Chapter 6

Virtual company formation for agile manufacturing using ANP & Goal Programming

6.1 Introduction

The continual competitiveness of manufacturing organizations in today’s economic and market climate requires organizations to introduce agile manufacturing practices (Presley and Liles, 2001). An agile organization is an enterprise that is capable of operating profitably in a competitive environment of continually, and unpredictably, changing customer opportunities and unpredictable change (Guisinger and Ghorashi, 2004; Webster and Sugden, 2003). Agile manufacturing builds upon methods of world class manufacturing including lean manufacturing, total quality management, empowerment of people, and production flexibility (Presley and Liles, 2001). This requirement of agility can be further supported through strategic alliances of organizations and integration using information technologies (Gupta and Gunasekaran, 2005).

The current market environment has compelled manufacturers to rapidly design and manufacture products that could provide instant customer satisfaction in a cost effective way. This balance of requirements is typically beyond the capabilities of any single isolated manufacturing enterprise, thus a partnering through temporary networks has arisen to meet this challenge and to exploit fast-changing market opportunities. A temporary network of organizations that come together quickly to exploit fast-changing opportunities has been defined as the Virtual Enterprise or the Virtual Corporation (VC)
VCs also provide the flexible, cohesive and synergistic business models needed for partner formation (Webster and Sugden, 2003). VCs have been as an alliance (usually temporary) of independent business processes or enterprises each contributing "core competencies" in areas such as design, manufacturing, and distribution to the corporation (Huang et al., 2004; Presley and Liles, 2001; Talluri et al., 1999). The formation and attributes of a successful VC depends on the selection of agile, competent, and compatible partners (Talluri et al. 1999).

Most researchers have discussed the attributes of the VC as an entity but Talluri et al. (1999) discussed their formation and also attributes of the companies forming these VC and emphasized that the success of VCs depend on the selection of agile, competent, and compatible partners termed as VCCs (virtual constituent companies). These VCCs have to be compatible and efficient as an individual company as well as a group joining together seamlessly. Thus selection of VCCs is critical for the formation and success of any VC. To the best of our knowledge no studies making use of Analytical Network Process (ANP) and Goal Programming (GP) together (qualitative/quantitative/perceptual and optimization approaches linked), and taking into account a detailed list of factors in regard to the formation of VC/selection of VCCs. This multistage approach has been developed to help address this relatively complex and rapid decision environment.

In this chapter a multi-phased analytical methodology is developed for the evaluation and selection of organizations needed for formation of a VC. These
organizations forming a VC termed as VCCs are evaluated for their suitability on qualitative and quantitative factors. Qualitative factors are defined as those factors on which direct data is not available and some subjective judgment is required, quantitative factors have direct quantifiable data available. Qualitative factors are evaluated using the ANP and with ANP outputs of the various potential VCCs integrated along with the quantitative factors in a second stage using zero–one integer goal program / programming (ZOIGP).

In the remainder of this chapter some background literature is presented to help set the foundation for the need and development of the two-staged analytical multiple criteria decision model approach developed in this part of research, followed by an overview of the approach. The methodology is then applied to a small VC case study. Discussion of the results and findings is then presented before a summary and conclusions completes this chapter.

6.2 Agile Manufacturing and Virtual Corporations

To understand the synergy and mutual support between agile manufacturing and VCs need to be defined more clearly. Agile manufacturing and agility were terms initially introduced by the Iacocca Institute study in 1991 and has been defined in a number of ways, but involves the capability to respond quickly and effectively to the current and future configurations of market demand, and also to be proactive in developing and retaining markets in the face of extensive competitive forces (Bessant et al., 2001; Sarkis, 2001; Yusuf et al., 1999). Various definitions of agile manufacturing have resulted in a
large set of attributes (e.g. Yusuf et al., 1999, has identified 32 factors and 10 decision domains). Many of these attributes could be achieved through the realization of VCs. The vision of VCs to achieve agility is well documented in the literature (Meade et al., 1997; Pant et al., 1994; Presley and Liles 2001; Webster and Sugden, 2003).

VCs have been defined in various ways but the use of agile manufacturing and agility attributes have been central to the formation of VCs (Stough et al., 2000; Talluri et al. 1999; Tuma, 1998; Webster and Sugden, 2003). VCs are temporary institutions formed to exploit a specific market opportunity and may include various suppliers, manufacturers, marketers, customers, and even competitors. Most definitions of VCs incorporate the idea of extensive outsourcing to suppliers and subcontractors in order to achieve a flexible, responsive network-based organisation (Webster et al., 2004).

The VC is not a theoretical model. Examples of well-known corporations that are taking advantage of VCs are Verifone, Hewlett Packard, IBM, AT&T, McDonald’s, Whirlpool, Toyota, Nokia, Nike, Reebok, Intersolve Group, and Apple Computer (Kim, 1998; Stough et al., 2000).

