

Quantitative Approach to Supply Chain Relationships

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Abstract:

The objective of this research was the development of a methodology to define, measure and rank supply chain relationships.

The methodology offered by the authors presents supply chain integration as the optimisation of firm specific objectives while simultaneously satisfying system-wide objectives. This methodology may be used to evaluate the level of underachievement (overachievement) for intra-firm and / or inter-firm objectives. It also establishes a base for the development of quantitatively measured performance and control indicators. The methodology used software that combined Microsoft Excel spreadsheets with Visual Basic applications. Such an approach makes the methodology available for a broad range of potential applications.

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Problem Statement

Discussion and investigation of the ‘Supply Chain’ is a popular and important topic in agribusiness. Nevertheless, Supply Chain Management (SCM) has no agreed upon definition and theoretical base. This shortcoming makes the application of SCM methods to food and agribusiness situations difficult. Despite a lack of an agreed upon definition of SCM, it nevertheless is important to have analytical tools available to define and measure Supply Chain relationships. Such tools permit the unique aspects of SCM relationships to be clearly differentiated from other traditional business relationships such as distribution channel relationships.

Objectives

The objective of this research was the development of a methodology to define, measure and rank supply chain relationships that are defined in terms of goals and objectives.

Procedures

For this research, the authors define SCM as “an integration of each chain-member’s organisational activities in order to achieve particular objectives through achieving system-wide objectives.” “Organisational activities” were divided into two groups:

- Primary activities (inbound logistics, operations, outbound logistics, and marketing and sales, etc.), and
- Supporting activities (infrastructure maintenance, human resource management, financial management, product development, procurement, etc).

Each of listed above activities may be performed either by the organisation itself or outsourced – performed by other SC member(s). If the firm decides to outsource an activity, that action establishes SC relationships with other chain-member(s) for which those outsourced activities are primary activities. In the researchers view, the objective of SCM is to integrate outsourced activities of one SC-

member with the primary activities of other chain-members. This area of outsourced activities may also be referred to as the intersection of sets of goals where that set is not empty (Bailey).

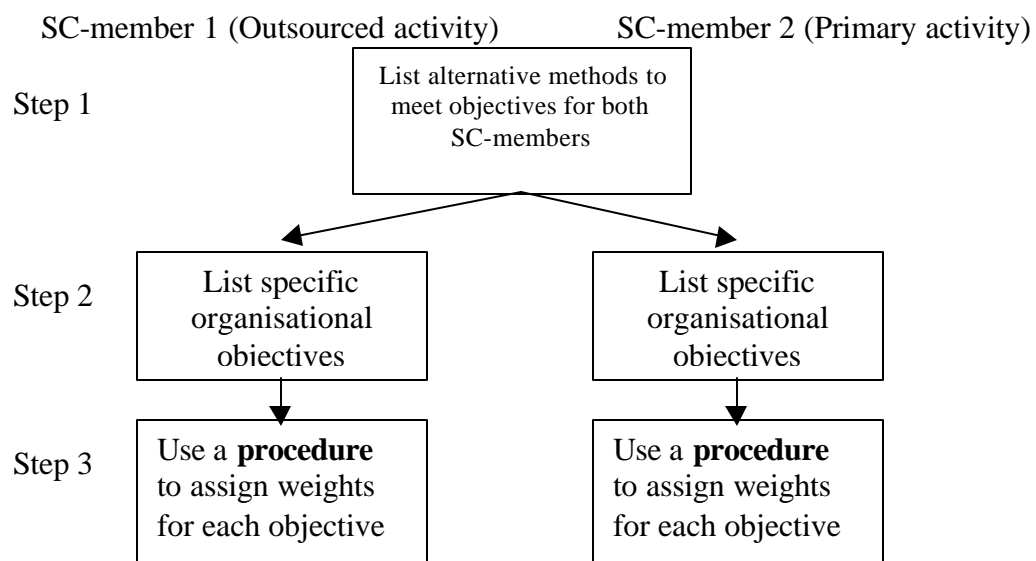
The specific goals of each chain-member may be achieved through establishing a set of supply chain-wide goals and attempting to meet those goals through cross-enterprise integration. Efficient use of such an approach requires an analytical tool that evaluates the alternatives available to SC members while taking into consideration each firm's specific (intra-firm) goals.

