IMPACT OF CYBER-SUPPORTED COLLABORATION ON THE SIGNIFICANCE OF DECISION FACTORS OF REGIONAL HEADQUARTERS

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ABSTRACT

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With the rising trend towards globalization of businesses around the world, executives are called upon to take strategic decisions regarding the location of regional headquarters. Such decisions are made keeping in mind certain factors depending on the industry, regional needs, and the desired roles of headquarter in a particular region. A comprehensive list of 76 factors was identified in an exhaustive literature survey done by *Finger and Menipaz (2008).* In literature, even though significant emphasis has been placed on location decision models and collaboration models, but not much work has been done in terms of the location of regional headquarters and on combining the two types of models together to study the impact of cyber-supported collaboration on the relative significance of these 76 factors. Collaboration can exist between enterprises, between governments, or between enterprise(s) and government(s). This research report (a) presents a taxonomy of existing location decision models, collaboration models, relative advantages, limitations and (b) classifies the factors into categories of significance, (c) analyses the impact of cyber-supported collaboration on the relative significance of the 76 decision factors. An experiment was conducted to study the impact of collaboration on the relative significance of one of the 76 factors (proximity to key suppliers). The results of this experiment are presented and analyzed. Finally, conclusions and potential areas of future research are presented.

CHAPTER 1 INTRODUCTION

Problem Definition

The landscape in which businesses operate is expanding rapidly. As the trend towards business globalization moves forward, executives are called upon to take strategic decisions regarding the location of regional headquarters. Such decisions are made keeping in mind certain factors depending on the industry, regional needs, and the desired roles of headquarter in a particular region. A comprehensive list of 76 factors was identified in an exhaustive literature survey done by *Finger and Menipaz (2008).* In literature, even though significant emphasis has been placed on location decision models and collaboration models, not much work has been done in the location decision problem domain of regional headquarters and on combining the two types of models together to study the impact of cyber-supported collaboration on the relative significance of these 76 factors.

Regional Headquarters (RHQ) and the 76 location factors

"Regional headquarters (RHQs) of multinational corporations (MNCs) are separate and independent subsidiaries, located in different geographical regions than the corporate headquarters, which have decision-making authority and power over other subsidiaries in their respective regions" as defined by *Finger and Menipaz (2008)*.

To identify the 76 factors that play a crucial role in the decision-making process for the location of RHQ, the literature survey was classified into (a) MNC perspectives on location factors; b) Host country perspectives on location factors; and c) Decision making process for location selection. The contribution of the literature was either: 1) Theoretical contribution; 2) Empirical research; or 3) Case studies. The literature focusing on the locational aspects of RHQs dealt mainly with factors influencing the location decision and the decision-making process. From the MNC's perspective, the literature includes mostly empirical research regarding the importance of various location factors. From the host country's perspective, the literature includes analysis and/or policy recommendations for countries attempting to attract RHQ operations by increasing country competitiveness. From an empirical point of view, one source provides an empirical tool to map a country's attractiveness based on the perception of its characteristics [22].

A complete list of the 76 factors as identified in the *Finger and Menipaz (2008)* literature survey is shown in the following table.

Table 1 List of 76 location factors as identified in *Finger and Menipaz (2008)* literature survey resequenced in order of grouping as shown in table 3

Factor Number (L)	Location Factor
1	Frequent and reliable international air flights
2	Low travel and transportation costs
3	Proximity to key suppliers

4	Proximity to key clients
5	High quality public infrastructure (utilities, roads, etc.)
6	Proximity to local supporting and related industries
7	Proximity to surrounding markets
8	Availability of reliable suppliers
9	Accessible central geographic location with region
10	Free movement of capital and profits
11	Easy access to local capital markets
12	Freedom to control domestic firms
13	Access to local venture capital
14	Access to local financial and commercial services
15	Low cost of capital
16	Access to regional financial and commercial services
17	Efficient banking systems
18	Efficient capital and foreign exchange markets
19	Free movement of information
20	Transparent regulatory environment
21	Low level of bureaucracy
22	Ethical business environment (Low level of corruption)
23	Flexible employment contracts
24	Low level of industrial / labor disputes
25	Availability of home-country language-speaking staff
26	Availability of English-speaking staff
27	Availability of highly-skilled staff
28	Competitively priced local staff
29	Presence of major multinational corporations
30	Presence of major international organizations
31	Presence of competing multinational corporations
32	Presence of regional decision-making bodies
33	High level of personal freedom
34	Available quality medical services
35	Available quality residential housing
36	Available quality K12 international schools
37	Attractive personal tax rates
38	High cultural compatibility with home country culture
39	Low cost of living
40	Personal safety and protection of property
41	Convenient time zone location
42	Attractive dividend withholding taxes
43	Reliable protection of intellectual property rights
44	Reliable protection mechanisms for foreign investors

45	Attractive government investment and start-up incentives
46	Attractive government operating incentives
47	Attractive corporate tax regulations
48	Stable economy
49	High level of regional economic integration
50	High level of global political integration
51	Availability of multilingual personnel
52	Cultural compatibility with countries in region
53	Multi-cultural environment
54	Membership in regional trading blocs (EU, NAFTA, etc.)
55	High level of global economic integration
56	High level of regional political integration
57	Adherence to international accounting standards
58	Favorable image of/for business activity
59	Proximity to world class universities and research
60	Proximity to tourist attractions
61	Proximity to cultural and recreational centers
62	Comfortable climate
63	High environment quality (low pollution, etc.)
64	Political stability
65	High level of country security
66	Efficient government
67	Reliable justice system
68	High local market growth potential
69	Large local market
70	Proximity to manufacturing subsidiaries
71	Proximity to R&D subsidiaries
72	Proximity to marketing subsidiaries
73	Low office rent
74	Low operating costs
75	High quality IT & telecommunication infrastructure
76	Low telecommunication costs

Of all these 76 factors, not every factor was found to be equally important in the selection criteria for the RHQ location. In fact, differences between important ratings of location factors were themselves dependent on the parameters such as industry, home country, target region, RHQ role, etc. However, still some factors were cited more than others in the selection criteria.

For easier understanding of the 76 factors, the list was sub-classified by *Finger and Menipaz (2008)* into 14 groups using Principal Component Analysis as shown in the following table.

Table 2 Grouping of the 76 location factors using principal component analysis in *Finger and Menipaz (2008)*

Group Number (G)	Location Factors	Major Underlying Location Factors
1	L1 – L9	Accessible Location
2	L10 – L18	Favorable Financial Environment
3	L19 – L22	Ease of Doing Business
4	L23 – L28	Employment Environment
5	L29 – L32	Regional Business Hub
6	L33 – L41	Attractive Standard of Living
7	L42 – L48	Supportive Business Environment
8	L49 – L58	Level of Global and Regional Integration
9	L59 – L63	Ambiance of Location
10	L64 – L67	Country Stability
11	L68 – L69	Market Size and Potential
12	L70 – L72	Proximity to Own Operations
13	L73 – L74	Low Operating Costs
14	L75 – L76	Telecommunications Infrastructure

Decision Making Process for RHQ Location

To identify the relative importance of the 76 factors, a factor hierarchy for decision-making model was generated by *Finger and Menipaz (2008)* using the literature survey as shown in Figure 1.

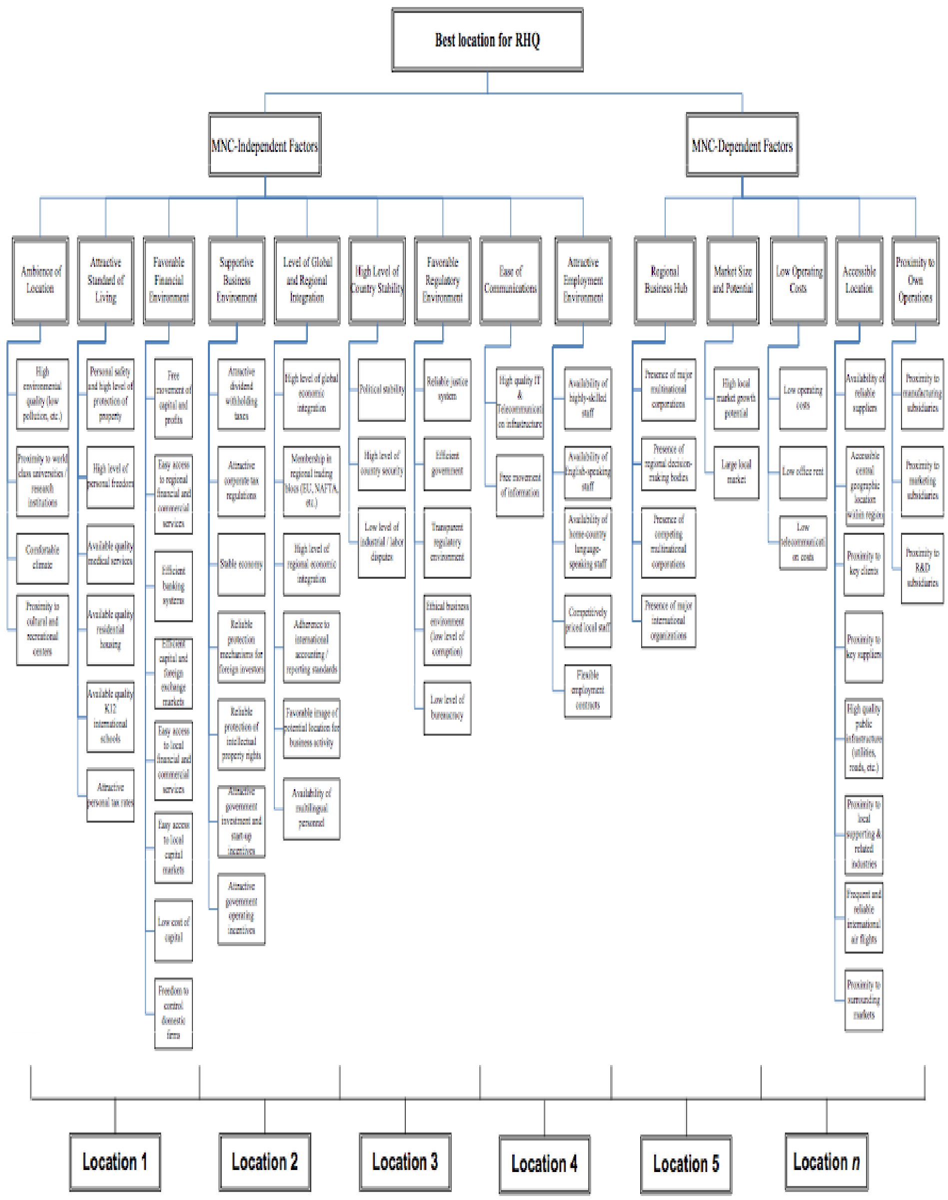

Figure 1 Factor Hierarchy for Decision Making Model (after [1])

Of all the possible *n* alternatives for selecting the location, pair-wise comparisons were done to provide a solution i.e. the best possible location for the RHQ. This model has been shown below:

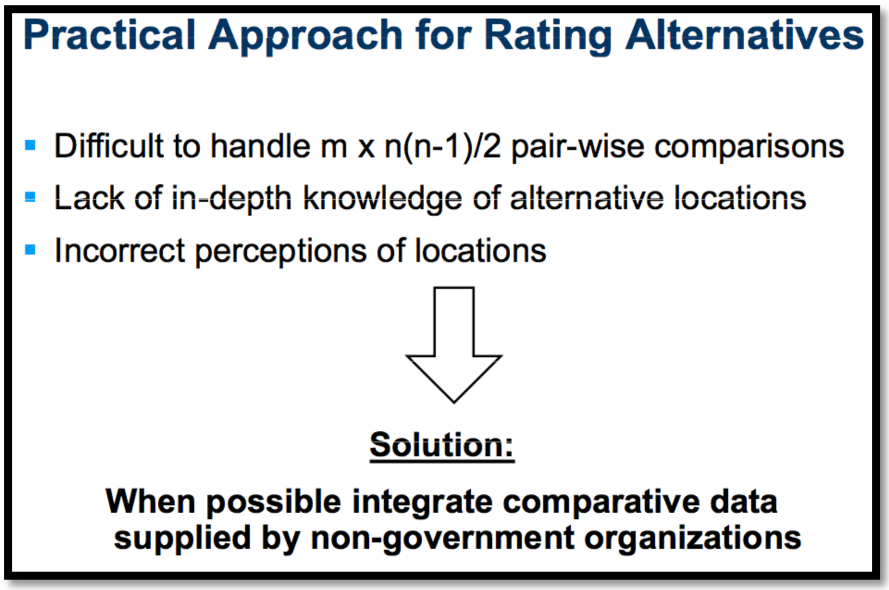

Figure 2 Practical Approach for Rating Alternatives (after [1])

The model was tested using the example of a software MNC for its Asia-Pacific Locations and the results were compared with the ones from Business Asia (2000), Far Eastern Economic Review (1997) and Asia Inc. (1996).

With a good understanding of the 76 location factors, it is important to learn more about Collaborative Control Theory and its applications.

