IMPLEMENTATION OF CONVENTIONAL FMEA AND ISM TECHNIQUES IN RISK EVALUATION WITHIN GSCM

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A B S T R A C T
Green supply chain management is an essential aspect of any manufacturing or production company. Minimizing wastage and time consumed in complete supply chain unit is at utmost priority. Hence, in the present work GSCM is studied in a plastic manufacturing company in India. A total number of 16 failure modes have been evaluated in the SCM. Implementation of conventional failure mode effective analysis (FMEA) is done and risk priority numbers have been calculated for all the failure modes. The results are again verified by the application of ISM technique. Results are discussed for both ISM and FMEA methods.
Keywords: GSCM, ISM, FMEA, Risk

1. INTRODUCTION

Supply chain management The management of the Supply chain includes planning as well as management of all the activities such as sourcing as well as procurement in addition with the conversion along with all the activities of management logistics. Significantly, coordination as well as collaboration is also included with the channel partners, which can be suppliers as well as intermediaries along with the third party service providers in addition with the customers. Moreover, the management of supply chain incorporates the management of supply as well as demand within as well as across the companies. **Supply Risks** Any risk that includes the raw resources or semi-finished goods or finished goods that are to delivered to the next level in the supply chain comes under supply risk. The problem may be delay or insufficiency or low quality of raw material. This may result due to many reasons. When a supplier has any issue it directly affects the organization. The risk of company shutdown as well as bankruptcy will occur due to disruption of the company. By keeping the track of financial records of critical suppliers as well as searching for alternative suppliers along with providing some aid to them might be helpful. Cargo reimbursements are controllable if the aggregate value is less and parts are not injured further than they can be mended. But if it is the other way outcomes increase in per part cost as well as inadequacy of parts. Its sub categories includes Materials quality, Supplier satiation, Global sourcing, Exclusive supplier, Delivery times, Cargo damages, Bankruptcy of supplier etc. There are so many kinds of risk which are involved in the supply chain management, they are, demand risk, operational risk, Social/Political risks, Competitive/economic risk and Control/Plan risk.

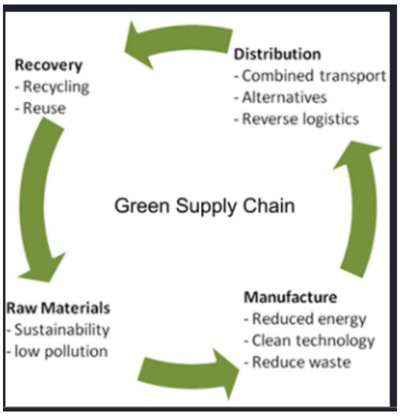

Figure 1. GSC

Figure 2. GSCM

GSCM, which has already been introduced in developed nations, but, relatively, is a fresh idea from a developing nation context.
In recent years, however, various nations like China, India, Japan, Thailand and Taiwan are promoting environmental measures and enforcing or encouraging organizations to adopt the green trend to ensure sustainable production in their business activities (Chien & Shih, 2007). With regard to the GSCM, it is to be noted that an adequate implementation of all stages in the process of green initiatives will uncover probable risks and risk related issues affecting GSC.

Need of Study

It has also been mentioned in their study that FTA focuses only on one top event at a time, which means an entire tree needs to be generated for each top event. Consequently, upcoming work may be directed using other risk assessment techniques, such as FMEA, that overcome the limitation of the FTA method. Along with these, in the existing literature, there is a lack of studies, particularly on exploring the assessment and management of risk with regard to GSC and GSCM (Ma, Yao & Huang, 2012; Mangla, Kumar &Barua, 2014, 2015). In this connection, the present research work attempts to close this research gap by proposing an evaluation framework for risk assessment and or management in GSC, which is the need of hour for optimizing the GSC performance in organizational context (Mangla, Kumar &Barua, 2015).To resolve the above-mentioned research issues, a fuzzy FMEA based approach that over comes the limitations of classical FMEA has been utilized in this work to assess the risks linked to GSC. To the end, this research work will help in managing the risks relevant to a successful implementation (execution of various activities) of GSC business initiatives, and thus enhance ecological-economic gains.