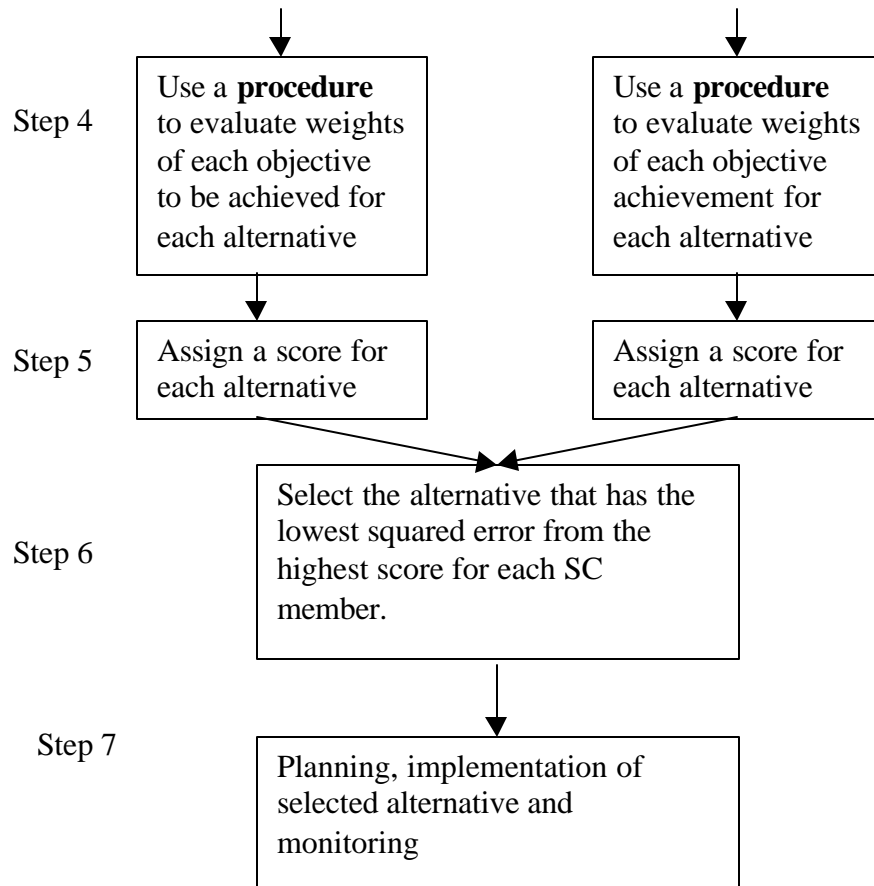
Each firm has specific objectives that may be achieved through SC integration. For example, objectives may be defined from the mission statement, financial goals, etc. The number of objectives and their definitions are different for each SC member. Some of those objectives are of interest only within the firm (private actions) while other objectives may best be met through co-ordination with firms outside the business (joint actions). Each firm has private actions that may be affected by joint actions and joint actions that may be affected by private actions. Because joint actions are, by definition, actions that affect two or more chain members, some methodology should be established so that the chain members may mutually rank those objectives while taking into consideration private actions.

The ability to mutually rank goals and objectives is a key component of SCM. Without agreement on the importance of goals that affect shared objectives, firms will reduce joint actions and increase private actions.

Consequently, a methodology to evaluate and rank joint and private actions was developed (See Figure 1).

Figure 1. Sequential steps in evaluation of SC alternatives





Step 1.

SC members list and agree upon a set of integrated alternatives available to SC members to achieve system goals.

Step 2.

Each SC member identifies its own specific objectives to be achieved as a result of SC integration. For example, organisational objectives (private actions) defined from the mission statement, financial goals, or other internal communications. The number and nature of those objectives vary across SC members.

Step 3.

Utility theory is independently applied by each SC-member in order to assign weights to each objective identified by individual firms in Step 2.