Collaborative Control Theory (CCT)

In today's world, it is very important that collaborative decisions are made through a computerized system. This need for computerized decision support results from the importance of group decision-making and problem solving carried out predominantly during meetings [25]. There are various common problems associated with a meeting such as: overemphasis on social-emotional rather than task activities, failure to adequately define a problem before rushing to judgment, pressure constricting creativity felt by subordinates in the presence of bosses, and the feeling of disconnection/alienation from the meeting [29]. A number of other problems hampering the effectiveness of meetings include: getting off the subject, too lengthy, inconclusive, disorganized, no goals or agenda, individuals dominate discussion, not effective for making decisions, rambling, redundant, or digressive discussion [26] and [after 27]. Despite these negative effects, the attractiveness of a group approach to decision-making comes in general from the fact that individual contributions are increased by a synergistic effect resulting from meeting dynamics [25]. Several human decision-making abilities that information technology might augment in meetings, such as (1) help decision-makers formulate, frame, or assess decision situations by identifying the salient features of the environment, recognizing needs, identifying appropriate objectives by which to measure the successful resolution of an issue; (2) provide support in enhancing the abilities of decision-makers to obtain and analyze possible impacts of alternative courses of action, and (3) enhance the ability of decision-makers to interpret impacts in terms of objectives, leading to an evaluation of alternatives and selection of a preferred alternative option were identified in [28]. Consequently, a final outcome of a computer-supported meeting can be more than a simple sum of individual contributions. The attractiveness of a computer-supported group approach to location decision-making comes from a possibility of engaging diverse participants as competent stakeholders through computer-mediated communication, problem exploration, and negotiation support [24].

Before identifying the effect of Collaborative Control Theory (CCT) on the factors that go into making the location decision, it is important to clearly distinguish the difference between *coordination, cooperation* and *collaboration,* since they are significantly different from each other despite the fact that they may seem closely related. *Camarinha-Matos and Afsarmanesh* (2006, 2008) [2,3] and *Nof (1994)* [4] have provided a number of definitions that help clarify the differences in terms of set theory.

Coordination occurs when two or more parties work harmoniously with each other to reach mutual benefits through the use of communication and information exchange [5].

Cooperation occurs when two or more parties coordinate in such a way so that they can share resources to achieve their common goal. Division of labor is a common attribute of cooperation. Thus, *coordination* is a subset of *cooperation* [5].

Collaboration occurs between two or more parties when the participants in their efforts to jointly plan, implement and assess the set of activities that are required to achieve their common goal share information, resources and responsibilities to do so. Thus, *cooperation* is a subset of *collaboration* [5].

There are various ways in which the attributes of collaboration can be implemented when parties (collaborative units) undergo collaboration to form a collaborative network. One such way is *e-Work*. e-Work has been defined as any collaborative, computer-supported and communication-enabled activities in highly distributed networks of humans and/or robots and autonomous systems [6]. e-Work consists of an array of activities such as e-Manufacturing, e-Healthcare, e-Logistics, e-Operations, etc. These activities were used to assess the effect of cyber-supported collaboration on the relative importance of many of the 76 factors. Figures 3, 4 and 5 demonstrate the scope of collaborative e-Work as the foundation of various e-Activities.

Figure 3 Scope of collaborative e-Work as the common foundation of e-Activities (after [7])

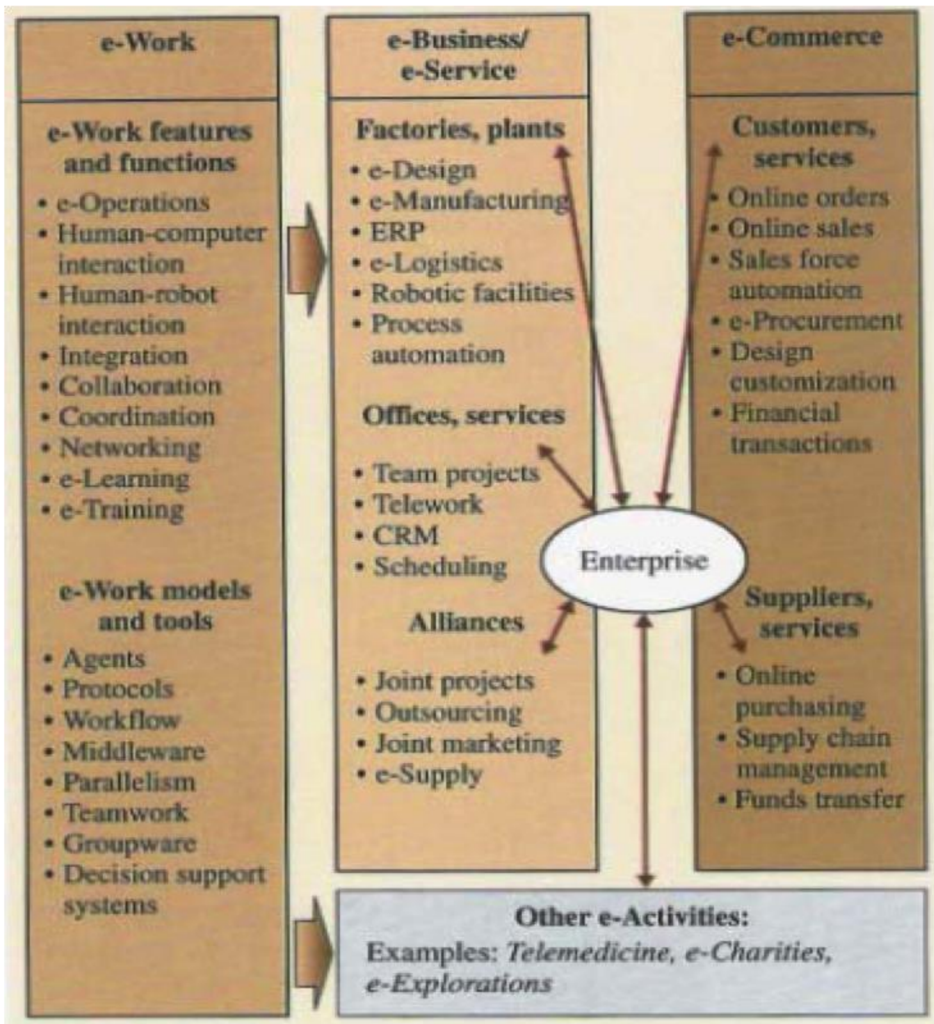

Figure 4 e-Work as the foundation for e-Business, e-Service, e-Commerce, & other e-Activities [6]

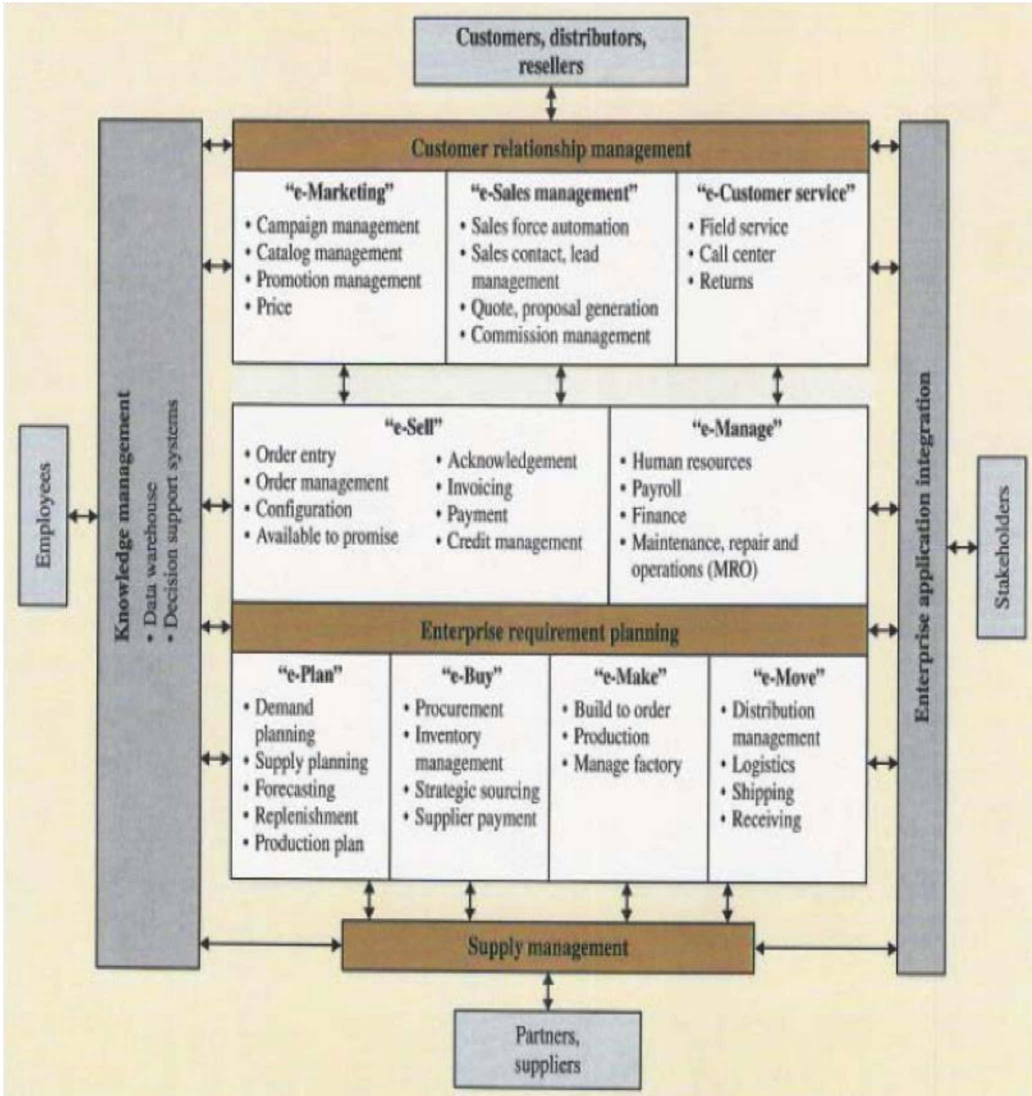

Figure 5 e-Business application framework (after [8])

The "four wheels (e-Work; Distributed Decision Support; Integration, Coordination, Collaboration and Active Middleware)" and their 15 e-dimensions enable collaborative e-Work as shown in Figure 6 [9].

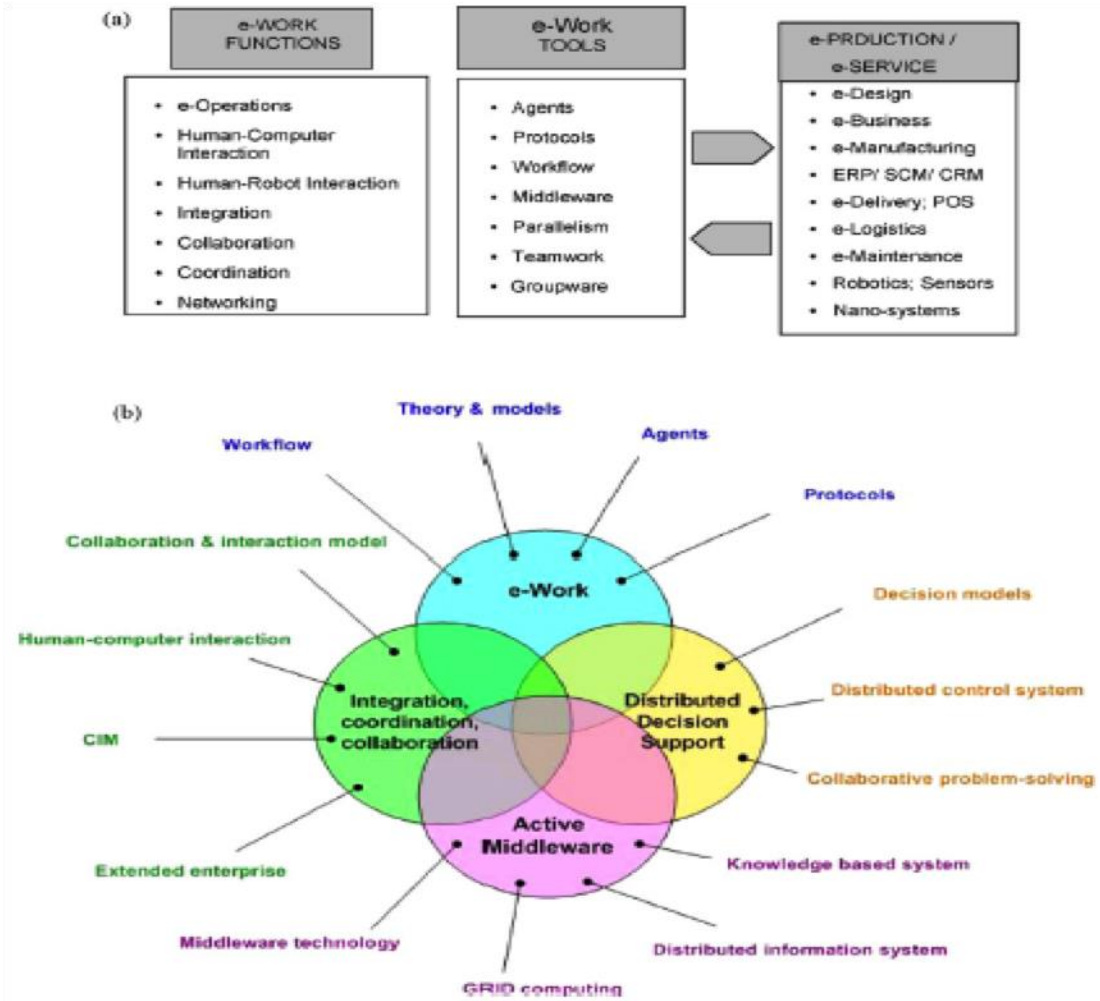

Figure 6 e-Work, e-Production, e-Service (a) function & tools; (b) 4 wheels of e-Work along with 15 e-dimensions (after [9])

To summarize, the chapter familiarized the reader with the concept of RHQ, location factors, their groupings, decision-making model and CCT. In the following chapter, we will take a look at the existing location and collaboration models that are provided in the literature. Both the advantages and the limitations of these models are studied, following which in chapter 3, a selection decision criterion combining the features of location and collaboration models is proposed. Chapter 4 presents and analyzes the results of an example using the methodology proposed in chapter 3. Finally, conclusions and potential areas of future research are presented in chapter 5.