2. LITERATURE SURVEY

(Sachin Kumar Mangla, Sunil Luthra, 2017)contribution develops a benchmarking framework that facilitates GSCM related with the managers as well as the planners associated to model and in addition with the entrance in the GSC risks and inclusive of the failures with probable conditions. This research usuallysuggest to the utilization of the fuzzy type of FMEA approach for assessing the risks which are allied with GSC. In conducting fuzzy FMEA analysis for risk assessment in GSC, the opinion of experts has been utilized and integrated to quantify linguistic expressions. To identify major risks, sixteen failure modes are selected. The failure modes were determined after an extensive literature survey and from consultation with different experts in relation of the field. Further, the arrangement of the decision making in relation with the risk priorities, the RPN and FRPN is determined. According to the conclusion of this work, the failure modes, given as Improper green operating procedure i.e. process, operations, etc (R6) and Green issues while closing the loop of GSC (R14) hold the highest RPN and FRPN scores, obtaining the top rank by both classical and fuzzy FMEA analysis. It means ‘Improper green operating procedure, i.e., process, operations’ and ‘Green issues while closing the loop of GSC’ impede organizations in implementing GSC initiatives in supply chains. Thus, it requires significant managerial effort in this direction. The proposed GSC risk assessment model is extended to an industrial example of a plastic manufacturing firm in India.

(Kant, 2017)to study, examines and ranks the various GSCMEs for successful implementation of GSCM to establish relationship between them and to find out the driving and the dependence power of these GSCMEs. This study identified all the GSCMEs by reviewing a number of research articles and discussion with experts. The present study shows the utilization of an innovative approach to the GSCM implementation in Indian manufacturing organization where the case of automobile sector is considered. The nationwide questionnaire survey of Indian automobile industries was conducted to prioritize these GSCMEs. From survey analysis mean of each enabler is calculated and used to reduce the number enablers from 35 to 29 GSCMEs (see Table 2) by considering mean ≥ 3.00 for further analysis. The ISM and fuzzy MICMAC approach which have been utilized to analyze the contextual relationship as well as includes the integrated model which is fully developed between these 29 GSCMEs. Through the ISM, an interrelationship model among GSCMEs has been developed. This model has been increased with the source of literature review, questionnaire survey, and input from experts. The result of the ISM is utilized as an contribution to the fuzzy MICMAC analysis to recognize the driving as well as the level of dependence power.

(Kumar, 2016)research presents a structural framework for understanding the concept of risk related with the network design in GSC. Through this study, the authors tries to fill up the gap in GSCM dimension by demonstrating the identification, as well as the understanding level, and in addition with assessment of risk in GSC. The present study proposes an operational model for risks analysis in GSC. Further, the proposed integrated FTA-fuzzy AHP methodology provides way to incorporate the method of qualitative and quantitative group decision-making for assessing risks in relation of GSC, where it is usually surrounded by fuzzy segmentation. Additionally, the proposed methodology contribution is two-fold: initially, the fault-tree diagram provides a framework for systematic qualitative and quantitative analysis for resolving an undesired top event (GSC risks assessment) into causes (criteria) and sub-causes (sub-criteria) and later, fuzzy AHP helps in determining the relative priorities of identified risk criteria and in addition with the sub-criteria in GSC. The study findings depict that eight risk criteria (C1 to C8) and 30 sub-criteria (SC1 to SC30) were analyzed for risk assessment using an industrial case study. The product recovery risks (C8) and process risks (C4) criteria possess the highest likelihood in comparison to other risk criteria and therefore, both require more attention in comparison to others.

(Malviya and Kant, 2016)develops and predicts a forecasting framework to facilitate association so that they can lead to build awareness of the critical GSCMEs, and measures the achievement opportunity of GSCM implementation. Since GSCM implementation is a long-term process and its impact is not immediate, a forecasted possibility of success or failure is essential for decision makers. The model is generated for a generalized GSCM implementation and the GSCMEs are determined by the type of literature appraisal and in addition with expert opinion from industries and academics. A nationwide questionnaire survey of Indian automobile organizations was accomplished to mar up the positions related with the GSCMEs and in addition for identifying the relationship along with 1 GSCMEs. 29 GSCMEs out of 35 GSCMEs were selected (Mean ≥ 3.00) for analysis. The result of the survey was used for proposed integrated fuzzy DEMATEL and FMCDM method. The assessment of the experts was based on the correlation coefficient values obtained by survey (see Table 5). Fuzzy set assumption as well as the linguistic type of variables are easily quantified using TFNs which are usually utilized to establish the significance of the weights in relation with the key GSCMEs and the achievable evaluation with the connection of successful GSCM implementation. The ability of a model to forecast precisely depends on how correctly the users ranked the GSCMEs.