VC evaluation and formation can take on numerous managerial and economic dimensions including risk/security (Frank, 1996; Hallikas et al., 2002), standards and standardization (Clements, 1997), transaction costs such as acquisition of information, selection of potential partners, negotiation, agreement, settlement and controlling of distributed business processes (Tuma, 1998), cultural issues (Oertig and Buergi, 2006),
and VC architecture (Lin and Lu, 2005; Lee et al., 2003; Presley and Liles, 2001; Presley et al., 2001; Smith and Wolfe, 1995).

Most of the literature has discussed the attributes of the VC as an entity but yet the formation and attributes of the VCCs (agile, competent, and compatible partners) are needed for successful VCs (Talluri et al., 1999). Thus selection of VCCs is critical for the formation and success of any VC. Masella and Rangone (2000) discussed that supplier and partner selection is one of the most critical tasks for purchasing managers. Lau et al. (2005) pointed that partner selection becomes a major process of business operation. Unlike typical supplier selection models, the decision maker for VC formation may not be a purchasing manager in a company, but a broker dealing with numerous entities whose power-relationship structures are not clearly defined (Sarkis and Sundarraj, 2002). Thus, models for this type of environment will prove greatly beneficial for VC brokers who need to manage VCs.

6.3 Models of Virtual Corporation Formation and Evaluation

A significant amount of research and investigation has sought to address the importance of selecting supplier attributes for making decisions on supplier and VCC selections for VCs (Choy et al., 2004). The main questions in the determination of the criteria on the selection process are the needs of the firm in its practice and the level of the success of the selection criteria to fulfill these needs (Dogan and Sahin, 2003). Cost and time savings no longer the only factors to be considered in the partner formation and selection process, but also a wide range of other factors such as quality, flexibility,
innovation, organization and culture, with a view to make decisions by considering the whole supplier-partner capability in a long-term and strategic way (Pujawan and Goyal, 2005; Sarkis and Talluri, 2002b).

In practice, item cost, product quality, delivery performance, and supply capacity have been found to be the most frequently used vendor evaluation criteria. A review of 74 supplier selection articles by Weber et al. (1991) found that these four criteria received the greatest amount of attention in the recent literature. Dickson (1966), in one of the early works on supplier selection, identified over 20 supplier attributes which managers trade off when choosing a supplier or partner. However, converting requirements into useful criteria may be difficult due to qualitative issues and concepts, whereas the criteria typically need to be specific requirements that can be quantitatively evaluated. These quantitative and qualitative factors will also need to be practical (Kahraman et al., 2003). Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) have been recommended due to their capability for providing quantitative weights against a set of qualitative evaluation criteria but is neither efficient in evaluating large number of alternatives nor in choosing the performance frontiers (Sarkis, 1999).

ANP has seen a growth in application due to its many advantages, including: enterprise partner selection for vocational education (Chen et al., 2004); justifying strategic alliances and partnering (Meade et al., 1997); analyzing organizational project alternatives for agile manufacturing processes (Meade and Sarkis, 1999); analyzing alternatives for improvement in supply chain performance (Agarwal and Shankar, 2002);
selecting and evaluating third-party reverse logistics providers (Meade and Sarkis, 2002); selecting and analyzing the alternatives for on-line trust building in e-enabled supply chain (Agarwal and Shankar, 2003); investigating the linkage between organization performance criteria and the dimensions of agility, e-supply-chain drivers and knowledge management (Raisinghani and Meade, 2005); for the selection of an appropriate design method of a CIFMS (computer-integrated flexible manufacturing system) (Hassan and Kikuo, 2005); and to provide a quantitative multicriteria decision-making approach to knowledge management in construction entrepreneurship education at business schools (Chen et al., 2006). Thus, ANP shall be used to evaluate the various VCCs on qualitative criteria.

In the quest to enhance supplier development initiatives and possibly overcoming shortcomings associated with the traditional supplier selection techniques, many researchers have gone further to apply various decision support techniques. Examples include the Data Envelopment Analysis (DEA), AHP, activity based costing, principal component analysis, fuzzy sets theory, mixed-integer programming modeling approaches, artificial intelligence technique, expert systems, ant colony optimization, and neural networks, to name a few (Albino and Garavelli, 1998; Fischer et al., 2004; Morlacchi et al., 1997; Nwankwo et al., 2002; Teng and Jaramillo, 2005; Vokurka et al., 1996; Lau et al., 2005; Moynihan et al., 2006).

The selection of VCCs for a VC, along the lines of supplier selection, but includes the complexity due to simultaneous decision upon multiple and heterogeneous set of
vendors, involves numerous objectives and constraints including capacity constraints, compatibility constraints, and multiple, sometimes conflicting goals. To address this issue a two-stage decision support procedure is suggested that integrates ANP with GP. The application of these tools is quite valuable in the linkage of qualitative and quantitative factors as well as seeking to determine the best set, based on perceptions, goals and constraints of decision makers of VCC for VC formation. This will be the first time that these two tools will be applied for VC formation purposes. These two tools have the advantages of integrating a complex set of factors (tangible and intangible), simultaneous decision on multiple and heterogeneous set of potential VCCs (in contrast to DEA), providing consideration of multiple objectives, incorporating various organizational and operational constraints, while seeking to arrive at an optimal answer.