CHAPTER 2 BACKGROUND

The previous chapter introduced the reader to the concept of RHQ, location factors, decision-making process, and CCT. Extending on this knowledge, the following chapter provides a taxonomy of the literature review, presents location-decision and collaboration models from literature, identifies their advantages and limitations in terms of their impact on the relative significance of the 76 location factor and the 14 major underlying groups. Our focus will then shift to identifying the potential impact of some of the models in literature on the 14 major underlying groups of the 76 factors.

Based on the literature review, it was found that not much emphasis has been made on the impact of cyber-supported collaboration on the location factors of RHQ. The table below lists and classifies these papers based on the potential impact their models can have on one or more of the 14 major underlying groups.

Table 3 References with potential impact of collaboration on the 14 major underlying groups

Group Number	Major Underlying Location Factors	Collaboration - References
G1	Accessible Location	[10] [11], [14], [20], [36], [37], [38], [42]
G2	Favorable Financial Environment	[30], [31]
G3	Ease of Doing Business	[10], [14], [20], [21]
G4	Employment Environment	[14], [20], [21], [42]
G5	Regional Business Hub	[10], [42]
G6	Attractive Standard of Living	[21], [40]
G7	Supportive Business	[18], [39]

	Environment	
G8	Level of Global and Regional Integration	[10], [21], [35]
G9	Ambiance of Location	[18], [40], [42]
G10	Country Stability	[33], [35]
G11	Market Size and Potential	[32], [38], [39]
G12	Proximity to Own Operations	[11], [36], [42]
G13	Low Operating Costs	[14], [20], [21], [42]
G14	Telecommunications Infrastructure	[10], [11], [14], [20], [21], [37], [42]

The next few sections of the chapter provide details on some of the existing location decision models and collaboration models and tools to identify their advantages and limitations relative to their impact on the significance of the location decision factors. A table of summary is provided at the end of section 2.7

2.1 <u>Decision model for planning of regional industrial programs [35]</u>

In today's world, there is a significant global trend for countries to be a part of various economic integration schemes on a regional basis in order to ensure the planning of industrial development programs. Plant allocation decisions coupled with cost/benefit distribution decisions form the characteristics of these regional industrial programs. The following model is useful since it can be used in scenarios where multiple parties have the incentive for cooperating with each other even when the elements of self-interest bring in the possibility of conflict.

The paper addressed these issues by combining the traditional mathematical programming approach for determining plant location, size, timing, with a game theoretic approach for determining a reasonable distribution of costs and benefits among the members of a collectivity.

It is important to note that even though an incentive for cooperation is evidently present in the situation, yet the elements of self-interest give rise to the possibility of conflict. To address the potential for conflict and collaboration, the strategic interdependence of the parties involved, and the fundamental goal of achieving economic efficiency and growth, a multi-disciplinary approach that brings together and builds upon the concepts from operations research and management science, game theory and public economics is required, and the success of this paper lies in providing such a framework. New concepts of Sharing Mechanism and Durable Bargaining Equilibrium are evaluated and explored further before the new model was proposed.

The parameters of the model are listed in the following figure along with the model.

Mathematical programming model for regional industrial investment planning

The variables

Z = production levels;
X = intra-region shipments;
E = exports to world markets;
F = imports from world markets;
Y = 0-1 plant investment decisions;
H = plant sizes.

The sets and indexes

$i, j \in I$ = nations;
$\tau, t \in T$ = time periods;
$c \in CF$ = final products;
$c' \in CI$ = intermediate products;
$c'' \in CR$ = raw materials;
$p \in NP$ = plants.

The parameters

a = process inputs/output;
b = capacity utilization;
k = initial capacity;
s = capacity retirement;
d = demand;
$E_{\max}$ = maximum export;
$F_{\max}$ = maximum import;
$H_{\min}, H_{\max}$ = minimum and maximum plant sizes.

Figure 7 Parameters for the decision model for planning of regional industrial programs (after [35])

Objective function

Maximize present value of net economic benefits

Net Economic Benefits = Total ValueAdded − Total Costs

Where

(Total Costs) = (Capital costs) + (Production costs) + (Transportation costs) + (Import costs) − (Export revenues).

Capital costs = Fixed charge + Linear portion of capital costs.

Production costs = Fixed prod. costs + Variable prod. costs.

Constraints

(1) Final products: material balance

$$Z_{cit} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{cjit} + F_{cit} \geq d_{cit} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{cijt} + E_{cit},$$

$$(\forall\, i \in I, c \in CF, t \in T).$$

Figure 8 Decision model for planning of regional industrial models (after [35])

(2) Intermediate products: material balance

$$Z_{c'it} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{c'jit} + F_{c'it} \geq \sum_{c \in CF} a_{c'c} Z_{cit} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{c'ijt},$$

$$(\forall i \in I, c' \in CI, t \in T).$$

(3) Raw materials: material balance

$$Z_{c''it} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{c''jit} + F_{c''it} \geq \sum_{c \in CF} a_{c''c} Z_{cit}$$

$$+ \sum_{c' \in CI} a_{c''c'} Z_{c'it} + \sum_{\substack{i,j \in I \\ j \neq i}} X_{c''ijt},$$

$$(\forall i \in I, c'' \in CR, t \in T).$$

(4) Import and export constraints

$$\sum_{i \in I} F_{cit} \leq F_{\max_{ct}}, \quad (\forall c \in (CF \cup CI \cup CR), t \in T),$$

$$\sum_{i \in I} E_{cit} \leq E_{\max_{ct}}, \quad (\forall c \in (CF \cup CI \cup CR), t \in T).$$

(5) Capacity constraints

$$Z_{cit} \leq (k_{ci} - s_{cit}) + \sum_{\tau \leq t} \sum_{p \in NP} bH_{cpi\tau},$$

$$(\forall c \in (CF \cup CI \cup CR),$$

$$p \in NP, i \in I, \tau \in T, t \in T).$$

(6) Plant size constraints

$$(H_{\min_c}) Y_{cpit} \leq H_{cpit} \leq (H_{\max_c}) Y_{cpit},$$

$$(\forall c \in (CF \cup CI \cup CR), p \in NP, i \in I, t \in T).$$

(7) Other constraints

$$0 \leq Y_{cpit} \leq 1, \text{ integer } Y_{cpit}.$$

$$Y_{cp'it} \leq Y_{cpit} \text{ for } p' > p$$

$$(\forall c \in (CF \cup CI \cup CR), p \in NP, i \in I, t \in T).$$

Non-negativity constraints for variables.

Figure 9 Decision Model for planning of regional industrial programs - Contd. (after [35])

Analysis of the model through a numerical example showed that the proposed decision mechanism: (1) allows generation of a regional industrial plan that is economically efficient; (2) possesses weak individual incentive compatibility; and (3) provides a reasonable cost/benefit sharing scheme that will be acceptable to rational, maxi-min strategy players [35]. Also noteworthy, is the result that the applicability of the proposed decision mechanism is not limited to regional industrial planning situations involving multiple nations. Results show that it is generally applicable to any situation involving multiple parties where the incentive for cooperation is present even when the elements of self-interest bring in the possibility of conflict. Other parallel situations include multiple corporate entities in a supply chain making coordinated operational decisions, and a conglomerate of companies planning to jointly introduce a new line of products, or jointly decide where to introduce a new regional headquarter. This is very important pertaining to our research since it promotes collaboration. The model with its ability to promote high level of regional economic integration can be applied to bring about a high level of global and regional integration.

2.2 Price-Based Approach for Activity Coordination in a Supply Network [36]

With the rising trend towards market globalization and concomitant competition, more number of manufacturers depends on their suppliers to provide raw materials and component parts. This is done to save cost by shifting the focus towards their core competence. Consequently, it is essential that suppliers are able to respond to dynamic market conditions. This purpose is achieved through the coordination of activities across a network of suppliers. Thus, this paper provides a model for coordination amongst suppliers in order to better meet the needs of their clients by providing faster delivery. An extension of this model can be used by suppliers to collaborate with each other, which can decrease the need for RHQs to be located close to key suppliers. For example, say for a manufacturing plant located in A, there are a few suppliers (S1, S2, S3) in that region A. However, the key supplier of the manufacturing plant is S4 located in some other region B. S4 can collaborate with S1, S2 and S3 using this model to meet the demands of the manufacturing plant.

A novel framework combining mathematical optimization and the contract net protocol is presented for make-to-order supply network coordination in [36]. The interactions among organizations are modeled by a set of inter-organization precedence constraints. This is done keeping in mind the objective to achieve the organizations' individual and shared goals of fast product delivery and low inventory.

The inter-organization model [36] has been stated as follows:

$$J = \sum_{i=1}^{I} J_i = \sum_{i} \sum_{j} f_{ij}(T_{ij}, E_{ij}).$$

s.t.

$$d_{ij}^{t} \leq d_{ij}^{r} \quad \forall (i,j) \in O_i^{T}.$$

$$d_{ij}^{p} \leq d_{ij}^{r} \quad \forall (i,j) \in O_i^{C}.$$

Furthermore, these inter- organization constraints are relaxed by using a set of inter-organization prices that represent marginal costs per unit time for the violation of such constraints. To solve the problem, the overall problem is decomposed into organizational sub-problems. At this individual inter-organizational level, scheduling of activities is based on their internal situations and inter-organization prices. It is important to note here that coordination is achieved through an iterative price-updating process carried out in a distributed and asynchronous manner. Once the prices are dynamically updated and schedules have been adjusted, this approach coordinates activities to fulfill existing commitments. This process can happen in parallelism with the system maintaining the flexibility to take on new orders.

The flowchart explaining this process has been shown in the following diagrams.

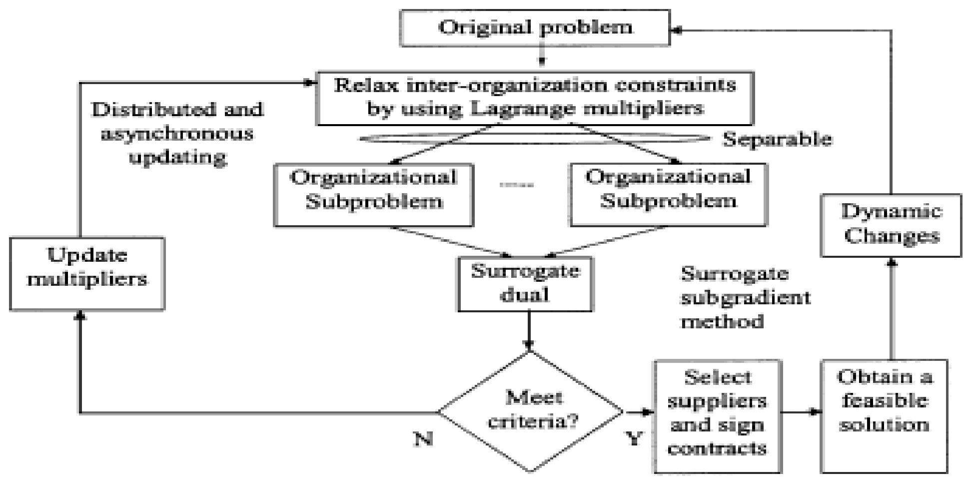

Figure 10 Summary of the solution process (after [36])

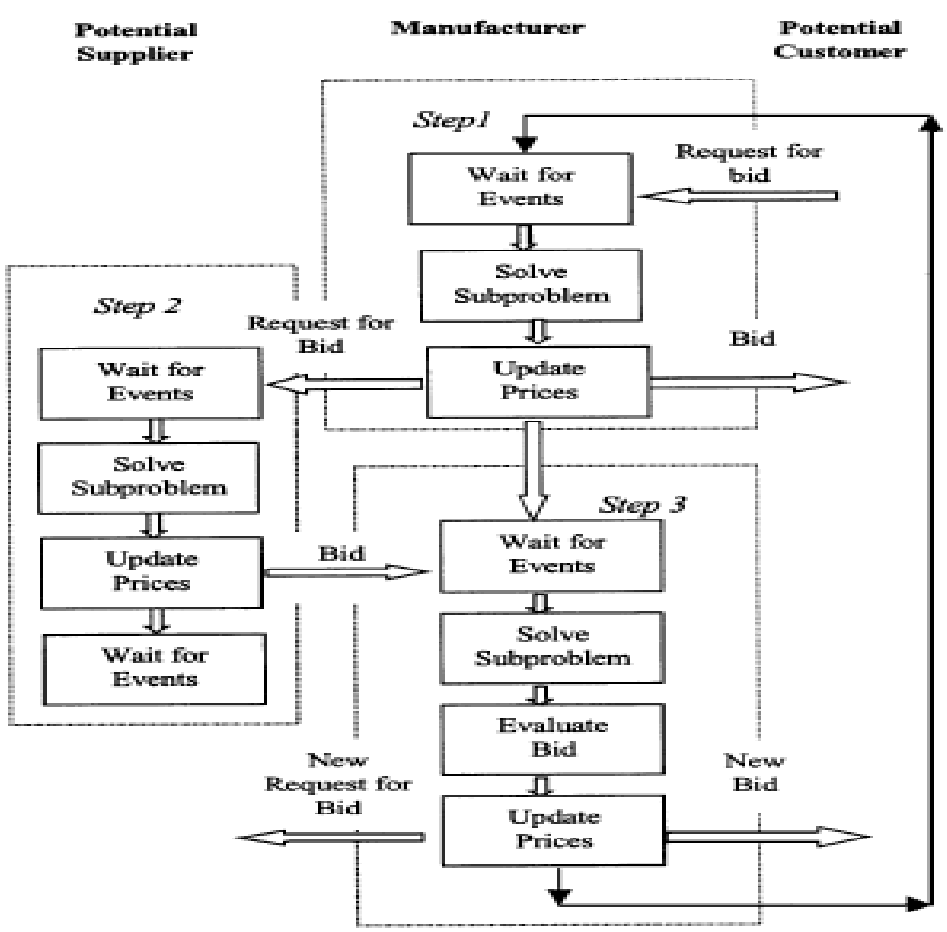

Figure 11 Coordination Process (after [36])

Analysis in the form of a numerical testing was performed, the results of which show that inter-organization prices converge. It was also found that prices might change, as new orders arrive to reflect the new pressure on deliveries. Consequently, the method thus provides a novel framework for activity coordination across a supply network [36].

