for different projects as a future work. Readers are also encouraged to apply Star Optimization Model (SOM) to solve trade-off problems arising in their field.

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