6.4 Goal Programming and AHP/ANP

GP introduced by Charnes and Cooper (1961), deals with the problem of making a decision while balancing a set of conflicting goals and falls within the purview of multiple objective linear programming tools. The objective function searches to minimize deviations from the set of pre-assigned goals. GP attempts to achieve a best solution based on preferences and weights, rather than a strict “optimal” solution due to conflicting goals and varying decision maker requirements (Gokeyn and Erel, 1997).

GP can be solved in two ways: (i) using of the simplex algorithm directly if weights given for goals are precisely defined and (ii) using of the preemptive GP if weights given for goals are not precisely defined, but are ordered
A1>>>M2>>>G3>>>... (e.g. where criteria associated with A1 is much greater in importance than M2 and M2 is much greater in importance than G3) (Schniederjans, 1995; Gokeen and Agpak, 2006). In a preemptive GP model, the upper level goals are first optimized before lower level goals are considered. In a non-preemptive model, the goals are given some weights and considered simultaneously. More detail on the GP formulation is presented later.

In general, identifying the importance levels and objective function weights in GP is a complicated exercise. Several additional methods such as Analytical Hierarchy Process (Ramanathan and Ganesh, 1995) have been employed for deriving the importance levels. In the literature there are various studies that have used AHP and GP as synergistic decision support tools (Myint and Tabucanon, 1994; Schniederjans and Garvin, 1997; Lee and Kwak, 1999; Badri, 1999; Badri, 2001; Wang et al., 2004). In these studies, AHP is used to rank the alternatives on various qualitative criteria, and the outputs of the AHP model are incorporated into the GP objective function. No studies making use of ANP and GP together in regard to the formation of VC/selection of VCCs were found.

In the next sections some more detail on the use and application of ANP and GP is provided for the problem situation discussed in this chapter. An integrated framework making use of ANP and GP is evaluated and developed within the context of a small company case study.
6.5 The Synergistic ANP – GP Methodology for the selection of Virtual Constituent Companies (VCCs)

AHP/ANP and GP provide synergistic advantages when linked together, primarily through the systemic integration of qualitative and quantitative factors (Wang et al., 2004). It shall be described and shown how the methodologies are utilized separately and together to arrive at a general approach for the selection of VCCs.

6.5.1 The Analytical Network Process

To be able to model complex situations, Saaty (1980) introduced AHP. ANP is a more general form of AHP, incorporating feedback and interdependent relationships among decision attributes and alternatives. This provides a more accurate approach when modeling a complex decision environment (Saaty, 1996). ANP is similar to AHP except:

1. there are interdependencies among attributes and attribute levels that may be represented by two-way arrows (or arcs) among levels, or if within the same level of analysis, a looped arc.

2. there is no strict hierarchical relationship among attributes and attribute levels i.e. a level may both dominate and be dominated, directly or indirectly, by other decision attributes and levels (defined as decision network hierarchy).

To elicit preferences of various components and attributes, the decision-maker compares two components at a time with respect to a “control” criterion. In ANP, like AHP, pairwise comparisons of the elements at each level are conducted with respect to their relative importance toward their control criterion. The control criterion for these pairwise comparisons can be the criteria at the upper, lower, or the same levels.
of the decision network hierarchy (Chen et al., 2004). The relative importance or strength of the impacts on a given element is measured on a ratio scale similar to AHP i.e. on a scale of one to nine. For the case example cited in this chapter, the relative importance weights (e vector) are calculated by freely available software for academic purposes known as “Super Decisions”.

The ANP approach is capable of handling interdependent relationships among elements by obtaining the composite weights of the standard control mechanisms defined in the previous paragraph, and then through the development of a ‘supermatrix’. The supermatrix development requires a series of steps for assessing the model. In summary, these steps include:

1. completing pairwise comparisons of the components on their controlling factors;
2. taking the results relative importance weights (eigenvectors) and placing them in submatrices within the supermatrix;
3. adjusting the supermatrix so that it is ‘column stochastic’ (i.e. the summation of the values in the columns of the supermatrix sum to one); and
4. raising the supermatrix to a sufficiently large power until the weights have converged and remain stable.
5. The final results (weights) of the ANP for the alternatives (VCCs) are those that appear in the first column of the converged supermatrix, under the objective (Saaty, 1996).