The model is useful in our research as it helps promote collaboration amongst the suppliers. An extension of this model can be used to reduce the decision-maker's dependency on the factor that the regional headquarter needs to be located close to the suppliers.

2.3 Facility location–allocation problem in random fuzzy environment: Using (alpha, beta)-cost minimization model under the Hurewicz criterion [37]

From literature review and real-life examples, one can deduct that Facility location–allocation (FLA) has proved to be a valuable method in locating service facility. Real-life examples include emergency service systems, telecommunication net works, public services, etc. Even though many researchers have studied the FLA problem using a deterministic, stochastic or fuzzy environment approach, it is important to note that such models cannot satisfy various customers' demands in some cases. To solve this problem, [37] considers the FLA problem under random fuzzy environment using (alpha, beta)-cost minimization model under the Hurewicz criterion.

Through mathematical analysis, it was proved that this model could deal with various FLA problems in random, fuzzy and random fuzzy environments. By varying the values of (alpha, beta), the task of balancing the optimistic level of the decision makers was done. In order to solve the random fuzzy model efficiently, the simplex algorithm, random fuzzy simulation and genetic algorithm were integrated to produce a hybrid intelligent algorithm.

In order to model the capacitated FLA problem, the following notations are introduced:
$i = 1, 2, \ldots, n$ is the index of facilities;
$j = 1, 2, \ldots, m$ is the index of customers;
(a_j, b_j) denotes the location of customer j, $1 \le j \le m$;
d_j is the demand of customer j, $1 \le j \le m$;
s_i is the capacity of facility i, $1 \le i \le n$;
(x_i, y_i) is the decision variable which represents the location of facility i, $1 \le i \le n$;
z_{ij} denotes the quantity supplied by facility i to customer j, $1 \le i \le n$, $1 \le j \le m$.
For convenience, we also write

$$(\boldsymbol{x}, \boldsymbol{y}) = \begin{pmatrix} x_1 & y_1 \\ x_2 & y_2 \\ \cdots & \cdots \\ x_n & y_n \end{pmatrix}, \qquad \boldsymbol{z} = \begin{pmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{pmatrix}.$$

For an capacitated FLA problem, we need to select n locations from a certain region $R = \{(\boldsymbol{x}, \boldsymbol{y}) | g_i(x_i, y_i) \le 0, i = 1, 2, \ldots, n\}$ and decide the amount z_{ij} from facility i to customer j. Also the facility i can not supply things endlessly, which means they have capacity s_i. An allocation $\boldsymbol{z}$ is said to be feasible if

Figure 12 Facility Allocation Model (after [37])

$$\begin{cases} z_{ij} \geq 0, \quad i = 1, 2, \ldots, n, \; j = 1, 2, \ldots, m \\ \sum_{i=1}^{n} z_{ij} = d_j, \quad j = 1, 2, \ldots, m \\ \sum_{j=1}^{m} z_{ij} \leq s_i, \quad i = 1, 2, \ldots, n. \end{cases} \tag{1}$$

The second constraint states that the demand of each customer should be satisfied without wasting. The third constraint implies that the supplied amount of each facility should not exceed its capacity. We denote the feasible allocation set by

$$\mathbf{Z} = \left\{ z \,\middle|\, \begin{array}{l} z_{ij} \geq 0, \; i = 1, 2, \ldots, n, \; j = 1, 2, \ldots, m \\ \sum_{i=1}^{n} z_{ij} = d_j, \; j = 1, 2, \ldots, m \\ \sum_{j=1}^{m} z_{ij} \leq s_i, \; i = 1, 2, \ldots, n. \end{array} \right\}. \tag{2}$$

Then we can give the transportation cost with the best allocation z,

$$C(\boldsymbol{x}, \boldsymbol{y}) = \min_{z \in \mathbf{Z}} \sum_{i=1}^{n} \sum_{j=1}^{m} z_{ij} \sqrt{(x_i - a_j)^2 + (y_i - b_j)^2}. \tag{3}$$

If $\mathbf{Z}$ is an empty set, we can define

$$C(\boldsymbol{x}, \boldsymbol{y}) = \sum_{j=1}^{m} \max_{1 \leq i \leq n} d_j \sqrt{(x_i - a_j)^2 + (y_i - b_j)^2}. \tag{4}$$

Then what we should do is to minimize the transportation cost $C(\boldsymbol{x}, \boldsymbol{y})$, which is easy to solve.

Figure 13 FLA Model Continued (after [37])

To denote the random fuzzy demand of customer j , j = 1, 2, . . . ,m .

$$\mathbf{Z}(\theta, \omega) = \left\{ z \,\middle|\, \begin{array}{l} z_{ij} \geq 0, \; i = 1, 2, \ldots, n, \; j = 1, 2, \ldots, m \\ \sum_{i=1}^{n} z_{ij} = \xi_j(\theta, \omega), \; j = 1, 2, \ldots, m \\ \sum_{j=1}^{m} z_{ij} \leq s_i, \; i = 1, 2, \ldots, n \end{array} \right\}.$$

Then for each (θ, ω), we can give the transportation cost with the best allocation z,

$$C(\boldsymbol{x}, \boldsymbol{y} | \theta, \omega) = \min_{z \in \mathbf{Z}(\theta, \omega)} \sum_{i=1}^{n} \sum_{j=1}^{m} z_{ij} \sqrt{(x_i - a_j)^2 + (y_i - b_j)^2}.$$

If $\mathbf{Z}(\theta, \omega)$ is an empty set for some (θ, ω), we can define

$$C(\boldsymbol{x}, \boldsymbol{y} | \theta, \omega) = \sum_{j=1}^{m} \max_{1 \leq i \leq n} \xi_j(\theta, \omega) \sqrt{(x_i - a_j)^2 + (y_i - b_j)^2}.$$

Figure 14 Random fuzzy FLA problem (after [37])

Analysis of the computational results of the numerical experiments implied that it is effective to solve the (alpha, beta) –cost minimization model under the Hurewicz criterion. This model is useful since it helps in allocating a service facility from a decision-maker’s perspective.

2.4 UNCAPACITATED PLANT LOCATION UNDER ALTERNATIVE SPATIAL PRICE POLICIES [38]

Consider the scenario where a spatial system of clients' demand functions is given. For such a scenario, the model proposed in [38] provides solution methods to determine the locations, price(s), the number, the sizes, and the market areas of the plants supplying the clients. The goal of the model is to maximize the profit of the firm.

To achieve the objective, three alternative spatial price policies were considered: (i) uniform mill pricing (here, the same price is charged to the clients at the plant door, (ii) uniform delivered pricing (where clients pay the same delivered price irrespective of their locations, and (iii) spatial discriminatory pricing which is such that the firm sets client-specific prices based on their locations [38].

The profit of the firm is equal to its revenue, minus the total production cost, minus the total transportation cost. It is given by:

$$\Pi(\pi, y, X) = \sum_{i=1}^{m} \sum_{j=1}^{n} \pi_{ij} \cdot D_i(\pi_{ij}) \cdot x_{ij} - \sum_{j=1}^{n} (f_j \cdot y_j + v_j \cdot \sum_{i=1}^{m} D_i(\pi_{ij}) \cdot x_{ij})$$

$$- \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} \cdot D_i(\pi_{ij}) \cdot x_{ij}$$

$$= \sum_{i=1}^{m} \sum_{j=1}^{n} B_{ij}(\pi_{ij}) \cdot x_{ij} - \sum_{j=1}^{n} f_j \cdot y_j \qquad \text{where}$$

$$B_{ij}(\pi_{ij}) = D_i(\pi_{ij}) \cdot (\pi_{ij} - t_{ij} - v_j) = D_i(\pi_{ij}) \cdot (p_{ij} - v_j)$$

Can be interpreted as the gross benefit obtained from supplying client i from plant j at the delivered price π_{ij}

The problem of the firm can be expressed as follows:

$$\Pi^* = \underset{\pi, y, X}{\text{Max}}\ \Pi(\pi, y, X)$$

$$= \underset{\pi, y, X}{\text{Max}} \left[\sum_{i=1}^{m} \sum_{j=1}^{n} B_{ij}(\pi_{ij}) \cdot x_{ij} - \sum_{j=1}^{n} f_j \cdot y_j\right] \qquad (1)$$

subject to:

$$\sum_{j=1}^{n} x_{ij} \leq 1, \qquad i = 1, \ldots, m, \qquad (2)$$

$$0 \leq x_{ij} \leq y_j, \qquad i = 1, \ldots, m; \qquad j = 1, \ldots, n, \qquad (3)$$

$$y_j = 0 \text{ or } 1, \qquad j = 1, \ldots, n. \qquad (4)$$

Figure 15 Uncapacitated plant location model (after [38])

Constraints (2) prevent the firm from supplying a client with more than its demand [38]. Constraints (3) imply that the fixed costs are incurred for all the operating plants [38].

Based on the analysis of the computational results, it was found that:

1. The model can cope with more general demand functions.

2. The firm's spatial price policy has often a significant impact on its plant configuration, thus confirming the importance of the interaction between locations and pricing. More specifically, in many cases uniform mill pricing tends to favor a certain proliferation of plants, caused as a result that the firm tries to capture as much as possible of the total demand by erecting plants close to the clients. On the other hand, spatial discriminatory and uniform delivered pricing yield more or less similar location patterns. The reason being that transportation costs are entirely borne by the firm in both those cases, which leads it to choose cost-minimizing configuration (conditional upon distribution plans). This is in sharp contrast with what happens under uniform mill pricing [38].

3. A major limitation of the above approach is the absence of competition.

4. The lack of the impact of collaboration on the location factors.

2.5 Facility Location Under Zone Pricing [39]

Zone pricing is the process of determining simultaneously several delivered prices together along with the zones where these prices apply. The model and algorithm proposed in [39] determines optimal facility locations, prices, tariff-zones, and market areas in order to maximize the firm's profit under zone pricing.

The resulting nonlinear mixed-integer program is tackled by projecting the objective function on the price space, solving repeatedly un-capacitated facility location problems for fixed values of the prices. The implicit profit function so defined is optimized by the branch-and-bound.

The profit of the firm is equal to its revenue, minus the production costs and the transportation costs. The profit function along with the mathematical model is as follows:

$$P(\underline{\pi}, x, y) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} \pi_k D_i(\pi_k)\, x_{ijk}$$

$$(1) \qquad - \sum_{j=1}^{J} [\, f_j y_j + v_j \sum_{i=1}^{I}\sum_{k=1}^{K} D_i(\pi_k)\, x_{ijk}]$$

$$- \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} t_{ij} D_i(\pi_k)\, x_{ijk}$$

$$= \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} B_{ijk}(\pi_k)\, x_{ijk} - \sum_{j=1}^{J} f_j y_j$$

where $\Sigma_{i=1}^{I}\Sigma_{k=1}^{K}\ D_i(\pi_k)\, x_{ijk} = q_j$ denotes the total production of plant j and $B_{ijk}(\pi_k) = (\pi_k - v_j - t_{ij})\, D_i(\pi_k)$ can be interpreted as the gross benefit obtained when supplying market i from plant j and assigning it to the tariff-zone k wherein the uniform delivered price π_k is charged. The problem of the firm is expressed by the following mathematical program:

$$P^* = \max_{\underline{\pi}, x, y} P(\boldsymbol{\pi}, \mathbf{x}, \mathbf{y})$$

subject to

$$(2) \qquad \sum_{j=1}^{J}\sum_{k=1}^{K} x_{ijk} \le 1, \qquad i = 1, \ldots, I$$

$$(3) \qquad x_{ijk} \le y_j, \qquad i = 1, \ldots, I; \quad j = 1, \ldots, J; \quad k = 1, \ldots, K$$

$$(4) \qquad x_{ijk} = 0 \text{ or } 1, \qquad i = 1, \ldots, I; \quad j = 1, \ldots, J; \quad k = 1, \ldots, K$$

$$(5) \qquad y_j = 0 \text{ or } 1, \qquad j = 1, \ldots, J$$

$$(6) \qquad \pi_k \ge 0, \qquad k = 1, \ldots, K$$

Figure 16 Profit function and model (after [39])

Constraint (2) implies that each market cannot be assigned to more than one plant and one tariff zone. Constraint (3) implies that markets can be allocated to open plants only.

The model in [39] can be computed for reasonable large problems in reasonable time. The effectiveness of the model arises from the fact that it is essential for a supportive business environment and market opportunities, but does not emphasize on the impact of collaboration on these factors.

2.6 MERP [40]

MERP is very useful in terms of e-Learning and e-Training. Based on the principle of learning theory, it has its area of application in ERP systems.