3-A) All objectives defined in Step 2 for SC-member k ($k=1,2$)

(Objective 1,..... Objective n_k) are pair wise compared. Results of these comparisons are placed in a pair wise comparison matrix (C^k_{ij} $k=1,2; i=1,\dots,n_k ; j=1,\dots,n_k$).

Table 1. Pair wise comparison matrix for SC-member k Objectives

	Objective 1	...	Objective j	...	Objective n_k
Objective 1	1	...	$C^k_{1n_k}$		$C^k_{1n_k}$
...
Objective I	C^k_{j1}	...	C^k_{ij}	...	$C^k_{in_k}$
...
Objective n_k	$C^k_{n_k1}$...	$C^k_{n_kj}$...	1

For example, if the achievement of Objective 1 is 5 times more important than the achievement of Objective 2, then $C^k_{12}=5$ and $C^k_{21}=1/5$.

In this matrix:

$$C^k_{ji} = 1/C^k_{ij}$$

and

$$C^k_{ji} = 1 \text{ if } i=j$$

3-B) The matrix is transformed to normalised form. Each element is divided by the sum of all elements in the corresponding column.

$$\bar{C}^k_{ij} = \frac{C^k_{ij}}{\sum_{i=1}^{n_k} C^k_{ij}} \quad (\text{Formula 1})$$

3-C) For each row an average value is calculated. This step gives weights to each Objective.

$$W^k_i = \frac{\sum_{j=1}^{n_k} \bar{C}^k_{i,j}}{n_k} \quad (\text{Formula 2})$$

$i= 1, \dots, n_k$

3-D) The initial pair wise comparison matrix is multiplied by the Objective Weights column.

$$\bar{W}^k_i = \sum_{j=1}^{n_k} W^k_j \times C^k_{ij} \quad (\text{Formula 3})$$

$i= 1, \dots, n_k$

3-E) The resulting column is synthesised by dividing each element by the corresponding Objective Weight from 3-C).

$$WN^k_i = \frac{\bar{W}^k_i}{W^k_i} \quad (\text{Formula 4})$$

$i= 1, \dots, n_k$

3-F) A Consistency Index is calculated as below:

$$\text{Consistency_Index}_k = \frac{\sum_{i=1}^{n_k} WN^k_i - n_k}{n_k - 1} \quad (\text{Formula 5})$$

If the Consistency Index determined is divided by the Consistency Index of a randomly generated pair wise comparison matrix (See Table 2) and results in a value less than 0.1, then the initial pair wise comparison matrix is sufficiently consistent.

Table 2. The consistency index (RI) of a randomly generated pair wise comparison matrix.

n_k	3	4	5	6	7	8
RI	0.58	0.9	1.12	1.24	1.32	1.41

Random indexes in Table 2 are calculated as the average values for Consistency Indexes if entries in the pair wise comparison matrix were selected randomly. If this Consistency Index divided by the Consistency Index of a randomly generated pair wise comparison matrix (See Table 2) is equal to or greater than 0.1, the decision maker has significant inconsistency in defining the initial pair wise comparison matrix. Values in this matrix must be re-evaluated and made internally consistent.

This may be described by the following logical statements:

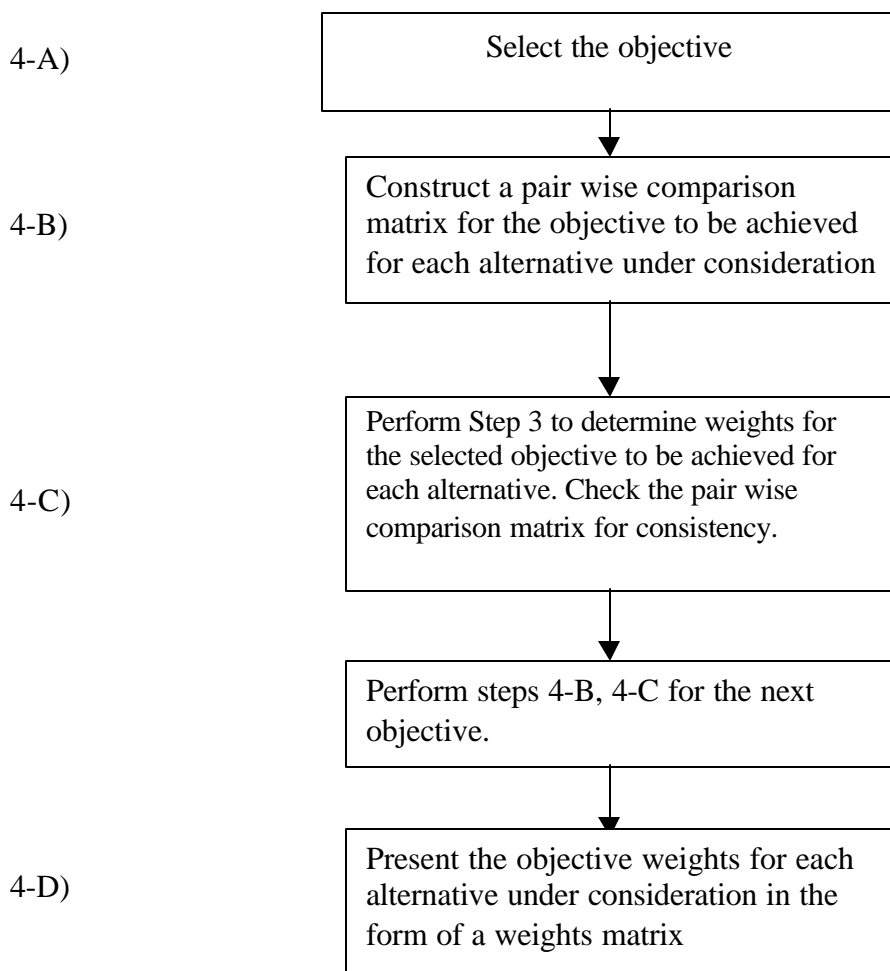
$$\text{If } \frac{\text{Consistency_Index}_k}{\text{Random_Index_for_}n_k} < 0.1 \quad \rightarrow \text{Sufficient consistency} \quad (\text{Formula 6})$$

$$\text{If } \frac{\text{Consistency_Index}_k}{\text{Random_Index_for_}n_k} \geq 0.1 \quad \rightarrow \text{Significant inconsistency}$$

Step 4

The following sequential procedure may be used to evaluate the weights assigned for achieving each objective for each alternative under consideration (Figure 2).

Figure 2. Sequential steps in the evaluation of weights of each objective achievement



4-A) Both SC members linked through their SC relationship should rank the same array of alternatives ($N > 1$).

4-B) Firm k ($k=1,2$) uses the above procedure to construct a pair wise comparison matrix of available alternatives based on the level of achievement of each of objectives.

For each objective $j=1\dots n_k$
 construct a pair wise comparison matrix A^{kj} level of objective j achieved by
 firm k .

**Table 3. Pair wise comparison matrix for the alternatives to achieve objective j
 by SC-member k**

	Alternative 1	...	Alternative m	...	Alternative N
Alternative 1	1	...	A^{kj}_{1j}		A^{kj}_{1N}
...
Alternative i	A^{kj}_{i1}	...	A^{kj}_{im}	...	A^{kj}_{iN}
...
Alternative N	A^{kj}_{N1}	...	A^{kj}_{Nm}	...	1

4-C) Perform Step 3 to determine the weights of the selected objective
 achieved using each alternative. Check pair wise comparison matrix
 consistency.

Table 4. Weights of objective j achieved by SC-member k)

	Objective j
Alternative 1	WA^{kj}_{1j}
...	...
Alternative i	WA^{kj}_{ij}
...	...
Alternative N	WA^{kj}_{Nj}

4-D) Weights are calculated for each of the objectives ($j=1\dots n_k$) and
 then placed into the Weight Matrix, Table 5.

Table 5. Weight matrix (SC-member k)

	Objective 1		Objective n_k
Alternative 1	WA^{k}_{11}		$WE^{k}_{1n_k}$
...

Alternative i	WA_{i1}^k		WE_{ink}^k
...
Alternative N	WA_{N1}^k		WE_{Nnk1}^k

Step 5.

