

## CHAPTER-4

# DEVELOPMENT OF INTERRELATIONSHIP AMONG SCR VARIABLES

A large number of directly and indirectly interrelated SCR variables in the Supply Chain (SC) may affect supply chain performance. The nature and number of SCR variables may vary in SC of companies depending upon their nature, size and level of operations etc.. Small-scale companies are also facing various risks associated with their supply chain. Understanding of the interactions among various SCR variables is essential for better supply chain risk management. This will help the firms to develop suitable strategies to manage supply chain risks according to the relative importance of each SCR variables (Faisal, 2009). To understand and develop an interrelationship among SCR variables, several methods can be applied. ISM is one such technique that can be used to do the same.

Interpretive structural modelling (ISM) is a tool, which is widely used in research to understand and establish interrelationships among various variables related to the research problem (Warfield, 1974; Sage, 1977). It enables understanding of a hierarchy of complex inter-relationship among various variables of a problem (Jharkharia and Shankar, 2004; Ravi and Shankar, 2005). An SCRM-ISM model is developed by using interpretive structure modelling (ISM) to exhibit the interrelationship among all identified SCR variables.

This chapter presents the development of interrelationship structural model of supply chain risk variables using Interpretive Structural Modelling (ISM) for the Indian case organisation. The steps of this methodology are shown in Figure 3.1. The same, as being implemented to the case-organisation, are explained in the following sections.

### 4.1 Identification of relevant SCR variables

The first step is to identify the supply chain risk variables, which are relevant to the research

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problem. This could be done either by primary research (survey method, expert opinion etc.) or secondary research (literature review, etc.). In the current work, initially SCR variables were identified through literature review. For the purpose, research papers from 2001 to 2019 were used. Keywords such as supply chain risk management (SCRM), risk management, supply chain disruption, uncertainty, etc., were used in the search process. Expert opinion through group discussion was sought to identify the significant SCR variables associated with the supply chain of the case organisation. Experts from the case organisation and academia were involved. . Such relevant SCR variables associated with the case organisation is shown in Table 4.1. At the time of group discussion, experts also gave their opinion about the SCR attributes of these seven SCR variables identified from the literature survey (Chopra and Sodhi, (2004), Diabat *et al.* (2011), and Tummala and Schoenherr (2011)). These attributes are shown in Table 4.2. Though, this Table 4.2 is presented in this chapter, it is also used in later chapters.

After Identification of these seven SCR variables, the contextual relationship has been developed through detail discussion with experts. This contextual relationship among SCR variables is illustrated in the following section.

#### **4.2 Establishing a contextual relationship among SCR variables**

As explained in section 3.1.2, contextual relationship may be of several types like comparative, influential, neutral or temporal relations (Austin and Burns, 1985; Warfield, 1974). In this step, the contextual relationship between SCR variables are established by the experts' opinion. These Experts are having experience more than 15 years in the domain of SC. Four symbols are used to represent the direction of the relationship between any two variables ( $i$  and  $j$ ) as explained in Chapter 3 and reproduced here in context of SCRM for ready reference.

Table 4.1. Supply chain risk variables identified by researchers

	Source																	
Supply Chain Risk	Finch (2004)	Chopra and Sodhi (2004)	Faisal <i>et al.</i> , (2006b)	Cucchiella and Gastaldi (2006)	Rao and Goldsby (2009)	Tummala and Schoenherr (2011)	Pfohl <i>et al.</i> , (2011)	Cagliano <i>et al.</i> , (2012)	Ghadge <i>et al.</i> , (2013)	Faisal (2013)	Kumar and Routroy (2014)	Hachicha and Elmsalmi (2014)	Venkatesh. <i>et al.</i> , (2015)	Rogers <i>et al.</i> , (2016)	Chand <i>et al.</i> , (2017)	Shenoi <i>et al.</i> , (2018)	Moktadir <i>et al.</i> , (2018)	Alkhalidi <i>et al.</i> , (2020)
<b>Environmental Risk</b>	√	√		√	√	√	√	√		√	√	√	√	√	√	√		√
<b>Information Technology Risk</b>	√	√	√			√	√		√	√						√	√	
<b>Supply Risk</b>	√	√	√	√		√	√		√	√		√	√	√	√	√	√	
<b>Process Risk</b>		√		√		√	√	√	√	√		√	√		√	√	√	√
<b>Transportation Risk</b>						√	√				√	√		√	√	√		√
<b>Delay Risk</b>		√				√	√			√	√	√	√					√
<b>Demand Risk</b>		√				√			√	√		√	√	√		√	√	