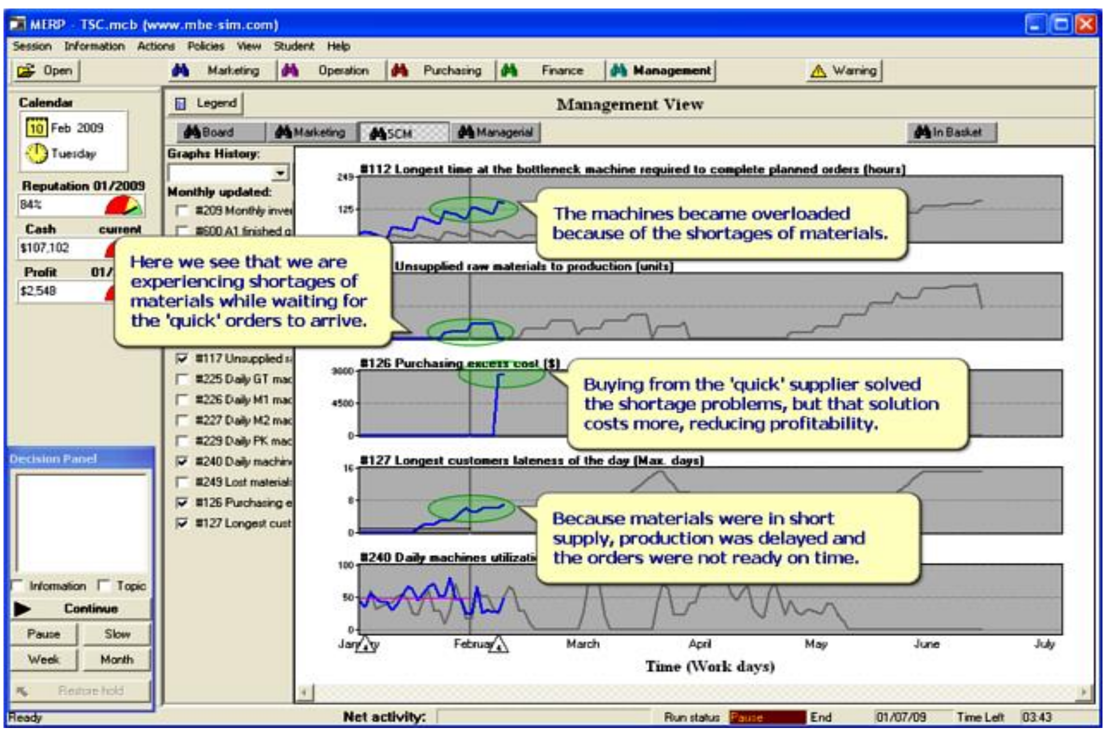

Figure 17 Screenshot of MERP (after [41])

2.7 A Multi-Agent Approach for Engineering Design Knowledge Modeling [42]

The paper addresses the issue of product design when experts are located in different geographical locations. Usually the product design process involves collaboration between these experts, but because they are located in different geographical locations, the decision-making process becomes slow and more difficult. With the definition of variable and constraints being a key issue in the product design process, a multi-agent system is proposed in this paper, which tutors experts in a standardized manner for the definition of variable and constraints. Using this domain-specific knowledge, “Constraint Satisfaction Problem (CSP)” models can be built to support the beginning stages of product design.

Traditionally, a CSP model is built by an intensive process of communication between experts, who try to reach consensus about their interests and include those interests into the model as constraints. This process is manual and takes a lot of time to be completed. Through this paper this communication process is done automatically using cyber-supported collaboration.

The multi-agent system consists of a Tutor Agent (TA) and a Database Agent (DBA). The communication between the two agents results in the selection of experts and the assigning of variables to them. Consequently, each expert gets a TA assigned, while the

DBA controls interaction with the database as shown in Figure 22. This communication process consists of three stages – Validation, Negotiation and Decision. The knowledge modeling process should start by eliciting it in terms of the following components:

- V is a set of n variables that are defined by the experts.

$V = \{v_i \mid v_i$ is a variable from the design problem, with $i = 1, 2, 3, \ldots, n\}$ (1)

- D is a set of n domains of each variable

$D = \{d_i \mid d_i$ is the domain of the variable vi , with $i = 1, 2, 3, \ldots, n\}$ (2)

- C is a set of m relations between variables call constraints.

$C = \{c_i \mid c_i$ is an equation that represent relations among variables of the set V, with $i = 1, 2, 3, \ldots, m\}$

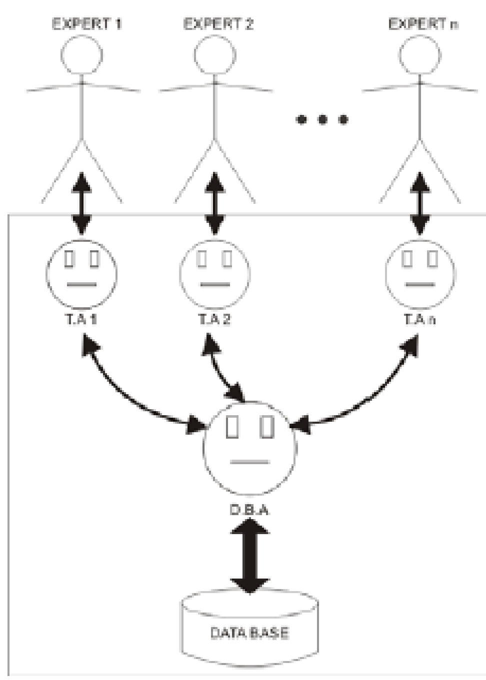

Figure 18 Prototype Architecture of the Multi-Agent System (after [42])

Once the experts have been defined, their knowledge is represented through variables, domains and constraints that are gathered and defined in the model. Finally the model is executed in Con'flex and a reduced solution space is obtained. From the analysis of this solution space, the design team can select the most appropriate designs to be modeled.

Thus, this system is very useful in collaborative design process. However, its limitation lies in scenarios where conflicts arise between experts sharing the same variables.

Such a system is very useful in regard to our research. It not only helps in collaborative design process (Proximity to Own Operations), but also reduces the need for the regional headquarter to be located near key and reliable suppliers (Accessible Location), world-class universities and research (Ambiance of Location), highly qualified staff (Employment Environment), presence of regional decision-making bodies (Regional Business Hub). It is also beneficial in terms of bringing down operating costs (Low Operating Costs) if suppliers use this system to negotiate and collaborate with each other. Even for competitive organizations, such a collaborative structure can be useful. It is important to note that since effective communication forms the basis of this system, it is essential that the quality of IT and communication infrastructure (Telecommunication infrastructure) is high.

To summarize the papers listed in sections 2.1 through 2.7, we have the following table.

Table 3 Summary of Location and Collaboration models/tools

Model	Reference	Main Decision Objective	Decision Procedure/ Protocol/ Workflow	Relative Advantages	Limitations
Decision model for planning of regional industrial programs	[35]	Maximize present value of net economic benefits	Mathematical programming approach combined with game theoretic approach	(1) Allows generation of economically efficient regional industrial plan (2) Allows application in scenarios involving multiple parties where incentive for cooperation is present, even when there is scope for potential conflicts	(1) Does not pay much emphasis on impact of collaboration location factors; (2) Weak individual incentive compatibility
Price-Based Approach for Activity Coordination in a Supply Network	[36]	Fast product delivery and low inventory	Framework combining mathematical optimization and contract net protocol	Promotes collaboration amongst suppliers	(1) Does not pay much emphasis on impact of collaboration location factors; (2) Prices of suppliers may increase as a result of increased pressure to meet customer demands
Facility	[37]	Minimize cost	Hybrid	Can be used	Does not pay

location–allocation problem in random fuzzy environment: Using (alpha, beta)-cost minimization model under the Hurewicz criterion			intelligent algorithm comprising simplex algorithm, random fuzzy simulation and genetic algorithm	to make location decisions from the decision-makers perspective by balancing the level of optimism.	any emphasis on impact of collaboration location factors;
Uncapacitate-d Plant Location under Alternative Spatial Price Policies	[38]	Maximize profit of the firm	Mathematical optimization model	The model can help the decision maker pick an optimal location from a pool of potential locations	(1) The location model does not pay much emphasis on the impact of collaboration the proximity of RHQs to clients
Facility Location Under Zone Pricing	[39]	Maximize firm's profit under zone-pricing	Non-linear mixed integer model	The model helps the decision-maker determine optimal facility location, prices, tariff zones, and market zones	Does not emphasize on the impact of collaboration on business environment and market opportunities
MERP	[40]	Multiple objectives depending on user need	ERP System	Good for e-Learning and e-Training	Does not support the business plan of all kinds of businesses
A Multi-Agent Approach for Engineering Design Knowledge Modeling	[42]	Optimal Design from a set of possible designs	Constraint Satisfaction Problem Model	Useful for Collaborative Design Process with experts distributed geographicall-y	Conflicts can arise between experts sharing the same variables

So far we have seen that the existing location models have not put much emphasis on the impact of cyber-supported collaboration on the location factors of RHQ. The following section looks at a few other papers from the literature along with their objectives.

2.8 Other models

Table 4 Main objective of papers in the literature

Model	Reference	Objective
Liu (2008)	[16]	A discussion of location decision in terms of proximity to R&D subsidiaries.
Kho (*2007)*	[10]	The effects of collaboration software on improving a company's productivity through open collaboration amongst the company's employees, partners and customers
Georgopoulos, et al (2010)	[11]	Ability to make fast and informed decisions by a coordinator of a search and rescue mission who usually stays at the headquarters away from the mountainous terrain where the search and rescue missions are undergoing
Kibrick et al (2004, 2006)	[14], [20]	A study on distributed decision making
Anschuetz (1998)	[21]	A discussion on the management of geographically distributed teams

Becher et al (2003)	[12]	e-Government initiatives, diversity in geographic and business cultures, and the importance and effect of collaboration in the aviation industry to improve productivity
Derenzi et al, (2009), Vinturini et al (2008)	[13], [15]	Challenges faced and lessons learned during the process of implementing collaborative efforts for integrating people, process, and technology inside collaborative environment has been studied
Sales (2001)	[17]	Collaboration for disaster recovery addresses issues in location decision-making in terms of the safety factor
Burgess et al (2005)	[18]	The result of collaboration efforts between various government agencies to improve the productivity of coastal and marine ecosystems.
Farish (2009)	[19]	Effect of collaboration on factors such as office costs, time zone and geographic location
Zurbagiu (2010)	[22]	Studied distance-learning programs (e-Learning) and need for related security measures
Johnson (1987)	[23]	Discussed knowledge support and information sharing over distributed networks.

With a basic understanding of the research done in the papers shown in Table 5, we can now look for their potential impact of on the 14 major underlying groups.

(G1) Accessible Location

Many factors such as frequent and reliable international air flights, low travel and transportation costs, proximity to key suppliers, clients, local supporting and related industries, surrounding markets, availability of reliable suppliers, high quality public infrastructure and accessible central geographic location within region. It is important to note that collaboration with various entities helps remove the challenges faced by this group. For example, using the Keck Remote Observing Model [14, 20], over 90% of all of Keck's operations were done from geographically distributed off-site locations which had access to the instruments using the same interactive applications that were being used to control the instruments located on the remote summit. Using video-conferencing and other means of telecommunications, conflicts arising due to lack of proper communication were addressed. As such there was no real need for travel between any two sites, since most of the information sharing, tech support and training was provided using secure online protocols. Similarly, the use of collaboration software for enterprises [10] helps bring everyone on the same page irrespective of their location. Using dynamic alert systems such as LARS [11], one can have access to real-time information on the availability of reliable suppliers in the region.

(G2) Favorable Financial Environment

One of the collaborative systems studied under the types of collaborative systems is the collaborative banking system. The collaborative banking system has several advantages over the classical banking system. For example, full transparency, perfect communication between employees, fostering teamwork, increased quality of services and rapid progress [30]. When the same system is implemented electronically, for example over Internet, then such a system becomes more efficient. If such systems work the way they are designed to, then they are efficient in achieving results accurately and completely [31].

(G3) Ease of Doing Business

Free movement of information, transparent regulatory environment, low level of bureaucracy and ethical business environment comprise the group “Ease of Doing Business.” Models such as Keck Remote Observing Model [14, 20], Tec-Ed’s Virtual Team Model [21] encourage free movement of information. Under the Keck Remote Observing Model, multiple sites had access to the same information as the rest of them using VNC protocol encapsulated within secure shell (ssh) tunnels. Use of collaboration software for enterprises such as JIVE Software [10] ensures through free movement of information that all employees in an organization are on the same page irrespective of their location. Trust amongst employees is a key factor for free flow of information within any organization. For example, if an employee feels that having access to a particular piece of information is the only way he/she can rise up the company hierarchy, and then he/she will be hesitant in distributing such knowledge to his/her peers. On the other hand, if there is a system where any member of a team can be assigned the role of a project leader, mentor, trainer, substitute, peer or guide depending on the project then he/she would be more willing to share their knowledge with other members of the team based on trust. Also, their will be a more transparent regulatory environment within the team, as each member will have an equal say in the proceedings of the project. Tec-Ed's Virtual Team Model helps develop this bond of trust amongst team members to allow free movement of information and set up a transparent regulatory system. Such a model also helps in creating an ethical business environment within the organization as members trust each other and are aware of the company's mission, goals and their individual responsibilities.

<u>(G4) Employment Environment</u>

Keck Remote Observing Model [14, 20] was developed with the primary motivation of minimizing the number of technical and administrative staff at each of Keck's station. Thus, challenges arising from competitively priced local staff and availability of English-speaking and highly skilled staff are resolved, since most of the operations are handled remotely. Also, the uniformity in the transmission protocols allows better interactive performance with lower latency. Thus, a staff member on one site can train another staff member on another site, and also provide tech support to each other. On the other hand, the Tec-Ed's Virtual Team Model [21] addresses the challenge rising due to the lack of home-country language-speaking staff, as at least one of the team members has to be a "local" client. Upon completion of the project under this model, the teams are dissolved and its members have the flexibility to work on other projects in different teams. Thus, virtual team members enjoy flexible employment contracts.

(G5) Regional Business Hub

The use of collaborations software addresses the challenges faced by factors such as presence of major multinational corporations, international organizations, competing multinational corporations, regional decision-making process. The availability of information provided by collaboration software (e.g. JIVE Software for One Economy [10]) empowers the regional decision-making bodies with the same information as the corporate decision-making bodies. As such, they can make better-informed decisions by interacting within the enterprise using the software.

(G6) Attractive Standard of Living

With geographically distributed team members under Tec-Ed's Virtual Team Model [21], one could take advantage of the time zone differences to work on a project for longer hours without personal sacrifice. Also, since the "local" client/team member is already based in that region, he/she saves on the traveling, relocation expenses bringing down their cost of living. Once the project is over, the team members are disbanded and are free to work on another project. Thus, they have a higher level of personal freedom.