These steps are further detailed and illustrated in the case example in a later section.
6.5.2 The GP model formulation

The GP formulation can either be a basic or preemptive priority formulation depending on whether the priority weights in the objective function have set or preemptive priorities. The GP is now presented. The objective function (equation 1) minimizes the weighted sums (if weights are not assigned, LINDO automatically attaches some weights to find the best solution for all the goals and under the existing constraints) of the negative and positive deviations if solved as a non-preemptive GP, and if solved for preemptive GP, the goal of the highest priority is satisfied first and then a goal of next lower priority and so on. The goal constraints are then included with minimizing (equation 2) and maximizing (equation 3) goal constraint sets listed separately. A selection constraint (equation 4) is included where only one VCC per process is to be selected for the VC. The side constraints have not been listed since they would be dependent on various constraints for either the VC or a particular VCC. In the example problem below some compatibility (or incompatibility) constraints have been included that would not allow certain pairs of VCC’s to be included in the VC. Various capacity constraints on the various VCCs have also been included. Finally the various non-negativity and integer constraints (equation 5) are included for each of the variables.

\[
\text{Minimize } Z = \sum_{i=1}^{n_{\text{in}}} P_i d_i^+ + \sum_{j=1}^{n_{\text{out}}} P_j d_j^- \tag{1}
\]

subject to

\[
\sum_{\lambda=1}^{P} \sum_{j_{\lambda}=1}^{M} f_{i_{\lambda}} x_{\lambda j_{\lambda}} - d_i^+ = 1 \quad \forall i \in n_{\text{in}} \tag{2}
\]

\[
\sum_{\lambda=1}^{P} \sum_{j_{\lambda}=1}^{M} f_{i_{\lambda}} x_{\lambda j_{\lambda}} + d_j^- = 1 \quad \forall j \in n_{\text{out}} \tag{3}
\]
\[
\sum_{k=1}^{M} x_{jk} = 1 \quad \forall \lambda \in P
\]  

(Side constraints, e.g. compatibility and capacity constraints)

\[
d^*_i, d^*_j \geq 0, \quad x_{jk} \in (0,1)
\]

where,

\( P \) = number of processes (also defined as VCC candidate groups) required within the VC

\( M \) = number of candidate VCC’s for VC process \( \lambda \)

\( n_{\min} \) = number of goals (factors) that are to be minimized

\( n_{\max} \) = number of goals (factors) that are to be maximized

\( P_i \) = preemptive priority associated with the \( i \)th factor that is to be minimized;

\( P_j \) = preemptive priority associated with the \( j \)th factor that is to be maximized;

\( d^*_i \) = positive deviational variable for a minimizing factor \( i \)

\( d^*_j \) = negative deviational variable for a maximizing factor \( j \)

\( x_{jk} \) = \( k \)th candidate VCC of VC process \( \lambda \)

\( f_{i;k}^{\min} \) = final normalized factor score for minimizing factor \( i \), process \( \lambda \), \( k \)th candidate VCC of VC process \( \lambda \)

\( f_{j;k}^{\max} \) = final normalized factor score for maximizing factor \( j \), process \( \lambda \), \( k \)th candidate VCC of VC process \( \lambda \)

To arrive at the final normalized minimizing and maximizing factor scores, \( f_{i;k}^{\min} \) and \( f_{j;k}^{\max} \), respectively, three steps are to be completed (1) mean normalize the factor scores,
These steps are now detailed.

Step 1: Factor mean normalization

\[ f_{MN}^{i} = \frac{f_{RAW}^{i}}{\sum_{\lambda=1}^{P} \sum_{k=1}^{M_{i}} f_{RAW}^{ik}} \quad \forall i \in (n_{max} \cup n_{min}) \quad (6) \]

\[ f_{MN}^{i} \] is the mean normalized score and \[ f_{RAW}^{i} \] are the raw scores for factor i (which includes both minimizing and maximizing factors), process \( \lambda \), \( k^{th} \) candidate VCC of VC process \( \lambda \), respectively.

Step 2: Determine initial raw goal for each of the factors:

For each minimization factor the goal, \( G_{i}^{\min} \), will be determined by summing the minimum mean factor values from each of the processes. That is

\[ G_{i}^{\min} = \sum_{\lambda=1}^{P} \sum_{k=1}^{M_{i}} f_{MN}^{ik} \quad \forall i \in n_{\min} \quad (7) \]

For each maximization factor the goal, \( G_{j}^{\max} \), will be determined by summing the maximum mean factor values from each of the processes. That is

\[ G_{j}^{\max} = \sum_{\lambda=1}^{P} \sum_{k=1}^{M_{j}} f_{MN}^{jk} \quad \forall j \in n_{\max} \quad (8) \]

Step 3: Final goal normalization of the factor scores:

This step is completed for the minimizing constraints by:
\[ f_{\text{min}}^{\text{MNV}} = \frac{f_{\text{min}}^{\text{MNV}}}{G_i} \quad \forall i \in n_{\text{min}}, \lambda \in P, k_\lambda \in M_\lambda \]  

This step is completed for the maximizing constraints by:

\[ f_{\text{max}}^{\text{MNV}} = \frac{f_{\text{max}}^{\text{MNV}}}{G_j} \quad \forall j \in n_{\text{max}}, \lambda \in P, k_\lambda \in M_\lambda \]  

6.6 Case Development: A Small Organization Illustrative Example

A small virtual organization example is utilized to help illustrate the decision methodology. To detail the characteristics of the decision environment requires a little background on the organization seeking to make decision on VC formation. The company was established in 1985 by qualified and experienced professionals to cater to complex equipment requirements of the Tube Industry worldwide. The organization is an India-based company that designs, manufactures, supplies and commission equipments/lines in very wide ranges comprising of Tube Mills along with complete cold drawing plants and other Strip Processing Lines like Hot / Cold Rolled Slitting Lines, and other related equipments. It has a large customer set to support its commitment to quality and actively supplying their world-class equipments to UK, USA, Spain, Poland, Turkey, China, Nepal, Malaysia and many other countries.