Table 4.2. Supply chain risk variables and their attributes

SCR Variables	SCR Attributes	Source
Environmental Risk (ER)/ Disruption Risk	Natural disaster (such as an earthquake or flood) Man-made disaster (such as a fire, labor-strike, terrorist attack). Political instability and unrest Change in government regulation (legal system) Economic imbalances and social inequality risk Seasonal production	Kersten <i>et al.</i> (2006); Hachicha and Elmsalmi (2014)
Information Technology Risk (IR)	Distortions in information sharing Failure in IT systems System integration or extensive system networking Cyber-attacks, virus etc.	Chopra and Sodhi (2004); Diabat <i>et al.</i> , (2012)
Supply Risk (SR)	Supplier failure Supplier fulfilment errors Selection of wrong partners Poor responsiveness and delivery performance Inflexibility of supply source Supplier bankruptcy	Zsidisin (2003); Tummala and Schoenherr (2011)
Process Risk (PR)	Internal labor strikes Shortage of skilled employees Productivity and quality failure Inventory and stock failure High product cost Changes in product designs Lack of flexibility in manufacturing process	Tummala and Schoenherr (2011); Hachicha and Elmsalmi (2014)
Transportation Risk (TR)	High paperwork and scheduling Process Transport Union strikes Delay at ports due to limited port capacity Higher costs of transportation Depends on transportation mode chosen	Tummala and Schoenherr (2011)
Delay Risk (DE)	Excessive handling due to border crossings Port capacity and congestion Long Custom clearance process at ports Delay in Material or information flow Production failure System breakdown Supplier's inability to respond quickly to a change in demand	Tummala and Schoenherr (2011); Mohammaddust <i>et al.</i> , (2017)

Demand Risk (DR)	Inaccurate forecasts due to longer lead times bullwhip effect or information distortion Demand uncertainty Product variety Short life cycles Information distortion due to sales promotions and incentives Exaggeration of demand during product shortage	Chopra and Sodhi (2004)
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- V: SCR variable *i* will proliferate/lead to SCR variable *j* (relation from *i* to *j*, but not in both direction);
- A: SCR variable *j* will lead to SCR variable *i* (relation from *j* to *i*, but not in both direction);
- X: SCR variable *i* and *j* will lead to each other (relation from *i* to *j* and *j* to *i*); and
- O: SCR variables *i* and *j* will not lead to each other (No relationship).

A consensus has been obtained for these relationships through group discussion. These contextual relationships are used as input for construction of SSIM as explained in next section.

#### 4.3 Construction of structural self-interaction matrix (SSIM)

A matrix known as Structural Self-Interaction Matrix (SSIM) is formed using the contextual relationship. This Matrix shows the pair-wise relationships among SCR variables. Table 4.3 illustrates the pairwise relationship among identified SCR variables. This SSIM of Table 4.3 shows that

1. SCR variable 1 (ER-environmental risk) leads to SCR variable 2 (IR-Information risk), and on the other hand, SCR variable 'IR' is not playing a significant role to lead to the SCR variable 'ER'. Therefore, symbol 'V' is used to denote the direction of the relationship between these SCR variables ('ER' and 'IR'),

2. SCR variable 4 (PR-process risk) is led by SCR variable 7 (DR-demand risk), but 'PR' is not affected by 'DR'. Hence the relationship among these variables is reverse (the only relation from j to i) and unidirectional, so it is shown as 'A' in SSIM,
3. SCR variable 3 (SR-supply risk) and SCR variable 7 (DR-demand risk) proliferate each other, so the relationship is shown as 'X' in SSIM, and
4. No relationship seems to exist among SCR variable 6 (DE-delay risk) and SCR variable 7 (DR-demand risk), so it is represented as 'O' in SSIM.

Similarly, based on the expert opinion, all the contextual relationship among seven SCR variables are shown in Table 4.3. This table is used to develop the reachability matrix and examine the transitivity.