(G7) Supportive Business Environment

Under the National Oceanic and Atmospheric Administration's (NOAA) Ecosystem Approaches to Management (EAM) [18], emphasis is laid on transitioning from the current management approach to a more cohesive, collaborative management approach. Under this strategy, it is essential that government agencies – local, state, tribal and federal collaborate with business and academic communities to help facilitate the production of better products and services. Such a strategy would result in more attractive government operating initiatives, tax regulations and start-up incentives.

(G8) Level of Global and Regional Integration

One of the principles on which the Tec-Ed's Virtual Team Model [21] is based on states that at least one team member must be a "local" client. When this model is extended geographically, this attribute of the model helps bring about higher level of global and regional integration by taking care of factors such as availability of multilingual personnel, cultural compatibility with countries in region and by fostering a multi-cultural work environment. Also, good collaboration software for enterprises (e.g. JIVE Software [10]) is usually language independent, thereby providing the exact same information to an employee in another country or region speaking a different language and coming from a different culture.

(G9) Ambiance of Location

Under the National Oceanic and Atmospheric Administration's (NOAA) Ecosystem Approaches to Management (EAM) [18], emphasis is laid on transitioning from the current management approach to a more cohesive, collaborative management approach. Unlike current management practices laying more emphasis on sectoral, short-term perspectives, with humans independent of ecosystems, NOAA-EAM puts emphasis on ecosystem-based, long-term perspectives where humans are an integral part of the ecosystem. Under this strategy, it is essential that government agencies – local, state, tribal and federal collaborate with business and academic communities to help facilitate the production of better products and services. Such an ecosystem-based management approach helps improve the quality of the environment.

(G10) Country Stability

Using statistical models, it was shown that countries with higher level of political stability, efficient government and reliable justice system are more attractive for outside firms [33].

(G11) Market Size and Potential

Businesses that undergo collaboration enjoy a higher market growth potential than the ones that do not undergo collaboration [32]. This impact is evident in the form of increased sales for businesses that underwent collaboration in comparison to the ones that did not. Thus, pre-entry and post-entry collaboration positively influences businesses' annual sales growth.

(G12) Proximity to Own Operations

The group "Proximity to Own Operations" encompasses factors such as proximity to manufacturing, R&D and marketing subsidiaries. Some of the challenges that need to be addressed involve an exact knowledge of the resources available to the RHQ, along with coordination and monitoring of these subsidiaries in a dynamic environment using a quick alert system. Such a system should be reliable and durable to provide a dynamic update on the availability and proximity of such resources. This problem is addressed by the Location Awareness Rescue System (LARS) developed in [11] for search and rescue missions on mountainous regions. A modified version of this system can be used to address the challenges faced by this group.

(G13) Low Operating Costs

Keck Remote Observing Model [14, 20] was developed with the primary motivation of minimizing the number of technical and administrative staff at each of Keck's station. Thus, such a model reduces the cost of office rent and other operating costs. Besides, the use of a uniform protocol system ensures a shorter training period for new employees. Under the Tec-Ed's Virtual Team Model [21], it is essential to have at least one "local" client as a team member. This attribute also helps lower the operating cost by saving on the expenses spent on relocating an employee(s) to the project site. The same attribute of the model also helps in reducing the amount of carbon footprint caused by all the relocation.

(G14) Telecommunications Infrastructure

A high quality telecommunications infrastructure is essential for efficient collaboration to exist between entities. Such an infrastructure should also be secure to prevent loss of information. Keck Remote Observing Model [14, 20] ensures their information security by encapsulating their protocols (X, VNC, etc.) within secure shell (ssh) tunnels. A low cost but high quality IT and telecommunication infrastructure reduces the chances of conflicts arising due to lack of proper communication. Under Tec-Ed's Virtual Team Model [21], it is important that people trust one another. To build this bond of trust, it's important that people stay-in-touch and communicate with each other even when they are not working on the same team. To enable free movement of information (for example, using collaboration software [10]), and to have any type of system that requires collaboration through an electronic network [11], it is essential to have a high quality telecommunications infrastructure.

Using the models defined in the references, one can propose a functional relationship with the 14 major underlying groups.

Table 5 Nomenclature for the models/tools from the references

Model Number (M)	Model Abbreviation	Reference	Model Name
1	CSE	[10]	Collaboration Software for Enterprises (e.g. JIVE Software used by One Economy)
2	e-CBS	[30], [31]	Electronic Collaborative Banking System
3	K	[14]	Keck Remote Observing Model implemented using a combination of the

			best features of X, VNC and ssh protocols
4	$K_{VNC\text{-}ssh}$	[20]	Keck Remote Observing Model implemented using the VNC-based approach encapsulated within ssh
5	LARS	[11]	Location Awareness Rescue System
6	T_{VT}	[21]	Tec-Ed's Virtual Team Model of geographically distributed teams
7	NOAA-EAM	[18]	National Oceanic and Atmospheric Administration's Ecosystem Approaches to Management
8	CSP	[42]	Constraint Satisfaction Problem model using the multi-agent system
9	$C_{Pre\text{-}entry}$	[32]	Pre-market entry collaboration between businesses
10	$C_{Post\text{-}entry}$	[32]	Post-market entry collaboration between businesses
11	BLM	[33]	Binomial Logit Model
12	ROLRM	[33]	Rank-Ordered Logistic Regression Model

From the literature review, one can see that not much emphasis has been made to identify well-defined relationships between the models and the 76 location factors (14 major underlying groups). However, based on the results and applications of these models/tools, one can say that they can be extended to form a relationship with the factors. A functional relationship can be defined to study the impact of these models on the 14 major underlying groups. The following table lists such a functional relationship where $f(x_1, x_2, \ldots)$ represents a function dependent on the variables $x_1, x_2, \ldots$

Table 6 Functional relationship between the 14 major underlying groups and the models

Group Number	14 Major Underlying Groups	Impact of Collaboration – References
G1	Accessible Location	$f(CSE, LARS, K, K_{VNC\text{-}ssh}, CSP)$
G2	Favorable Financial Environment	$f(e\text{-}CBS)$
G3	Ease of Doing Business	$f(CSE, K, K_{VNC\text{-}ssh}, T_{VT})$
G4	Employment Environment	$f(K, K_{VNC\text{-}ssh}, T_{VT}, CSP)$

G5	Regional Business Hub	f(CSE, CSP)
G6	Attractive Standard of Living	f(T_{VT})
G7	Supportive Business Environment	f(NOAA-EAM)
G8	Level of Global and Regional Integration	f(CSE, T_{VT})
G9	Ambiance of Location	F(NOAA-EAM, CSP)
G10	Country Stability	f(BLM, ROLRM)
G11	Market Size and Potential	f($C_{Pre\text{-}entry}$, $C_{Post\text{-}entry}$)
G12	Proximity to Own Operations	f(LARS, CSP)
G13	Low Operating Costs	f(K, $K_{VNC\text{-}ssh}$, T_{VT}, CSP)
G14	Telecommunications Infrastructure	f(CSE, LARS, K, $K_{VNC\text{-}ssh}$, $T_{VT,}$ CSP)

<u>Conflict and Error Resolution in Collaborative Networks</u>

When parties undergo collaboration there can be two potential outcomes. One such favorable possibility is to achieve the common goal with as minimal of conflicts, errors and disputes as possible. However, with the lack of efficient protocols for conflict and error detection and mitigation, such collaborative units in the network might not completely achieve their common goal to its full potential. The principle of conflict resolution in collaborative e-Work (*Huang* and *Nof 1999 [24])* helps address this issue by utilizing conflict and error detection agents (CEDA) and protocols (CEDP) in the collaborative networks. This principle can be used to determine the effect of CCT based cyber-supported collaboration on the relative importance of the factors.

In this chapter, existing location decision and collaboration models and tools from literature reviewed, based on which it was observed that despite their advantages in terms of location and collaboration decisions, not much emphasis has been made on the impact of cyber-supported collaboration on the 14 major underlying groups (76 location factors) of RHQ. Consequently, in the following chapter a methodology has been proposed to identify the impact of cyber-supported collaboration on the location factors.

CHAPTER 3 METHODOLOGY

Chapter 2 discussed in detail how not much emphasis has been placed in literature to show the impact of cyber-supported collaboration on the location factors of RHQ. This chapter proposes a cyber-supported collaboration methodology that can be used to study its impact on the location factors of RHQ.

The following diagram gives an overview of a generic cyber-supported collaboration process. Depending on the location factor in consideration, the methodology can be adapted as shown with the help of an illustration. The communication pattern in the network is in three phases – (1) Validation, (2) Negotiation, and (3) Decision.

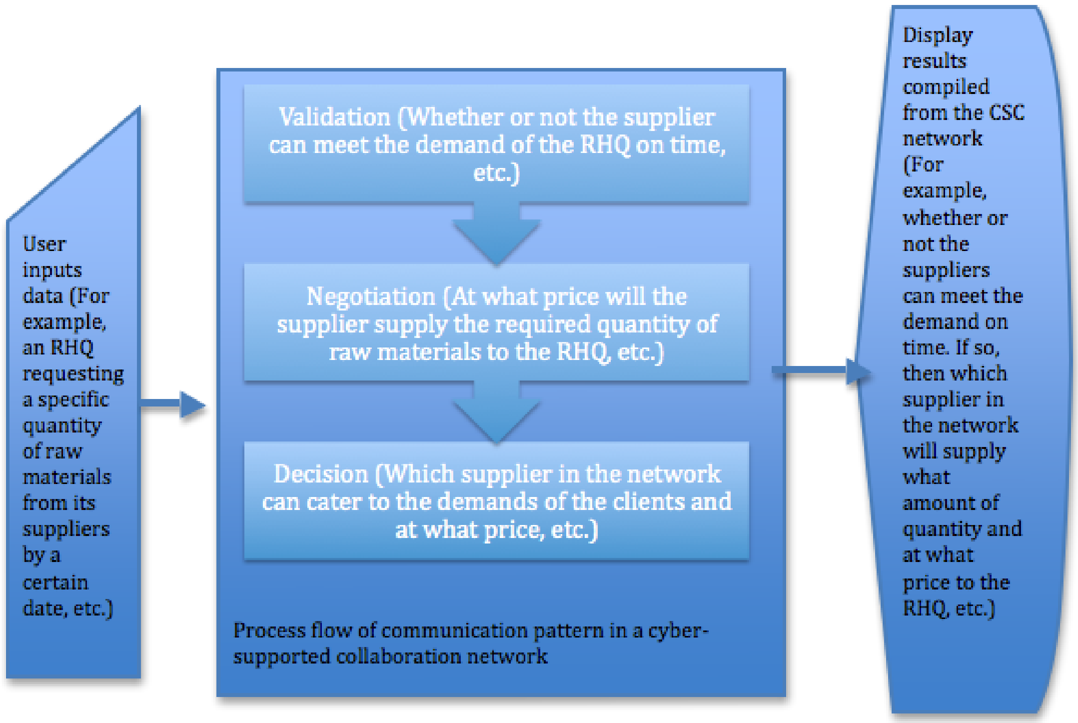

Figure 19 Overview of a generic cyber-supported collaboration process that can be modified depending on the nature of the collaborating units (For example, whether collaboration is between supplier and enterprise, between governments, between enterprise and government, etc.)

The communication pattern can be further understood with the help of the following UML sequence diagram, and the related description.

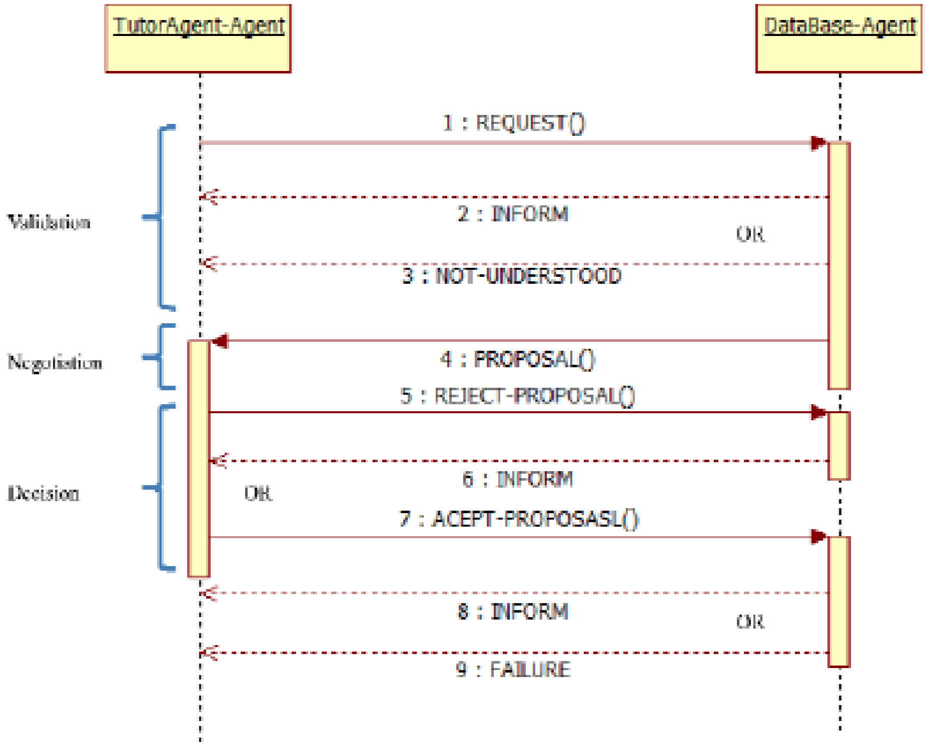

Figure 20 Sequence diagram between the Tutor Agent (TA) and the DataBase Agent (DBA) (after [42])

For the purpose of our research, the communication pattern as shown in Figure 20 can be used for the entities collaborating with each other. These entities can be suppliers interacting with each other to share resources in order to meet the demands of their clients, or a multi-national company collaborating with workers/knowledge experts distributed geographically, etc.