This organization is among the few companies in the world which can offer complete Tube Plants and services including all toolings and turnkey solutions by providing plant engineering for all utilities and auxiliary equipment. To strengthen their commitment to quality, the organization is an ISO 9001 certified company.
This company has design, manufacturing and distribution infrastructure for their regular products. However, the company has a policy to utilize the services of other organizations for design, manufacturing, and distribution of their new and innovative products. In doing so, this company has to select designers, manufacturers and distributors for the agile manufacturing of these products. Once these new and innovative products are established in the market, this company inducts these products into their mainstream products and develops complete infrastructure for them.

In identifying VCCs for an agile relationship for customized & innovative products manufacture, three VCCs each (a total of nine VCCs) fall within three process categories, Designers, Manufacturers and Distributors companies. The VCCs were initially selected through a screening exercise for rigorous assessment of their capabilities. The potential manufacturing VCCs were selected after an initial discussion between the manufacturing managers of both sides and then a visit of a team of engineers followed by discussions on the manufacturing capabilities of these VCCs. However, the decision makers preferred manufacturing process VCCs with a close geographic proximity to the case company. Thus, all the three potential manufacturing process VCCs were selected based on this initial criterion of close proximity to this case company. The other VCCs, the designer process and distribution process, were mainly selected on the basis of their general reputation and assessment of their capabilities through other projects undertaken by them. These initial VCCs will now be narrowed down for the final selection. The vendor development manager of the company in consultation with
his colleagues and interviews of the liaison managers of the VCCs made the decision on the various factors intended for the selection of VCCs.

6.6.1 Designing and Modeling the Decision Environment

The ANP decision network hierarchy is shown in Figure 6.1. As the intention is to select VCCs for the formation of a VC within an agile manufacturing environment (objective of the decision), the four dimensions of agility are applied for VCC selection as the controlling criteria. In this ANP model, the four controlling criteria associated with the agile manufacturing environment are: Ability to modify product/process, Schedule Reaction, Human Factors, and Agility Enhancing Factors. The other aspect of this decision network hierarchy is the evaluation of qualitative attributes of the VCCs whereas quantitative attributes are integrated at a later stage.

The various attributes used in this ANP model are derived from the literature. The various attributes under “Ability to modify product/process” are: Cross-functional teams within and across company borders (Yusuf et al., 1999); Continuous training and development (Yusuf et al., 1999); Research & development (De Boer et al., 1998; Petroni and Panciroli, 2002).

The various attributes under “Schedule reaction” are: Use of manufacturing/logistic and design-related technologies and methodologies (Petroni and Panciroli, 2002); Use of technology enhancing flexibility, skill and knowledge (Yusuf et al., 1999); Capabilities for innovation in product design/process and distribution strategy (Krause et al., 2001).
Objective: Evaluation of VCCs on qualitative attributes in an agile manufacturing environment

- Ability to modify product/process (AMP)
- Schedule Reaction (SR)
- Human Factors (HF)
- Agility Enhancing Factors (AEF)

Cross-functional teams within and across company borders (CFT)
Continuous training and development (CTD)
Research & development (R&D)

Use of manufacturing/logistic and design-related technologies and methodologies (MLDTM)
Use of technology enhancing flexibility, skill and knowledge (TEFSK)
Capabilities for innovation in product design/process and distribution strategy (CI)

Compatibility across levels and functions of buyer & supplier firms (CALF)
Culture of change (CC)
Capabilities for building new to new, temporary, speedy, efficient and effective relationships (CBR)

Capabilities of conflict resolution (CCR)
Developed business practice difficult to copy (DBP)
Response to changing market requirements (RCMR)

VCCs x11, x12 & x13 for design process
VCCs x21, x22 & x23 for mfg. process
VCCs x31, x32 & x33 for logistics process

Figure 6.1: ANP model for ranking the VCCs on qualitative attributes
The various attributes under “Human factors” are: Compatibility across levels and functions of buyer & supplier firms (Vokurka et al., 1996; Sarkis and Talluri, 2000); Culture of change (Yusuf et al., 1999); and Capabilities for building new to new, temporary, speedy, efficient and effective relationships (Sarkis and Talluri, 2000).