Table 4.3 Structural self-interaction matrix

SCR variables	7. DR	6. DE	5. TR	4. PR	3. SR	2. IR	1. ER
1. Environmental Risk (ER)	V	V	V	V	V	V	-
2. Information Technology Risk (IR)	V	V	V	V	V	-	
3. Supply Risk (SR)	X	O	X	V	-		
4. Process Risk (PR)	A	V	A	-			
5. Transportation Risk (TR)	V	V	-				
6. Delay Risk (DE)	O	-					
7. Demand Risk (DR)	-						

#### 4.4 Development of reachability matrix and examination of transitivity

As explained in section 3.1.4, an initial reachability matrix is developed using rules for converting V, A, X and O type relationship into binary numbers (0 and 1). These rules for conversion are reproduced below;

- If the  $(i, j)$  cell value in the SSIM is V, then the  $(i, j)$  cell value in the reachability matrix becomes 1, and the  $(j, i)$  cell value becomes 0.
- If the  $(i, j)$  cell value in the SSIM is A, then the  $(i, j)$  cell value in the reachability matrix becomes 0, and the  $(j, i)$  cell value becomes 1.

- If the  $(i, j)$  cell value in the SSIM is X, then both the  $(i, j)$  and  $(j, i)$  cell values of the reachability matrix become 1.
- If the  $(i, j)$  cell value of the SSIM is O, then both the  $(i, j)$  and  $(j, i)$  cell values of the reachability matrix become 0.

Based on the above rules, the SSIM is converted into an initial reachability matrix as shown in Table 4.4.

Table 4.4 Initial reachability matrix

SCR variables	1. ER	2. IR	3. SR	4. PR	5. TR	6. DE	7. DR
1. ER	1	1	1	1	1	1	1
2. IR	0	1	1	1	1	1	1
3. SR	0	0	1	1	1	0	1
4. PR	0	0	0	1	0	1	0
5. TR	0	0	1	1	1	1	1
6. DE	0	0	0	0	0	1	0
7. DR	0	0	1	1	0	0	1

This initial reachability matrix is subjected to examination of Transitivity to obtain the final reachability matrix. Checking transitivity is an important aspect of ISM methodology. Transitivity can be verified with the help of the method suggested by Malone (1975). This process is further explained and used by many researchers (Faisal *et al.* 2006, Pfohl *et al.* 2011, Ojha *et al.* 2014). Steps involved in the transitivity checking process are as follows.

- Initial reachability matrix multiplied with itself and the values  $\geq 1$  are replaced with 1 in the resultant matrix.
- Check this new resultant matrix, if this new matrix is same as the initial reachability matrix, final reachability matrix is obtained. If both are not the same, then repeat step one with the resultant matrix.
- Repeat this process until the final reachability matrix is obtained

- Compare the initial and final reachability matrix. If any cells value changes from 0 to 1 then it is marked as '1\*' in the final reachability matrix, where 1\* denotes transitivity reflecting new relationship surfaced up due to transitivity.

After incorporating transitivity, final reachability matrix is obtained, as shown in Table 4.5. In Table 4.5, 1\* representing the values after incorporating transitivity. The driving power and dependence of each variable are represented in this final reachability matrix of Table 4.5. The driving power of each SCR variable is calculated by the total number of SCR variables (including itself) which are affected by a particular variable, i.e. the sum of binary values in the columns. Based on the driving power, the ranking of each SCR variable can be found out and shown in Table 4.5. Higher the driving power implies higher the rank of SCR variable (Debnath and Shankar, 2012). Table 4.5 also shows the dependence power is the total number of SCR variables (including itself), which may be impacting it. Dependence power is the sum of binary values in the rows (Faisal *et al.*, 2006b). The driving power and dependence power of variables are used as input for level partitioning.

Table 4.5 Final reachability matrix

SCR variables	1. ER	2. IR	3. SR	4. PR	5. TR	6. DE	7. DR	Driving Power	Rank
1. ER	1	1	1	1	1	1	1	7	1
2. IR	0	1	1	1	1	1	1	6	2
3. SR	0	0	1	1	1	1	1	5	3
4. PR	0	0	0	1	0	1	0	2	4
5. TR	0	0	1	1	1	1	1	5	3
6. DE	0	0	0	0	0	1	0	1	5
7. DR	0	0	1	1	1*	1*	1	5	3
Dependence power	1	2	5	6	5	7	5	-	-

#### 4.5 Level Partitioning of reachability matrix

The reachability and antecedent set for each SCR variable were obtained from the final reachability matrix (Warfield, 1974, 1976). The reachability set ( $R_{si}$ ) means the total number of variables, which may be affected by a particular SCR variable (including itself),

whereas the antecedent set ( $As_i$ ) means the total number of variables which affect a specific SCR variable (including itself). These reachability and antecedent set leads to the intersection sets ( $Is_i$ ), i.e.,  $Is_i = Rs_i \cap As_i$ ; the common elements in both sets. It is found for each element i.e. SCR variable (Pfohl *et al.*, 2011).