For example, in case of suppliers collaborating with each other to share resources, the resources will be the variables while their inventory capacity will form the basis of the constraints. To address the management of variables, a prototype multi-agent system discussed in Chapter 2 section 7 is used. Tutor Agent (TA) and Data Base Agent (DBA) compose the system. TA interacts directly with the expert, which in our case is the supplier, through a tutoring process that helps experts to transform tacit knowledge into explicit knowledge needed to create a coherent model. The idea is to identify and to qualify relevant capacity knowledge through an organic analysis of the constraint problem. Each expert gets a TA assigned. The TA provides a series of questions that make experts inquire into his/her experience in order to extract knowledge about his/her discipline. The process is dynamic as throughout the process experts discover new constraints and represent their knowledge through them.

Finally, once knowledge has been captured, TA begins its role of an interpreter in a negotiation that takes place between an expert and the DBA. The DBA primarily acts a manager of the database, receiving every request to add, modify or delete variables and constraints from the knowledge data base, reducing cognitive redundancy and therefore increasing the model's quality [42].

The process of Validation commences when the TA sends a REQUEST message with the variable to add in the database as shown in the UML sequence diagram (For our example, it can be a supplier asking the database to inquire about the inventory capacity of an existing supplier or to add its own inventory capacity information). Then, the DBA defines if it is possible to add the variable after checking that there are no similar variables in the database by comparing attributes of each variable with the attributes of the requested one. If the DBA finds any similar variable, it makes a suggestion with the analogous variables. The message is interpreted by the DBA and a response is sent. There are three options of response: (a) The message is not well constructed or there might be an error producing a NOT_UNDERSTOOD response message; (b) An INFORM message is sent to the TA indicating that a new variable has been added and the interaction is finished; (c) The DBA finds one or more variables that have at least 60% (This value can be modified based on the system) of similarity with the expert's variables. This produces a PROPOSE message, which includes the set of similar variables, signifying the beginning of the second stage [42].

The process of Negotiation is where the expert defines if any of the recommended variables can be used instead of creating a new one (In our example, if any of the existing suppliers in the database can be collaborated with). The accompanying PROPOSE message contains a list with the similar variables. The interaction continues depending on the expert action that can be: ACCEPT_PROPOSAL, that indicates that this expert becomes a user of the proposed variable or REJECT_PROPOSAL that means the variables proposed do not satisfy the expert's needs. According to the type of message, the DBA can link the expert to the variable that he/she selected and then send a message informing the TA or it can add expert variable to the database and send a message informing that a new variable was created [42]. Thus, by using this system the suppliers can add their capacity information, get access to the capacity, proximity and other types of information about other suppliers and enter into a state of negotiation with them before deciding on whom to collaborate with to meet the demands of their clients.

Illustration of the methodology

For the purpose of illustration, let us use the methodology to show the communication pattern in case of cyber-supported collaboration amongst suppliers with information sharing to study its impact on the significance of the location factor #L3 – "Proximity to key suppliers" of RHQ. Here the RHQ will act as the client (TA) and the key supplier will act as the (DBA). The nomenclature and the list of assumptions used have been shown in tables 8 and 9.

Table 8 Nomenclature list for the cyber-supported collaboration model for #L3 –Proximity to key suppliers

Nomenclature	Full Form
CNO	Collaborative Network Organization
CSC	Cyber-supported collaboration network (used interchangeably with CNO)
Q	Quantity of raw materials needed
P	Fixed price that the client will pay
DOD	Date of delivery by which the client (RHQ) requires the materials
CPI	Collaborative Performance Index (Rate other suppliers in the network based on their collaborative efforts)
Y	Yes
N	No
D	Distance between the supplier and the client (RHQ)

Table 9 List of assumptions for the cyber-supported collaboration model for #L3 – Proximity to key suppliers

Assumption Number (A)	Assumption
1	All suppliers in the network carry equal inventory

2	Each supplier can meet the entire demand of the client following a successful negotiation
3	Initially, all suppliers in the CSC network have their respective Collaborative Performance Index (CPI) value set based on their proximity to the RHQ, and this value is given using the formula *f(x, y, mu_x, mu_y, sig_x, sig_y, rho)* [ii]
4	For a particular product inquiry, once a supplier has been negotiated with unsuccessfully, no more negotiations take place with it during the remainder of the CSC network list search

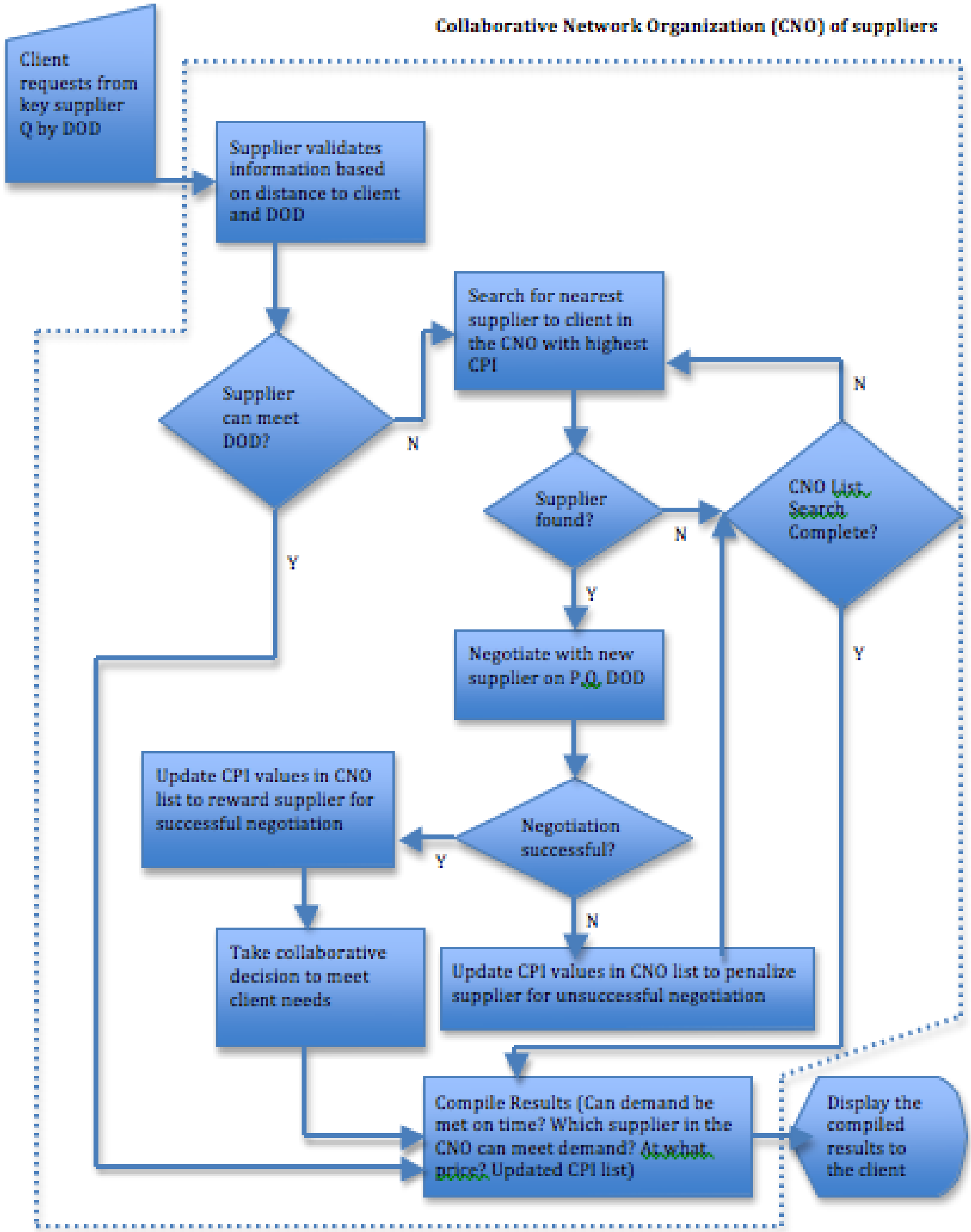

Figure 21 Cyber-supported collaboration (CSC) model amongst suppliers with information sharing enabled to clients (RHQ). This model is used in chapter 4 of the research report to study the impact of CSC network on the location decision factor of RHQ (#L3 – Proximity to key suppliers)

Before beginning the discussion on the illustration, it is essential to understand why "Proximity to Key Suppliers", henceforth referred to as #L3, is an important location decision factor. In terms of the supplier perspective, the closer the supplier is located to its clients, the shorter time it will take to meet the demands of the client, will incur lower transportation costs, and consequently, may charge lower fees depending on the type, quantity and availability of product. From a client's (RHQ's) perspective, location proximity is also essential for quick and timely delivery of raw materials, lower supplier fees and lower turnaround time in case the raw materials are of poor quality and fail to meet its specifications, etc. Thus, under normal circumstances, having key supplier(s) located in close proximity of a RHQ is beneficial for both the RHQ and the supplier.

Following the same chain of thought, we can safely assume that as the distance (let us call this distance *D*) between the RHQ and the supplier(s) increases, the supplier will be unable to meet the demands of the RHQ on time and at lower costs. The following distance formula is used to calculate the distance between any two points (x_1, y_1) and (x_2, y_2):

$$Distance(D) = SQRT[(x_2-x_1)*(x_2-x_1) + (y_2-y_1)*(y_2-y_1)] \qquad [i]$$

where SQRT is the square root function giving the square root of its argument

As the value of *D* increases, the ability to meet the demand of the RHQ by the supplier decreases. This is mathematically represented using the following exponentially decaying function *f(x, y, mu_x, mu_y, sig_x, sig_y, rho)*:

$$f = exp\ (-K_1 * (K_x + K_y - K_{xy})) \qquad [ii]$$

s.t.

$$K_1 = 1 / (2 * (1 - rho * rho))$$
$$K_x = ((x - mu\_x) / sig\_x) * ((x - mu\_x) / sig\_x)$$
$$K_y = ((y - mu\_y) / sig\_y) * ((y - mu\_y) / sig\_y)$$
$$K_{xy} = 2 * rho * (x - mu\_x)*(y - mu\_y) / (sig\_x * sig\_y)$$

where *x* and *y* are the coordinates of the current supplier, *mu_x* and *mu_y* are the coordinates of the client – RHQ, *sig_x*, *sig_y* and *rho* are chosen in a way to account for factors such as the topography of the region, region security, etc. Initially, the respective Collaborative Performance Index (CPI) value of each supplier is based on their proximity to the client (RHQ). The nearer the supplier, the higher is their value of *f* and CPI value as is clear from the equation [ii].

Over a period of time, based on the success or failure of negotiations between the suppliers and the key supplier, the CPI value of the suppliers in the CSC network gets updated according to the following formula:

$$CPI_i = CPI_{i-1} + k \qquad [iii]$$

s.t.

$k = 2$ (For every successful negotiation);

$k = -1$ (For every unsuccessful negotiation);

$$CPI_0 = f(x, y, mu\_x, mu\_y, sig\_x, sig\_y, rho)$$

Where ($1 <= i <= 1000$), and *i* represents the current period of time (or the current iteration). It is important to note that the CPI function can be formulated depending on the key supplier preference.

Each time the CPI value gets updated, the CSC network list gets sorted to reflect those changes with the supplier with the highest CPI value ranked at the top of the list. If the key supplier is unable to meet the demand of the client itself, then it will search the CSC network list to find the supplier with the highest CPI value and closest proximity to the RHQ. If a supplier is not found and the list search is complete, then the RHQ gets notified that the key supplier would not be able to meet their demand. However, if a supplier is found, then this information is also shared with the RHQ following which negotiations can take place between interested parties, firstly between the key supplier and the selected supplier, and then between the selected supplier and the RHQ over parameters such as price, flexibility on date of delivery, quantity, etc. Based on the outcome of this negotiation and decision process whether or not to receive the raw materials from the supplier, the CPI value of the supplier gets updated and the list gets sorted again with this new information made available again to the RHQ and the rest of the suppliers in the network.

In this chapter, a generic cyber-supported collaboration methodology for interested parties (amongst suppliers, amongst enterprises, amongst governments, between enterprise and government, between enterprise and its subsidiaries, etc.) was proposed and its communication pattern was studied, along with an illustration to show how the methodology can be adapted for the location factors of RHQ. The next chapter begins with an experimental design to validate the methodology proposed in this chapter. Following the ANOVA analysis of the methodology on location factor #L3, the relative significance of the factors from the survey are taken into consideration along with the effect of CCT based cyber-supported collaboration. The deductions are made based on the results from literature review done on various articles ranging from collaboration software to collaboration amongst search and rescue teams.

CHAPTER 4 RESULTS & ANALYSIS

To validate the methodology proposed in chapter 3, the following chapter begins with the design of experiment to study the impact of cyber-supported collaboration on the location factor #L3 – “Proximity to key suppliers.” Following analysis of the results using ANOVA, the relative significance and the potential impact of cyber-supported collaboration on each of the location factors has been listed.

4.1 Example to demonstrate the impact of cyber-supported collaboration on #L3 – Proximity to Key Suppliers

Let us assume that there is a manufacturing company interested in opening a new RHQ (0,0) as shown in the following figure with the black point. One of the key factors, the decision-makers keep in mind while making the RHQ location decision is #L3 - “Proximity to key suppliers.” There are 20 suppliers spread all throughout the terrain and represented by suppliers (S1, S2, S3, … , S20). The key supplier is represented by S0 (blue point in the following figure). It is important to note that all throughout the experiment the location of the suppliers (S1, … , S20) and the RHQ remains fixed. It’s only the location of the key supplier which varies to reflect the proximity issue faced by the RHQ location decision makers. The coordinates of the individual suppliers is represented in the following table.