(Hafezalkotob, 2015)assume that the rivalry between one green SC and one regular SC under government's financial interventions. Each chain consists of one manufacturer and one retailer, where the competition is of retail price among the retailers in the modest market. The government as a high-level decision maker imposes tariffs on SCs' products to pursue environmental protection or/and revenue seeking policies. The six scenarios has been formulated on the basis of government's objectives and SCs' decision-making structures (centralized or decentralized configurations). It finds that government's financial intervention applies major effects on the profits of SCs as well as their members; hence, there must be some specific boundaries for the government for competitive market to assure the imposed tariffs. The Sensitivity analyses done on the numerical for example, it has been demonstrated that when government focuses on increasing the profits, the impact of environment on SCs (in both centralized as well as decentralized SCs) increases. The government has an access to alleviate the impact of environment on the SC by increasing the tariffs of the product (chiefly, the tariff on the daily products). Besides, the sensitivity analysis discloses that the atmospheric influences of centralized SCs are greater than decentralized ones for all the policies of the government.

(Aqlan and Lam, 2014)study suggested an agenda for supply chain risk identification as well as measurement along with the prioritization. The framework combines qualitative as well as quantitative techniques for an effective valuation of supply chain risks. A uncertain inference system was established to recognize the scores of the risks considering risk factors as well as risk management factors. Assumed the specific and accumulated risk scores, decision makers can either implement top-down or bottom-up risk investigation and focus on the significant risks that can affect their business operations. Mathematical outcomes for the company measured in this study disclosed that the risk scores for the two main products are 22% as well as 19%. This means that product 1 risk values needs further mitigation to reduce the risk. In this study, simulation- optimization models can be used to study supply chain risks as well as recognize appropriate mitigation strategies for every single risk utilizing the risk scores acquired by FIS.

(Ahi and Searcy, 2013) Many diverse meanings for green supply chain management (GSCM) as well as sustainable supply chain management (SSCM) have been recommended. In this research literature evaluation was conducted to categorize the published definitions of GSCM as well as SSCM. This research delivers a needed reference point on the great variability of descriptions issued in these regions. The outcomes revealed that 22 as well as 12 distinct definitions have been issued to demonstrate GSCM as well as SSCM. The investigation displayed that there were many dissimilarities, both great and minor, between the issued descriptions. The descriptions wide-ranging in their analysis of 7 business sustainability characteristics (i.e., economic as well as environ- mental along with the social in addition with the stakeholder as well as volunteer along with the resilience in addition with the long-term focuses) and 7 SCM characteristics (i.e., flow as well as coordination in addition with the stakeholder as well as relationship along with the value in addition with the efficiency as well as performance focuses).

RESEARCH OBJECTIVES

The following are the required aims and objectives for the present work:

1. To implement green supply chain system in the proposed plastic manufacturing industry
2. To analyze the current states of supply chain running and assigning the failure modes
3. To implement Failure mode effective analysis FMEA on the defined failure modes
4. To calculate the risk priority number RPN of the various failure modes
5. To optimize the results by applying ISM technique
6. To identify the most vulnerable failure mode

3. METHODOLOGY

3.1 ANALYSIS APPROACH

Identifying the failure modes in the current GSC unit

Potential failure modes

1. Disruption/Irregularities in supply of green virgin and/or recycled material (R1)
2. Lack of environmental standards and certifications such as ISO, RoHS etc. (R2)
3. Green quality issues in supplying (R3)

4. Ineffectiveness in using environmental friendly inputs (R4)
5. Unskilled labor (R5)
6. Improper green operating procedure (R6)
7. Lack of green social responsibilities (R7)
8. Redundancy among customers for adopting the green products (R8)
9. Competitors approach regarding green initiatives (R9)
10. Used product collection irregularity (R10)
11. Uncertainties in secondary and returning market (R11)
12. Capacity and inventory related issues of reprocessing centre (R12)
13. Returning issues such as gate keeping and screening (R13)
14. Green issues while closing the loop of GSC (R14)
15. Lack of environment policies and regulations (R15)
16. Technology lag in going green policies (R16)