Table 4.6 Level Partition of reachability matrix

SCR Variables	Reachability Set ( $Rs_i$ )	Antecedent Set ( $As_i$ )	Intersection Set ( $IS_i = Rs_i \cap As_i$ )	Level
<b>Iteration 1</b>				
1. ER	1,2,3,4,5,6,7	1	1	
2. IR	2,3,4,5,6,7	1,2	2	
3. SR	3,4,5,6,7	1,2,3,5,7	3,5,7	
4. PR	4,6	1,2,3,4,5,7	4	
5. TR	3,4,5,6,7	1,2,3,5,7	3,5,7	
6. DE	6	1,2,3,5,6,7	6	1
7. DR	3,4,5,6,7	1,2,3,5,7	3,5,7	
<b>Iteration 2</b>				
1. ER	1,2,3,4,5,7	1	1	
2. IR	2,3,4,5,7	1,2	2	
3. SR	3,4,5,7	1,2,3,5,7	3,5,7	
4. PR	4	1,2,3,4,5,7	4	2
5. TR	3,4,5,7	1,2,3,5,7	3,5,7	
7. DR	3,4,5,7	1,2,3,5,7	3,5,7	
<b>Iteration 3</b>				
1. ER	1,2,3,5,7	1	1	
2. IR	2,3,5,7	1,2	2	
3. SR	3,5,7	1,2,3,5,7	3,5,7	3
5. TR	3,5,7	1,2,3,5,7	3,5,7	3
7. DR	3,5,7	1,2,3,5,7	3,5,7	3
<b>Iteration 4</b>				
1. ER	1,2	1	1	5
2. IR	2	1,2	2	4

Based on reachability, antecedent and intersection sets, the final reachability matrix is partitioned into different levels. For level partitioning, any reachability set having mostly similar element to intersection set ( $Rs_i = Is_i$ ) is assigned as Level 1 and this level is placed at the top in the ISM hierarchy. Now Level 1 is identified, so it is eliminated from the table

and the same process undergoes iterations until the level of each SCR variable is identified. The reachability, antecedent and interaction sets for each SCR variable and their level are shown in Table 4.6. The Entire level partitioning process is completed in 4 iterations as shown in Table 4.6.

From Table 4.6, the SCR variable 7 (DE-delay risk) is identified as Level-I or Top level, so it is located at the top of the ISM model. . From Iteration 2, SCR variable 4 (PR-process risk) is identified at level-II. Three SCR variables are (3-SR, 5-TR, 7-DR) identified at level-III from Iteration 3. In iteration 4, SCR variable 2 (IR) is identified at level-IV and SCR variable 1(ER-external risk) is identified at Level-V. These levels lead to the development of diagraph and final ISM model with the help of conical matrix.

**4.6 Development of conical matrix**

A conical matrix (lower triangular format) is developed by conglomeration of all SCR variables in the same level, across rows and columns of final Reachability Matrix (Chand et al., 2015). In the conical matrix, all the variables having the same level are pooled together, i.e. top level variable with most zeros (0) in the upper diagonal of the matrix and lower level of variables most unitary value (1) in the lower half of the matrix. The conical matrix is achieved by rearranging SCR variables based on their levels. The conical matrix for this case is shown in Table 4.7. Based on this matrix, a diagraph is developed.