The various attributes under “Agility enhancing factors” are: Capabilities of conflict resolution (Sarkis and Talluri, 2000); Developed business practice difficult to copy (Yusuf et al., 1999); Response to changing market requirements (Yusuf et al., 1999).

It is relatively difficult to assign quantitative and objective numbers to most of these attributes (and their influence on each other) and that is why ANP shall be used to quantify the results.

These qualitative suppliers/VCCs’ attributes are relatively self-explanatory and details, if required, could be found from their respective references. It has been assumed that the four control criteria as well as VCCs’ qualitative attributes under their respective controlling criterion have some interdependency that is shown in the ANP model by the arched arrows at their respective positions. Nine VCCs (alternatives) are judged on these attributes as per the decision network hierarchy. These nine VCCs comprise three designer companies, three manufacturing companies and three distribution (logistics) companies. The results of this ANP analysis are applied in the next stage of this analysis using the ZOIGP.
A set of quantitative attributes relevant to the process of selecting VCCs and to be integrated in the ZOIGP with the qualitative attribute performance from ANP include the following:

**Net Price:** The net price (including discounts) offered by a vendor/supplier/VCC for a component/product (Dickson, 1966).

**Service:** Statistics are used in the purchasing department for measuring the service level. Keeping a promise of due dates, and keeping the right amounts of orders are examined (Barla, 2003).

**Quality:** Supplier/VCC quality performance can be measured by the number of defect-free deliveries divided by the number of deliveries recorded over a period of time (Ryder and Fearne, 2003).

**Lead Time:** The time period required by a supplier/VCC from order to delivery of the part/product (Handfield, 1994).

### 6.6.2 Completing the ANP analysis

In order to obtain the equivalent quantitative data of the various qualitative attributes associated within and with each category (designer, manufacturer and distributor) of the VCCs, ANP is utilized. Using the ANP decision network hierarchy developed in the previous sections, ANP supermatrix approach will be applied to this framework.

The first step, as defined in section 6.5.1 for the ANP analysis is to complete the pairwise comparisons whose relative importance weight results will populate the
supermatrix. The analysis of the decision network hierarchy model shown in Figure 6.1 shall require the evaluation of 33 pairwise comparison matrices. An example pair wise comparison matrix and its eigenvectors and inconsistency scores are shown in Table 6.1.

<table>
<thead>
<tr>
<th>Schedule Reaction pairwise comparison matrix</th>
<th>Use of manufacturing / logistic and design-related technologies and methodologies</th>
<th>Use of technology enhancing flexibility, skill and knowledge</th>
<th>Capabilities for innovation in product design / process and distribution strategy</th>
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<td>3.000</td>
<td>6.000</td>
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<td>Use of technology enhancing flexibility, skill and knowledge</td>
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<td>0.5</td>
<td>1.000</td>
<td>0.111</td>
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Table 6.1: Pairwise Comparison Matrix

The second step is to populate the supermatrix using the eigenvectors (weights) to form sub-matrices, which were calculated through the pairwise comparison matrices in the first step. The supermatrix that is formed for the case example is shown in Table 6.2.
### Table 6.2: Supermatrix

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For convergence to occur, the columns of the supermatrix are to be column stochastic i.e. each column sum up to one. This is the third step of the procedure. The supermatrix shown in Table 6.2 is made column stochastic by dividing each entry of the column by the sum of that column.

The fourth step of the ANP process is to arrive at a stable set of weights for each of the alternatives. To accomplish this goal, the supermatrix is raised to a sufficiently large power, such that convergence of the weights occurs (in the present case example the supermatrix is raised to the 64th power, with convergence occurring to the 10^-4 level). The converged supermatrix is shown in Table 6.3.

The final results (weights) for the nine VCCs are those that appear in the first column of this converged supermatrix, under the goal i.e. 0.2167, 0.1753, 0.1848, 0.0924, 0.0928, 0.0785, 0.0542, 0.0526, 0.0527. Using the various agility factors and sub-factors and their interdependencies it has been found that the decision makers believe that the most important member of the VC, using these qualitative agility benefits, is the designer process group. The least important member is from the distribution process group. This difference in weights between process groups will not come into play for this decision since it is required to select one member (and only one) of each group, but could provide insights for managers when trying to negotiating and contracting for specific services (which is beyond the scope of this part of research). The weights for the nine VCCs are normalized as defined in section 6.5.2 and utilized in the GP as a constraint on the factor “Qualitative Benefits”.

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Table 6.3: Converged Supermatrix (raised to 64th power)
6.6.3 Integrating Qualitative and Quantitative valuations using Zero-One Integer Goal Programming

The performance data (raw) of the nine VCCs on various criteria is shown in Table 6.4. The case company wishes to reduce net price and lead time values ($n_{\text{min}} = 2$), and increase service, quality and qualitative benefits valuations ($n_{\text{max}} = 3$).