3.2 Conventional FMEA Approach

The conventional Failure Mode and Effect Analysis (FMEA) approach is a pro-active quality tool for evaluating potential failure modes and their causes. Failures are any error or defect in the product which can be potential or actual that affects the consumer. In this approach, failures are prioritized according to its consequences, frequent appearance and its detection. A process of conventional FMEA is as follows: -

Step 1: Identification of components and associated functions

Step 2: Identification of Potential failure modes

Step 3: Identification of Effect analysis (Severity, S)

Step 4: Identification of Reason analysis (Occurrence, O)

Step 5: Control and inspection (Detection, D)

Step 6: Calculation for Risk Priority Number (RPN), is calculated by multiplying of Severity (S), Occurrence (E) and Detection (D).

$R\,P\,N = S \times O \times D$……………..[1]

3.3 Calculation for FMEA Approach

The risk priority number is calculated from the failure modes which determines the most potential failure caused in the complete system. From equation, risk priority number = severity X occurrence X detection

Hence, for failure mode R1, S = 3, O = 7, D = 5

Therefore RPN = 3 x7 x5 = 105

Similarly based on the above method the values for RPN is calculated for all the failure modes from R1 to R16

Table 3.1: RPN calculation

Failure modes	Severity	Occurrence	Detection	RPN
R1	3	7	5	105
R2	6	7	6	252
R3	6	6	7	252
R4	8	9	8	576
R5	7	9	7	441
R6	8	9	9	648
R7	3	5	4	60
R8	6	8	5	240
R9	8	7	7	392
R10	8	7	7	392
R11	8	8	8	512
R12	8	8	7	448
R13	8	8	8	512
R14	8	9	9	648
R15	4	5	5	80
R16	7	8	6	336

3.4 ISM Method

Interpretative structural model (ISM) is a qualitative and interpretative method that corrects complex and unclear variables by mapping complex structures into an understandable model. ISM starts with an identification of variables, which are relevant to the problem or issue, and then extends with a group problem solving technique. The element set and the contextual relation, a structural self-interaction matrix (SSIM) is developed based on pair wise comparison of variables. In the next step, the SSIM is converted into a reach ability matrix (RM)and its transitivity is checked. Once transitivity embedding is complete, a matrix model is obtained.

Initial structural self-interaction matrix (SSIM) matrix

The complete failure modes are arranged in form of matrix as shown below

Table 3.2: ISM table based on V,X,O and A variables

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
R1	V	V	X	V	V	A	V	X	V	A	V	V	V	O	A	V
R2	V	V	V	A	A	V	V	V	X	V	O	V	A	O		
R3	O	O	V	V	V	V	V	X	V	X	X	V	X			
R4	A	X	V	X	V	A	X	O	V	V	V	V				
R5	V	V	X	V	V	X	X	V	O	V	V					
R6	X	X	A	V	V	O	A	A	V	O						
R7	O	V	A	V	A	V	A	V	V							
R8	O	V	V	O	O	X	O	X								
R9	X	O	O	V	V	V	V									
R10	V	V	X	A	X	V										
R11	V	O	V	A	V											
R12	V	V	V	V												
R13	A	X	O													
R14	V	X														
R15	V															
R16																

The steps for the ISM approach can be described as follows:

1. Selecting the elements/variables that are involved in the problem .The starting point is to select elements/variables that are relevant to the problem.

2. Performing contextual relationship classification. This step is to classify contextual relationships and assign a possible relationship for each variable with other variables.

3. Structuring a self-interaction matrix)SSIM .(This is to compare the relationships of individual elements/variables .In this process, it is the obligation of the experts to identify the relationship of each pair of elements/variables) such as i and j (by identifying the symbols .These symbols are described below.

V -for a relationship from i to j but not in both directions

A -for a relationship from j to i but not in both directions

X -for directional relationships, both from i to j and j to i, and O -if there is no relationship between elements/variables.

4. Create a matrix of relationships .This step is obtained by identifying the relationship symbols between the variables using the attribute to represent the relationship, i.e., the number 0 and the number 1.

- If the item) i, j (in SSIM is V, then the item) i, j (in reach ability matrix become 1 and the item) j, i (becomes 0.
- If the item)i, j (in SSIM is A then the item) i, j (in reach ability matrix becomes 0 and the item) j, i (becomes 1.
- If the item) i, j (in SSIM is X, then both items) i, j (and)j, i (of reach ability matrix are 1
- If the item)i, j (of SSIM is O, then both items)i, j (and)j, i (of reach ability matrix become 0.