Weights from 4-C and 3-D are used to calculate the total scores for the alternatives under consideration. Alternative scores are calculated by multiplying weight matrix (4-D) by objective weights column (3-B).

$$AL_{ik} = \sum_{j=1}^{n_k} WE_{ij}^k \times W_{i1}^k \quad i=1, \dots, N \quad (\text{Formula 7})$$

$k=1,2$

The results are grouped into a matrix that contains the scores of SC members for the alternatives, as in Table 6, below:

Table 6. Score matrix for SC alternatives

	SC member 1	SC member 2
Alternative 1	AL_{11}	AL_{12}
.....		
Alternative N	AL_{N1}	AL_{N2}

Step 6.

The above methodology provides an analytically derived objective basis to select the optimum alternative to achieve goals established for both SC-members. Once this objective assessment is made and a ranking established, SC - members may then use subjective criteria, if they choose, to determine how best to achieve share goals.

In the authors' research the alternative with the minimum squared error from the highest scores for each SC –member was selected (Alternative 1 in the algorithm described).

This selection process may be formulated as a non-linear programming problem. A suggested approach to this problem formulation is described below:

$$\text{Find } X_1, \dots, X_N$$

To minimise

$$\sum_{i=1}^N (1 - X_i)^2$$

subject to

$X_1 \dots X_N$ - binary

$X_1 + \dots + X_N = 1$

The selection process described above provides an objectively reached opportunity for mutual agreement on one of the alternatives available to chain members to reached system objectives. The scoring system provides each SC-member with a specific level to measure the degree to which each objective is achieved using an agreed upon alternative.

Step 7.

Following the above process, the selected alternative may now be presented in terms of organisational activity performance. Chain members should make plans to integrate the selected alternative into the operational plan for the SC. The plan should also establish specified performance measurement and control systems to monitor progress on how well the system is performing to meet the agreed upon objectives. The selected joint action plan should be integrated with the operational plans of each SC-member involved with this agreement. Intra-system performance and control systems must satisfy all requirements imposed on them.

Case Study. IT selection

Step 1.

A large agri-food processor and one of its supply chain partners – an overseas distributor - agreed in principle to introduce a new integrated information technology (IT) system.

There are three alternatives available to the two members for the introduction of a new IT system:

Alternative 1 - Purchase and install System X that is currently available;

Alternative 2 - Order a specialised system;

Alternative 3 - Hire a group of specialists to develop a system and upgrade the system to meet all system requirements.

SCM-member 1 (Agri-food producer)

Step 2-A. The Agri-food producer has the following list of objectives to be achieved with the decision to introduce a new IT system:

- Minimise net present value (NPV) of the required investment;
- Minimise business restructuring;
- Minimise documentation flow;
- Maximise the number of employees ‘freed up’ as a result of a new IT system.

Steps 3-A/5-A

Steps 3-5 are performed by the food producer. These Steps are detailed in Appendix 1. Table 7, below, is the result of Steps 3 – 5. The Table contains the scores for food-processor decision alternatives, taking into account the objectives listed in Step 2-A:

Table 7. Food processor scores for decision alternatives

	Priorities	Scores
Alternative 1	0.1238	3
Alternative 2	0.4988	1
Alternative 3	0.3776	2

SC-member 2 (Distributor)

Step 2-A. The Distributor has the following list of objectives to be achieved by the decision to implement a new IT system:

- Optimise customer database;
- Improve forecasting accuracy;
- Minimise order fulfilment lead-time.

Steps 3-B/5-B

The Distributor performs Steps 3-5. These Steps are detailed in Appendix 2. Table 9, below, is the result of Steps 3 – 5. The Table contains the scores for

Distributor's decision alternatives, taking into account the objectives listed in Step 2-A. The following table represents scores for distributor decision alternatives:

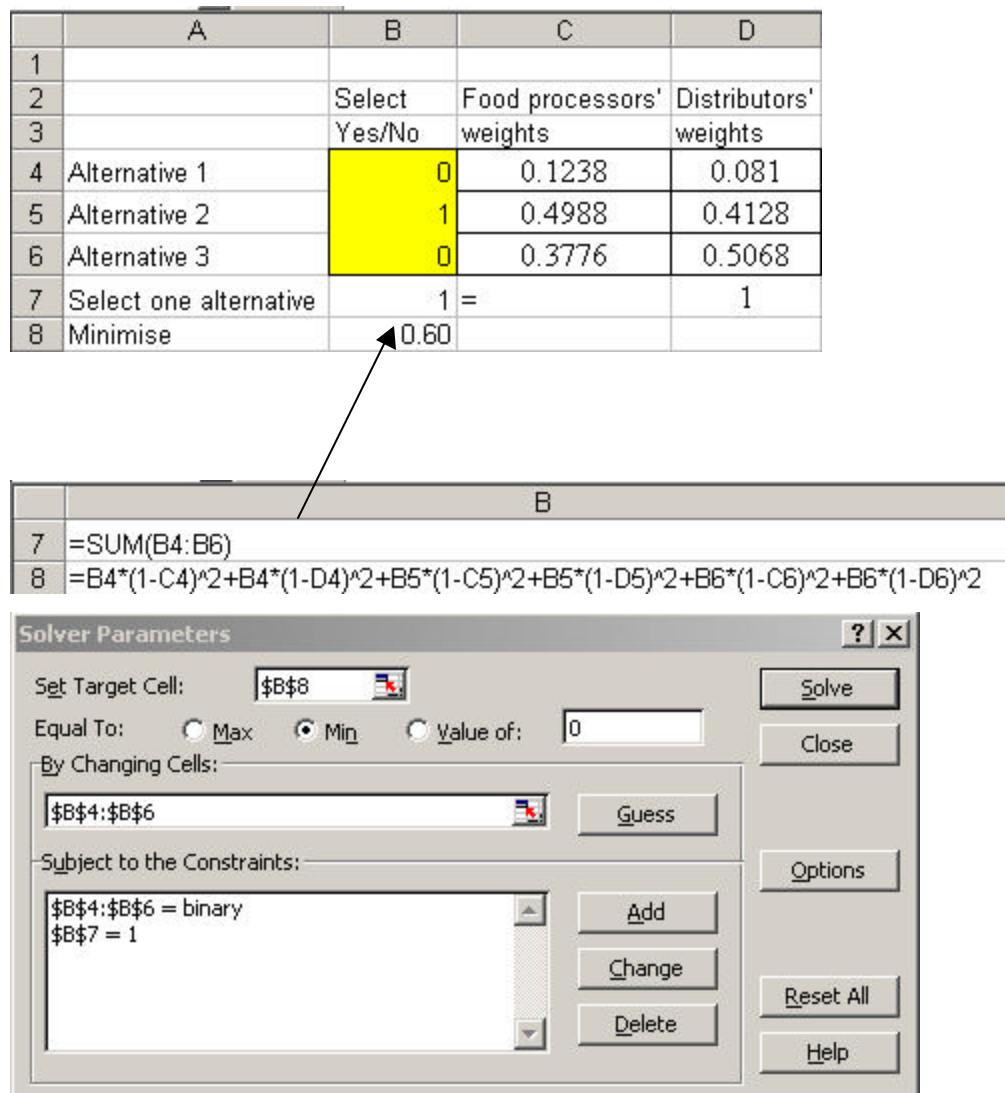
Table 8. Distributors' scores for decision alternatives

	Priorities	Scores
Alternative 1	0.081	3
Alternative 2	0.4128	2
Alternative 3	0.5068	1

Step 6

The priorities assigned to alternatives by the Food Processor and the Distributor, contained in Tables 8 and 9, are combined. A Microsoft Excel worksheet created to select the alternative with the lowest squared error from the highest weight for each SC –member is presented below.

Figure 3. Microsoft Excel presentation of alternative selection.



The optimum solution for this Case Study is to select the second alternative. In this Case Study, the optimum solution is obvious from the content of Table 9. However, in many joint action situations, there are more than two chain members involved.

An example of a decision that could affect many chain members could be a decision to modify container size or pallet loading. In such a situation, the alternative may be simply whether or not to change container size rather than attempting to select the optimum decision on alternative container sizes. A simple 'yes' or 'no' choice of alternatives – change container size or not - could have impacts on many chain members. These impacts could include items such as the number of people employed, whether or not purchasing new trucks would be required, if there would be an increase in documentation or if modifications in ocean freight scheduling would be necessitated. All of these private actions would be affected by the joint action.