Table 4.7 Conical matrix

SCR variables	6. DE	4. PR	3. SR	5. TR	7. DR	2. IR	1. ER
6. DE	1	0	0	0	0	0	0
4. PR	1	1	0	0	0	0	0
3. SR	1	1	1	1	1	0	0
5. TR	1	1	1	1	1	0	0
7. DR	1*	1	1	1*	1	0	0
2. IR	1	1	1	1	1	1	0
1. ER	1	1	1	1	1	1	1

Note: 1\* are the values after incorporating the transitivity

#### 4.7 Development of diagraph and Formation of ISM-based model

A diagraph is developed from the conical form of the reachability matrix of Table 4.7 and level partition of reachability matrix of Table 4.6. Using nodes and arrows, the SCR variables are arranged according to their level and transitive links obtained from the conical matrix. The relationship between SCR variable  $i$  and  $j$  is shown by an arrow which points from node  $i$  to node  $j$ . Each node represents a particular SCR variable. From the conical matrix, initial digraph is obtained and after removing indirect links final digraph is obtained, which is as shown in Figure 4.1.

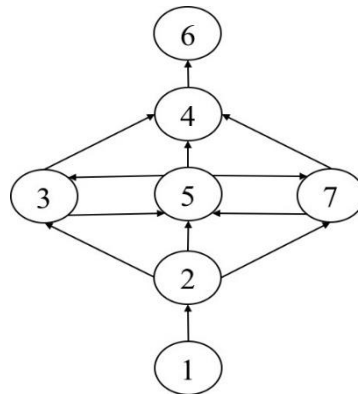


Figure 4.1 Final Digraph

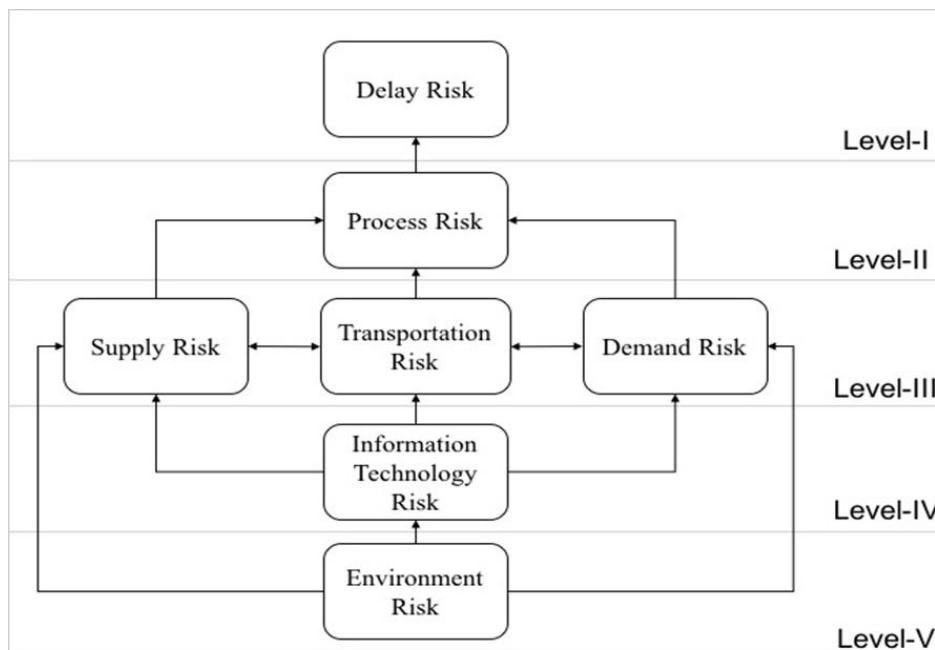


Figure 4.2 ISM Model

ISM model is basically a representation of pure hierarchical pattern of all identified SCR variables and it is obtained from the final digraph. Nodes numbers are replaced by their associated SCR variable in Figure 4.1 and all the level are mentioned to show the ISM model. Figure 4.2 shows the developed ISM model for the case organisation. This diagram clearly shows that the delay risk 'DR' variable is having level-1. So, 'DR' variable is one which have high dependency with low driving power. Similarly, Figure 4.2 shows all seven variables with their level, dependence power and driving power. SCR variable "Environmental Risk (ER)" is not dependent on any of the SCR variable considered and has the highest driving power among all the SCR variable. Depending upon these powers, the SCR variables are classified into four clusters using MICMAC analysis.