Also, the assumption in relation to each pair of elements/variables in the ISM technique is that if A constitutes B and B is related to C, it may infer that A is involved in C, and if in reach ability matrix (i, j) has a relationship of 0, there is no direct or indirect relationship between the elements/variables (i, j) at the beginning of the matrix generation access (i, j) is not directly or indirectly related .The value specified in the matrix will be 0.

5. Divide the level of reach ability matrix .This step is involved in the extraction of the hierarchy of an element/variable's relationship from the reach ability matrix .

6 .Draw the structural model derived from the order of elements/variables.

Initial Reachability matrix

Development of Initial reachability matrix (IRM) and Final reachability matrix (FRM)

First, we represent available information in the matrix in terms of 'V', 'A', 'X' and 'O' called structural self-interaction matrix (SSIM). Then this information is converted into the binary form in initial reach ability matrix (IRM) by the following rules.

- if the value of (i, j) in the SSIM is V, then in the IRM (i, j) becomes 1 and (j, i) becomes 0
- if the value of (i, j) in the SSIM is A, then in the IRM (i, j) becomes 0 and (j, i) becomes 1
- if the value of (i, j) in the SSIM is X, then in the IRM (i, j) and (j, i) both becomes 1
- if the value of (i, j) in the SSIM is O, then in the IRM (i, j) and (j, i) both becomes 0

Table 3.3: SSIM initial reachability matrix

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
R1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	0	1
R2	1	1	1	0	0	1	1	1	1	1	0	1	0	0		
R3	0	0	1	1	1	1	1	1	1	1	1	1	1			
R4	0	1	1	1	1	0	1	0	1	1	1	1				
R5	1	1	1	1	1	1	1	1	0	1	1					
R6	1	1	0	1	1	0	0	0	1	0						
R7	0	1	0	1	0	1	0	1	1							
R8	0	1	1	0	0	1	0	1								
R9	1	0	0	1	1	1	1									
R10	1	1	1	0	1	0										
R11	1	0	1	0	1											
R12	1	1	1	1												
R13	0	1	0													
R14	1	1														
R15	0															
R16																

Final reachability matrix

Depending on the IRM values the FRM values are evaluated and added in the matrix. The initial reachability matrix by adding transitivity to the latter manually, which is shown in Table below

Table 3.4: Final reachability matrix

	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16
R1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	0	1
R2	1	1	1	0	0	1	1	1	1	1	0	1	0	0	0	0
R3	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0
R4	0	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0
R5	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0
R6	1	1	0	1	1	0	0	0	1	0	0	0	0	1	1	1
R7	0	1	0	1	0	1	0	1	1	1	1	0	0	0	1	1
R8	0	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1

R9	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0
R10	1	1	1	0	1	0	0	0	0	0	1	1	1	1	0	0
R11	1	0	1	0	1	0	1	0	1	0	1	1	1	0	1	1
R12	1	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1
R13	0	1	0	1	0	1	1	1	1	1	1	0	0	1	0	1
R14	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1
R15	0	0	1	1	1	0	1	1	0	0	0	1	1	1	1	1
R16	1	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0

Driving power final matrix

Sum of all the attributes gives driving power. The table below shows the driving power

Table 3.5: Driving power calculation

	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R14**	**R15**	**R16**	**DERIVING POWER**
R1	1	1	1	1	1	0	1	1	1	0	1	1	1	0	0	0	11
R2	1	1	1	0	0	1	1	1	1	1	0	1	0	0	0	0	9
R3	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	12
R4	0	1	1	1	1	0	1	0	1	1	1	1	1	0	0	0	10
R5	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	13
R6	1	1	0	1	1	0	0	0	1	0	0	0	0	1	1	1	8
R7	0	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	13
R8	0	1	1	0	0	1	0	1	1	1	1	1	1	1	1	1	12
R9	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	10
R10	1	1	1	0	1	0	0	0	0	0	1	1	1	1	0	0	8
R11	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	14
R12	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	14
R13	0	1	0	1	0	1	1	1	1	1	1	0	0	1	0	1	10
R14	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	15
R15	0	0	1	1	1	0	1	1	0	0	0	1	1	1	1	1	10
R16	1	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	7