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<td>Lead Time (in days)</td>
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<td>Service (%)</td>
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<td>Quality (%)</td>
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Table 6.4: Performance Data (raw) of the various VCCs

For the ZOIGP used for this purpose refer to the appendix A4. The weights from qualitative analysis from ANP of the nine VCCs ($P=3$, $M_1=3$, $M_2=3$, $M_3=3$) are normalized and used as a goal constraint for the qualitative benefits factor in the ZOIGP. There are two sets of side constraints. The first set includes two compatibility constraints where VCC 1 of Process 2 (the first manufacturer) does not want to work with VCC 1 of
Process 1 (the first designer), and VCC 2 of Process 3 (the second distributor) does not want to work with VCC 2 of Process 2 (the second manufacturer). As per the requirement of the case company, the manufacturing process VCC shall be able to simultaneously manufacture at least 12 machines. Manufacturing process VCCs 1, 2, and 3 are able to simultaneously manufacture 10, 15, and 20 machines respectively.

The ZOIGP thus developed is solved using both preemptive and non-preemptive GP using the LINDO software package. For preemptive GP, the priorities set (as decided by the case company) are in the order of: “Qualitative Benefits”, “Net Price”, “Quality”, “Service”, and “Lead Time”. In case of non-preemptive GP, no weight is attached to the various factors and LINDO shall attach its own weighting procedure to obtain its solution. However, results of non-preemptive GP shall be checked for likely variation in the selection of VCCs with the variation in the weights attributed to the various factors (refer to the sensitivity analysis section of this chapter).

6.7 Results and Discussion

On solving the ZOIGP for non-preemptive GP with no weights using LINDO software package resulted in the selection of the first designing VCC ($x_{11}=1$), the second manufacturing VCC ($x_{22}=1$), and the third distributor VCC ($x_{33}=1$). The various deviational variable scores are: $d_5^-=0.004$, $d_1^+=0.024$, $d_2^- = 0.007$, $d_3^- = 0.017$, $d_4^+ = 0.349$. The conversion of the deviational variables to their equivalent values reveal that the factor “Qualitative Benefits” was within 0.048% of the target value, Net price was
within $40,677 of its target value, Quality within 0.677%, Service within 1.638%, and Lead Time within 15 days of its target value.

The ZOIGP solution for preemptive GP using LINDO software package resulted in the selection of the first designing VCC (x11=1), the second manufacturing VCC (x22=1), and the first distributor VCC (x31=1). The various deviational variables are: $d_5^- = 0$, $d_1^+ = 0.039$, $d_2^- = 0.007$, $d_3^- = 0.007$, $d_4^+ = 0.349$. The “Qualitative Benefits” goal was completely satisfied. Net price was $66.10 from target, Quality was within 0.677% of target, Service within 0.674% of the target, and Lead Time was within 15 days of target. The major tradeoff between a non-preemptive and preemptive GP solution was an improvement in meeting the qualitative benefits goals with a commensurate worsening of the net price goals.

The selection of the solution method (preemptive or non-preemptive) for this ANP-ZOIGP formulation for the selection of VCCs shall depend on the criteria of the company about the relative importance of the factors. If a company follows a rigid policy of almost completely satisfying a particular goal then it shall be appropriate to solve it as Preemptive GP with top priority assigned to that goal, otherwise it may be solved for optimization as a non-preemptive GP using suitable weights that may be derived using AHP which is further evaluated.
6.7.1 Sensitivity Analysis

In response to the shifting selection of VCCs and the variation in meeting goal targets, it was decided to complete a sensitivity analysis by changing the priority weights of the deviational variables in the ZOIGP formulation. The sensitivity of the obtained results was evaluated by varying the weights of the factor “Qualitative Benefits”. This factor was viewed, by the decision makers and analyst, to be the more critical factor that could significantly change results if weights were allowed to be more flexible.

The weights for all the four quantitative factors as well as “qualitative benefits” factor are derived by a simple pair-wise comparison matrix using the AHP methodology (see Table 6.5) with the assumption that no interdependence exists among the factors “Net Price”, “Lead Time”, “Quality”, “Service” and “Qualitative factors”.

| Objective: Selection of the VCCs for the formation of a virtual corporation representative of agile manufacturing environment |
|----------------------------------|------------------|------------------|------------------|----------------------------------|------------------------------|
| OBJEC-TIVE                      | Net Price | Quality | Service | Lead Time | “Qualitative Benefits” *(evaluated using ANP) | eVector (Inconsistency Index = 0.0065) |
| Net Price                       | 1.000     | 1.5     | 2.00    | 2.00      | 0.667                                      | 0.243                        |
| Quality                         | 0.667     | 1.000   | 1.5     | 1.8       | 0.5                                        | 0.181                        |
| Service                         | 0.5       | 0.667   | 1.000   | 1.5       | 0.4                                        | 0.134                        |
| Lead Time                       | 0.5       | 0.555   | 0.667   | 1.000     | 0.4                                        | 0.110                        |
| “Qualitative Benefits”**        | 1.5       | 2.00    | 2.5     | 2.5       | 1.000                                      | 0.332                        |

Table 6.5: AHP Pairwise Comparison Matrix
The variation in the weights of the factor “Qualitative Benefits” was made while keeping the ratios of the weights, as determined by the AHP, of all other factors constant as well as the sum of all the factors equal to 1. The factor weighting scheme for the sensitivity analysis is shown in Table 6.6.