#### **4.8 Classification of SCR variables on the basis of MICMAC analysis**

Matriced' Impacts Cruoses Multiplication Applique a un Classement (MICMAC) analysis is widely used to understand and analyze the driving power and dependence power of the variables by creating clusters. Four clusters, i.e. (i) autonomous, (ii) dependent, (iii) linkage and (iv) independent SCR variables, on the basis of their driving power and dependence power are usually drawn by plotting dependency-driver diagram as explained in section 3.1.8. Usig table 4.5, dependence power has been plotted against driving power. Figure 4.3 shows such plot classifying SCR variables into four clusters.

Figure 4.3 shows that

1. 'PR' and 'DE' variables as dependent variable in Cluster-II,
2. 'TR', 'SR' and 'DR' as linkage variables in Cluster-III
3. 'IR' and 'ER' as driver variables in Cluster-IV,
4. No SCR variable was found as autonomous variable in Cluster-I.

As no variable was autonomous variable, all the considered SCR variables are significant to SCR of the case organisation. MICMAC analysis highlights a clear classification of variable type, which, on the other hand, is not visible in ISM model of figure 4.2.

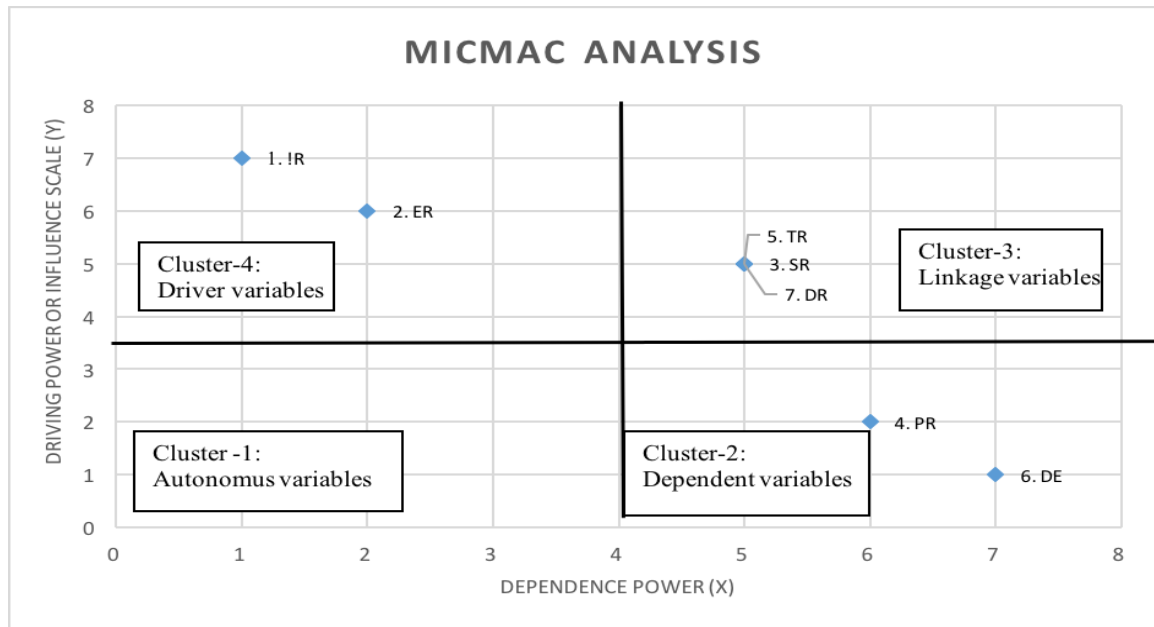


Figure 4.3 Classification of SCR variables on the basis of MICMAC analysis

#### 4.9 Conclusion

An ISM based model has been developed that exhibits the hierarchy of SCR variables. A better understanding of the SCR variables makes a robust supply chain risk management system. It is also important to understand the interdependence of these SCR variables to mitigate them effectively and efficiently. Through the literature survey and experts' opinion, seven SCR variables associated with the case-organisation have been identified out of several SCR variables. . The interrelationship hierarchy of these SCR variables has been established with the help of the ISM approach as shown in Figure 4.2. MICMAC analysis has been used to classify the SCR variables according to the dependency and impact of these variables. It is clearly shown in section 4.8 that supply risk , demand risk, transportation risk are the linkage variables; information technology risk and environmental risk are the driver variables while process risk and delay risk are dependent variables. No

autonomous variables out of these seven SC variables. Once the relationship among these SCR variables is established, assessment and prioritization of these SCR variables are carried out and explained in Chapter 5.