Results

The methodology offered by the authors presents supply chain integration as the optimisation of firm specific objectives while simultaneously satisfying system-wide objectives. This methodology may be used to evaluate the level of underachievement (overachievement) for intra-firm and / or inter-firm objectives. It also establishes a base for the development of quantitatively measured performance and control indicators. The methodology used software that combined Microsoft Excel spreadsheets with Visual Basic applications. Such an approach makes the methodology available for a broad range of potential applications.

Additional case studies, including numerical case studies and a study of potential complications, are available from the authors.

Conclusions

This research developed a methodology that quantitatively defines and measures the level of Supply Chain integration on an intra-company and inter-company basis. This is achieved through a structured search for alternatives. The methodology selects the alternative that is optimal for all parties involved. The selection process, after solving using an objective criterion, may be modified to meet intra and inter firm subjective criteria.

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Appendix 1				
Food processor				
Pair wise comparison matrix for decision objectives				
Step 3	Max NPV	Min business restructuring	Min documentation flow	Max number of employees
Max NPV	1	5	2	2
Min business restructuring	0.2	1	0.25	0.25
Min documentation flow	0.5	4	1	0.33
Max number of employees	0.5	4	3	1
Weight	0.422	0.068	0.192	0.318
Consistency index = 0.0613055				
Consistency ratio =0.0613055 / 0.9 =0.068				
Pair wise comparison of decision alternatives on the basis of net present value maximisation				
Step 4 - Objective 1	Alternative 1	Alternative 2	Alternative 3	
Alternative 1	1	0.5	0.25	
Alternative 2	2	1	1.5	
Alternative 3	4	0.67	1	
Weight	0.155	0.431	0.414	
Pair wise comparison of decision alternatives on the basis of required level of business restructuring				
Step 4 - Objective 2	Alternative 1	Alternative 2	Alternative 3	
Alternative 1	1	0.2	0.125	
Alternative 2	5	1	0.5	
Alternative 3	8	2	1	
Weight	0.07	0.326	0.604	
Pair wise comparison of decision alternatives on the basis of minimising the business documentation flow				
Step 4 - Objective 3	Alternative 1	Alternative 2	Alternative 3	
Alternative 1	1	0.17	0.17	
Alternative 2	6	1	1	
Alternative 3	6	1	1	
Weight	0.077	0.462	0.462	
Pair wise comparison of decision alternatives on the basis of number of employees				
Step 4 - Objective 4	Alternative 1	Alternative 2	Alternative 3	
Alternative 1	1	0.2	0.5	
Alternative 2	5	1	3	

Alternative 3	2	0.33	1	
Weight	0.122	0.648	0.23	
Priorities assigned to the decision alternatives by the producer				
Step 5	Max NPV	Min business restructuring	Min documentation flow	Max number of employees
Alternative 1	0.155	0.070	0.077	0.122
Alternative 2	0.431	0.326	0.462	0.648
Alternative 1	0.414	0.604	0.462	0.230
Objective weight	0.422	0.068	0.192	0.318
Assigning scores for decision alternatives				
	Priorities	Scores		
Alternative 1	0.1238	3		
Alternative 2	0.4988	1		
Alternative 3	0.3776	2		

Appendix 2			
Distributor			
Pair wise comparison matrix for decision objectives			
Step 3	Customer database	Forecasting accuracy	Order fulfillment lead time
Customer database	1	0.2	0.17
Forecasting accuracy	5	1	0.5
Order fulfillment lead time	6	2	1
Weight	0.082	0.343	0.575
Consistency index = 0.014580			
Consistency ratio = 0.014580 / 0.58 = 0.025			
Pair wise comparison of decision alternatives on the basis of quality of customer database			
Step 4 - Objective 1	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	4	2
Alternative 2	0.25	1	2
Alternative 3	0.5	0.5	1
Weight	0.566	0.242	0.192
Pair wise comparison of decision alternatives on the basis of forecasting accuracy			
Step 4 - Objective 2	Alternative 1	Alternative 2	Alternative 3
Alternative 1	1	0.2	0.125