4. RESULTS AND DISCUSSIONS

In the present study 16 failure modes were evaluated in the green supply chain as risk factors and further ranking is allotted depending the results obtained for risk priority number (RPN)

Table 4.1Rank allocation based on FMEA approach

Failure modes	**Severity**	**Occurrence**	**Detection**	**RPN**	**Rank**
R1	3	7	5	105	14
R2	6	7	6	252	11
R3	6	6	7	252	12
R4	8	9	8	576	3
R5	7	9	7	441	7
R6	8	9	9	648	1

R7	3	5	4	60	16
R8	6	8	5	240	13
R9	8	7	7	392	8
R10	8	7	7	392	9
R11	8	8	8	512	4
R12	8	8	7	448	6
R13	8	8	8	512	5
R14	8	9	9	648	2
R15	4	5	5	80	15
R16	7	8	6	336	10

From the above table it is clear that failure risk number R7 has the highest ranking, hence it is most vulnerable in the complete GSC followed by R15 and R1. The rank is provided considering the highest value of RPN as 1 and proceeding so on in descending order of RPN values.

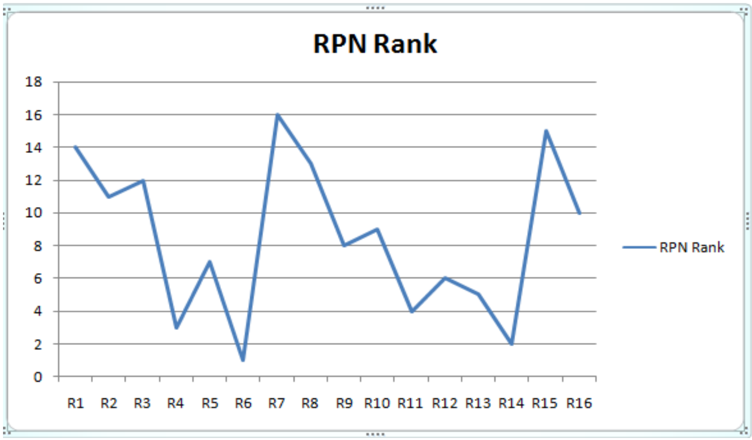

Figure 4.1Graph showing variation in rank obtained from RPN

Results obtained from ISM method

Table 5.2Rank allocation depending upon driving power

Failure modes	Driving Power	Ranking	RPN
R1	11	8	105
R2	9	13	252
R3	12	6	252
R4	10	10	576
R5	13	4	441
R6	8	15	648
R7	13	5	60
R8	12	7	240
R9	10	11	392
R10	9	14	392
R11	14	2	512
R12	14	3	448
R13	10	12	512
R14	15	1	648
R15	11	9	80
R16	7	16	336

The rank for driving power is allocated to highest value as 1. Hence, from the table above it is clear that R14 has the highest driving power which is ranked 1, followed by R11 and R12.

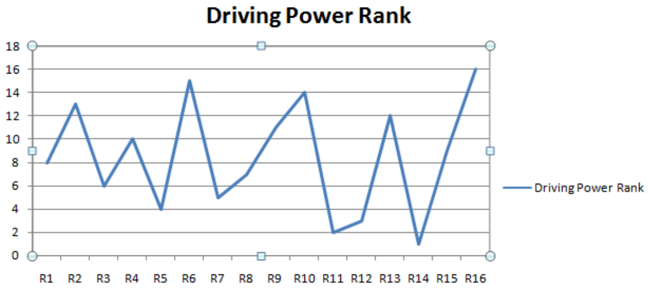

Figure 4.2 driving power rank

Result comparison based on the rankings obtained from FMEA approach and Ism method

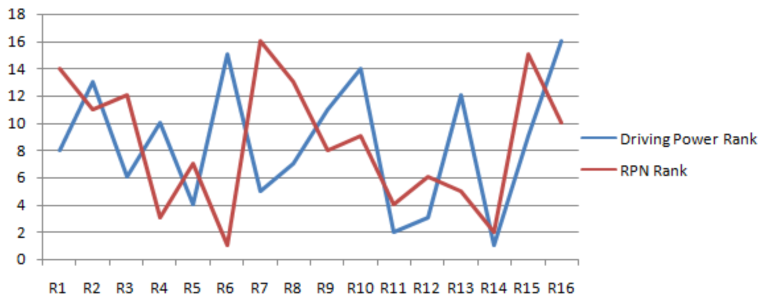

Figure5.3: driving power rank with RPN rank

5. CONCLUSIONS

A case study for green supply chain is studied in the present work in a plastic manufacturing industry in India. Altogether 16 failure risks modes were analyzed in the complete chain from R1 to R16. Conventional FMEA approach was used to priorities the failure modes and identifies the most vulnerable risk mode which needs to be checked. Further ISM technique is implemented to identify the same. Finally a comparison is done based on the rankings obtained for both ISM and FMEA methods. Here are the following conclusions