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Qualitative Benefits</td>
<td>0.1</td>
</tr>
<tr>
<td>Net price</td>
<td>0.33</td>
</tr>
<tr>
<td>Quality</td>
<td>0.24</td>
</tr>
<tr>
<td>Service</td>
<td>0.18</td>
</tr>
<tr>
<td>Lead Time</td>
<td>0.15</td>
</tr>
</tbody>
</table>

**Table 6.6:** Factor weighting scheme for Sensitivity Analysis

Solving the ANP-ZOIGP (non-preemptive) formulation, with the four set of weights of the factors shown in column 1, 2, 3 and 4 of Table 6.6, led to the selection of VCCs x11, x22 and x33 for each set. However, solving this ANP-ZOIGP (non-preemptive) formulation, for the set of weights shown in column 5 of Table 6.6, led to the selection of VCCs x11, x22 and x31 which is the same results as were obtained while solving this ANP-ZOIGP formulation for preemptive GP with factor priorities in the order of Qualitative Benefits, Net price, Quality, Service and Lead Time.

It could be easily inferred from the sensitivity analysis that as the weight of the factor “Qualitative benefits” is raised sufficiently in comparison to other factors, the
selection of the VCCs is same for both the non-preemptive solution and preemptive solution with “Qualitative benefits” as the first priority. This inference is in agreement with the solution procedure of LINDO that attaches a very high weight to the first priority factor while solving preemptive GP and shows that the solution is relatively robust.

This illustrative case study of the VCCs selection and formation methodology demonstrates its flexibility. The methodology can easily be adjusted to the requirements, priorities, goals, and constraints of the decision makers. This flexibility provided some confidence to decision maker’s in making an appropriate selection for their situation. They were comfortable with the process and the robustness of the solution. They hope to follow this methodology in the future as well for other decisions involving objective and subjective judgment with multiple goals. The formation of the VC using this methodology was in agreement with the initial general perception of the decision makers about the selected VCCs. This methodology has provided analytical validation to the decision makers’ perception and experience, further justifying their impressions.

6.8 Summary and Conclusions

VCs formed from multiple VCCs to meet a market opportunity are more commonplace these days due to shortened product life cycles and increased competition. Skills and resources of individual organizations are not typically adequate for this agile environment and thus the need for VC formation. To function within a VC a VCC needs to have agile capabilities and characteristics. Given this agile environment, this part of research introduces a multi-phased, multiple criteria methodology to evaluate and form a
VC from a group of VCCs. The methodology incorporates tangible and intangible factors that are typically required for a decision with this level of complexity. The methodology developed here incorporates agility and agile manufacturing characteristics into the evaluation, along with traditional operational performance measures. It uses ANP and GP in its evaluation, the first time that these two tools have been used synergistically for a VC formation decision. The methodology was applied to an actual case study situation, which showed the practical applicability and validation of the approach.

Even though numerous advantages exist for this approach, there are limitations. ANP can become quite involved and complex as the number of factors and relationships increase, causing decision maker and analysis fatigue. The case example showed a relatively robust solution, but due to perceptual inputs an optimal answer cannot be guaranteed. In addition, as the number of VCCs and factors increases data requirements becomes burdensome. Even though the structure follows a logical sequence, management decision makers may prefer a more transparent technique that incorporates a single phased analysis. Development into an effective decision support tool would help to overcome this last limitation.

The initial development and introduction of this methodology, and its limitations, sets the foundation for additional future investigations and developments. Future research directions may include the evaluation of each category of VCCs on qualitative attributes using a separate ANP model for each category of VCCs. The other approach
could be the consideration of interdependencies in this ANP model at the level of alternatives (VCCs). This ANP-GP model may be tested for a larger potential VCC sets. In the GP, additional constraints may be considered e.g., resource and risk constraints. For the non-preemptive GP, the weights have been determined using AHP considering that no interdependence exists among the factors could be relaxed and could be evaluated using ANP. This model has been tested for a customized and innovative product from the engineering sector, so this model could be tested for products from other sectors, more traditional production environments. This model could also be tested for a broker company, which has almost no resources of its own in regard to design, manufacturing, and distribution. The model may be relaxed and adjusted in other ways. For example, the criteria to select only one VCC from each category of Designer, Manufacturer and Distributor could also be relaxed. Time factors and the formation and dissolution decision, based on future demand estimates may also be incorporated to extend the longer-term planning of the methodology. Investigating inclusion of other approaches such as utility theory and fuzzy techniques may enhance the capabilities. Finally, further refinement and development into a decision support system will help in further inputs for improvement.