- By implementing FMEA technique it is found that risk number R7 has the highest RPN value and is ranked 1. Hence, Lack of green social responsibilities is most vulnerable factor in this method.
- From the results of ISM technique the rank obtained depending on the driving power shows that risk number R14 is most vulnerable. Hence, Green issues while closing the loop of GSC is most vulnerable factor in this method.

Therefore in the complete GSC system within the plastic industry it can be said that risk number R7 and R14 are the most risky factors which needs to be checked and rectified.

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APPENDIX-1

Table 5.1 Criteria in order to rank the SEVERITY (S) in FMEA

Effect	Severity Criteria	Ranking
Hazardous without warning	Very high severity ranking: Affects operator, plant or maintenance personnel; safety and/or effects non-compliant.	10
Hazardous with warning	High severity ranking: Affects operator, plant or maintenance personnel; safety and/or effects non-compliant.	9
Very high downtime or defective parts	Downtime of more than 8 hours.	8
High downtime or defective parts	Downtime of more than 4-7 hours.	7
Moderate downtime or defective parts	Downtime of more than 1-3 hours.	6
Low downtime or defective parts	Downtime of 30 minutes to 1 hour.	5
Very low	Downtime up to 30 minutes and no defective parts	4
Minor effect	Process parameters variability exceeds upper/lower control limits; adjustments or process controls need to be taken. No defective parts.	3
Very minor effect	Process parameters variability within upper/lower control limits; adjustments or process controls need to be taken. No defective parts.	2
No effect	Process parameters variability within upper/lower control limits; adjustments or process controls not needed or can be taken between shifts or during normal maintenance visits. No defective parts.	1

APPENDIX-2

Table 5.2 Criteria in order to rank the OCCURRENCE (O) in FMEA

Probability of Failure Occurrence	Possible Failure Rates Criteria	Ranking
Very high: Failure is almost inevitable	Intermittent operation resulting in 1 failure in 100 production piece or MTBF of less than 1 hour.	10
	Intermittent operation resulting in 1 failure in 100 production pieces or MTBF of less than 2 to 10 hours.	9
High: Repeated failures	Intermittent operation resulting in 1 failure in 1000 production pieces or MTBF of 11 to 100 hours.	8
	Intermittent operation resulting in 1 failure in 10,000 production pieces or MTBF of 101 to 400 hours.	7
Moderate: Occasional failures	MTBF of 401 to 1000 hours.	6
	MTBF of 1001 to 2000 hours.	5
	MTBF of 2001 to 3000 hours.	4
Low: Relatively few failures	MTBF of 3001 to 6000 hours.	3
	MTBF of 6001 to 10,000 hours.	2
Remote: Failure unlikely	MTBF greater than 10,000 hours.	1

APPENDIX-3

Table 6.3 Criteria in order to rank the DETECTION (D) in FMEA

Detection	Detection by Design Controls	Ranking
Absolute uncertainty	Machine controls will not and/or cannot detect potential cause/mechanism and subsequent failure mode; or there is no design or machinery control.	10
Very remote	Very remote chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode.	9
Remote	Remote chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure.	8
Very low	Very low chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure.	7
Low	Low chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure.	6
Moderate	Moderate chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	5
Moderately high	Moderately high chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	4
High	High chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery control will prevent an imminent failure and will isolate the cause. Machinery control may be required.	3
Very high	Very high chance a machinery/design control will detect a potential cause/mechanism and subsequent failure mode. Machinery controls not necessary.	2
Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode. Machinery controls not necessary.	1

- The ranking is given as per the value obtained by the RPN number of the various Failure modes. The maximum value of RPN number signifies Rank I and in same sequence the other ranking values are allotted as per the decreasing order of the RPN.