Table 7 Supplier list with respective name and X and Y coordinates

Supplier Name	Supplier X coordinate	Supplier Y coordinate
S1	-1	5
S2	4	-6
S3	4	5
S4	5	5
S5	-1	-6
S6	2	0
S7	2	-3
S8	-5	3
S9	-1	-2
S10	3	-5
S11	-3	-3
S12	2	3
S13	2	-5
S14	-5	-6
S15	-4	1
S16	5	-1
S17	-2	-3
S18	-2	-4
S19	-5	-1
S20	0	-1

The goal of this experiment is to show that cyber-supported collaboration decreases the significance of #L3 in the decision-making process. In other words, contrary to our well-established opinion that an increase in *D* will result in a decrease in the number of times the key supplier is able to meet the RHQ's demands, if there exists a cyber-supported collaboration network between the key supplier(s) of a RHQ and the surrounding suppliers and information of resources is shared with the supplier clients (RHQ), then the number of times the key supplier is able to meet the demands of the RHQ is not dependent on *D*. Thus, if there is a cyber-supported collaboration network amongst suppliers, the information of which is shared with the clients (RHQ), then proximity of a RHQ to its key supplier(s) is no longer an important location decision factor in the decision-making process. The experiment was simulated using the programming language JAVA, and the code has been attached in Appendix A.

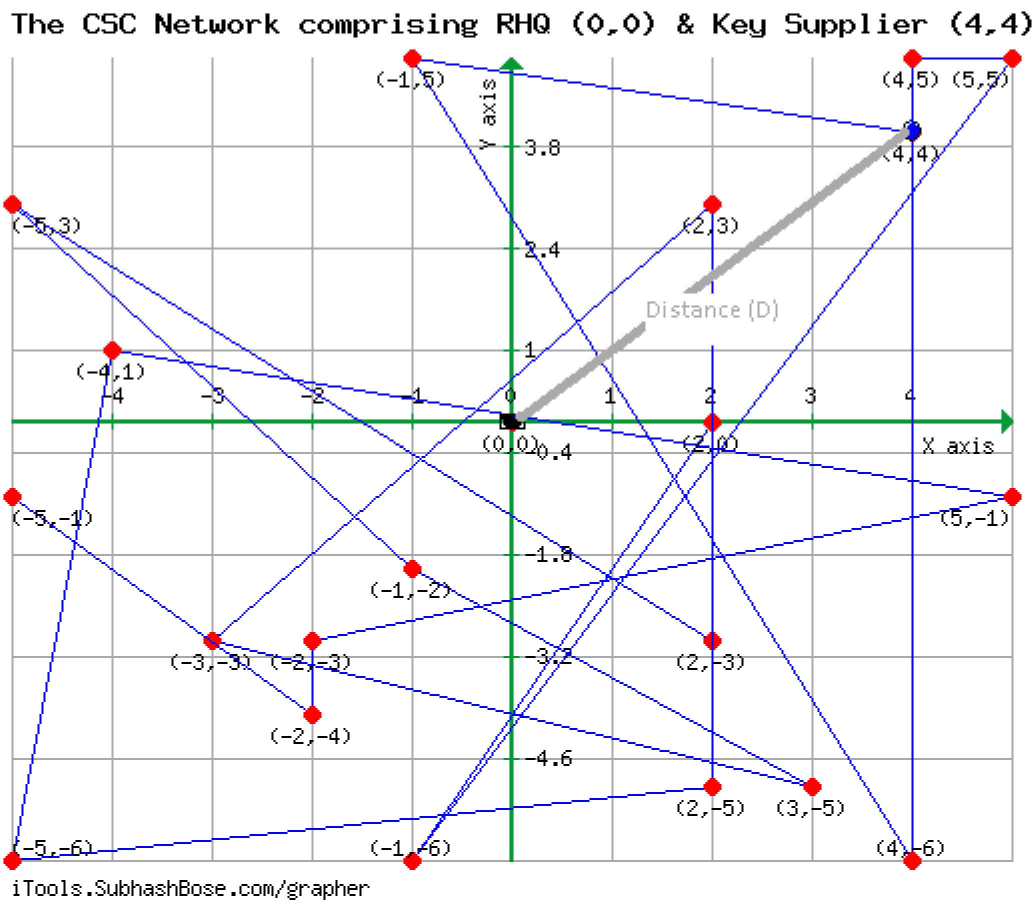

Figure 22 Plot to show RHQ (0,0) and Key Supplier (4,4) along with the other suppliers. The Distance (D) keeps changing as the (x,y) coordinates of the Key Supplier change in each simulation. The coordinates have been scaled down for the purpose of this experiment. To model real life scenarios, they can be scaled up by multiplying each coordinate with the desired scaling factor.

The experiment follows the CSC communication methodology discussed in Chapter 3 in the form of the illustrative example shown for #L3. All external factors, such as topography of the geographical region, transportation infrastructure, region security, etc. are held constant throughout the experiment as shown below. The experiment was repeated for 10 different trials, with each trial comprising 1000 scenario simulations. Each simulation represents a scenario where the RHQ*(0,0)* sends a raw material quantity request to its key supplier*(x,y)* along with the date of delivery by which the raw material is needed. The *x* and *y* values of the key supplier are randomly chosen from the domain [-6,6] using a random function generator. However, in each scenario these *x* and *y* values are kept constant. In the next scenario of the 1000 runs, another random value for each *x* and *y* is chosen to represent varying distance of the key supplier (with all the exact same attributes as the previous one except for its distance and location from the RHQ) at another distance *D* from the RHQ. This is done to ensure scenarios where the key supplier is at varying distances from the RHQ catering to the needs of multiple clients. As the value of *D* increases, the ability to meet the demand of the RHQ decreases.

Table 8 Constant values of external factors in the experiment

<table>
<tr><th>Variable</th><th>Value</th><th>Reasoning</th></tr>
<tr><td>mu_x</td><td>0</td><td>RHQ’s x-coordinate</td></tr>
<tr><td>mu-y</td><td>0</td><td>RHQ’s y-coordinate</td></tr>
<tr><td>sig_x</td><td>2</td><td rowspan="3">Constant numbers chosen randomly to represent the fixed values of external factors</td></tr>
<tr><td>sig_y</td><td>1</td></tr>
<tr><td>rho</td><td>0.5</td></tr>
</table>

To model the hypothesis that as the distance between the supplier and the RHQ increases, the ability of the supplier to meet the demand of the RHQ decreases, the exponentially decaying function *f* formula [ii] from Chapter 3 is used. The corresponding values from the table above are substituted to obtain the following plots.

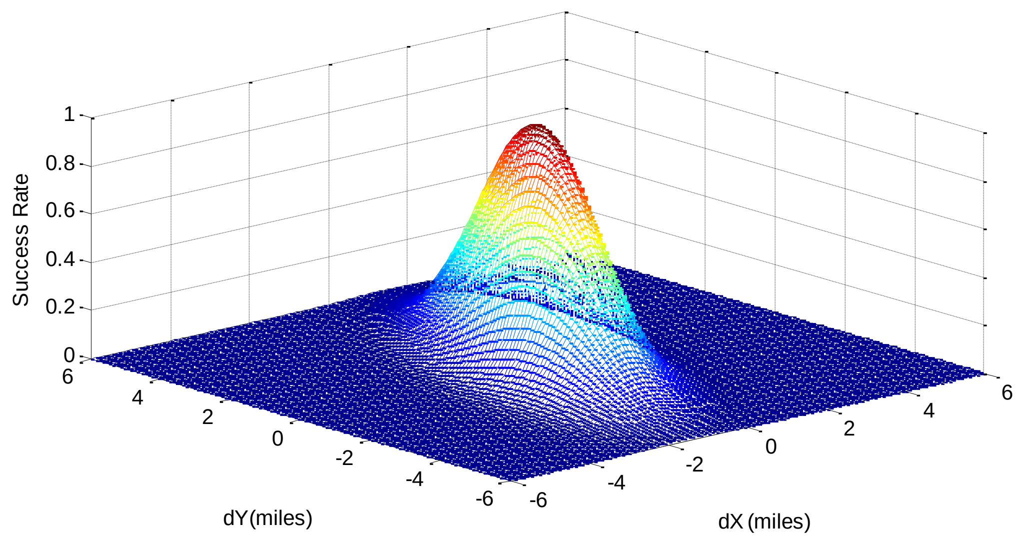

Figure 23 3-d plot to show that as the suppliers move away from the RHQ (0,0), their ability to meet the demands of the RHQ decreases

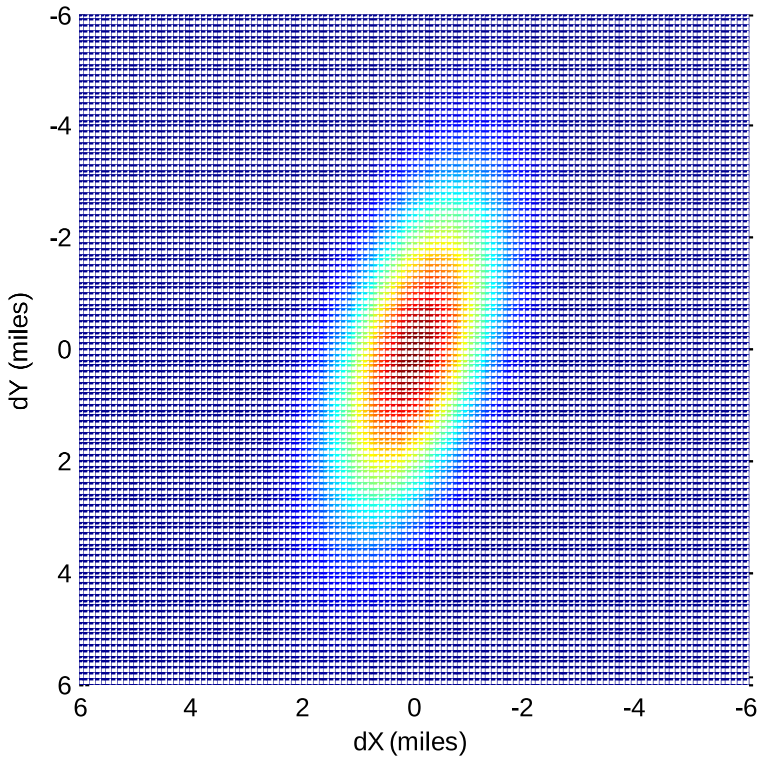

Figure 24 2-d image representing the contour of the region. The various shades of color represent the decrease in the ability of the supplier to meet the demands of the RHQ as the distance between the two increases

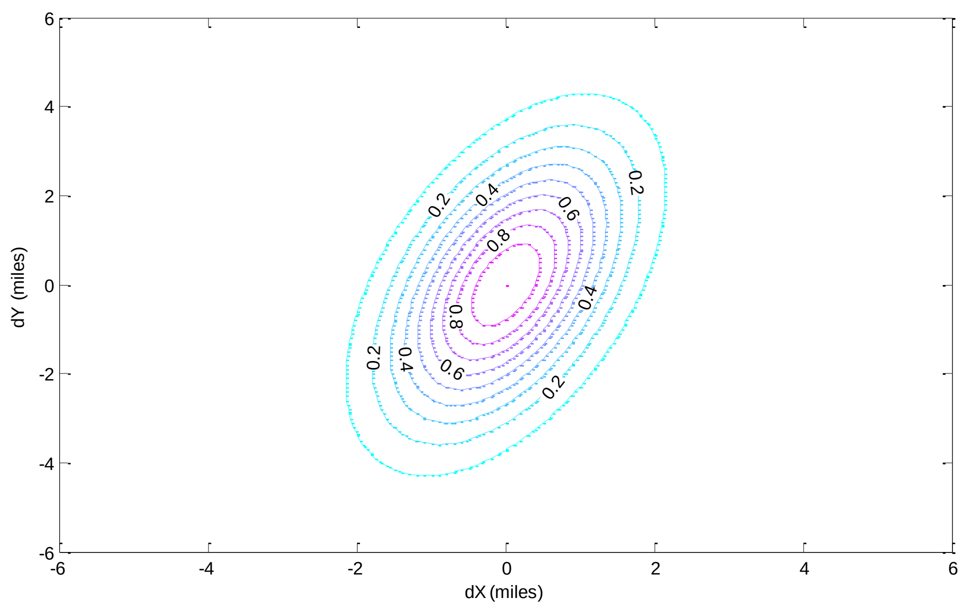

Figure 25 2-d image showing the values used in the experiment to model the decrease in the ability of the supplier to meet the RHQ's demands as distance between the two increases

A single-factor experiment was conducted followed by one-way ANOVA (analysis of variance) analysis. The single factor chosen is the existence or non-existence of a cyber-supported collaboration (CSC) network amongst suppliers with information sharing to their respective clients. Thus, the factor has two levels as demonstrated in the table below.

Table 9 Single factor experiment treatment levels

Level	Factor
0	Lack of a cyber-supported collaboration network amongst suppliers (i.e. When the RHQ and the key supplier(s) interact in the traditional way irrespective of surrounding suppliers)
1	Presence of cyber-supported collaboration between suppliers with information-sharing to clients (RHQ, etc.)

And our hyporesearch report can be stated as:

Hyporesearch report:

H_0: $\mu_0 = \mu_1$

H_1: $\mu_0 < \mu_1$

Where

Parameter	Hyporesearch report Parameter Description
μ_0	Average number of times (out of 1000 scenarios in each of the 10 trials) the key supplier is able to meet the demand of the RHQ in the absence of cyber-supported collaboration

μ_1	Average number of times (out of 1000 scenarios in each of the 10 trials) the key supplier is able to meet the demand of the RHQ in the presence of cyber-supported collaboration

The steps involved in the process are illustrated with the help of the following figure.

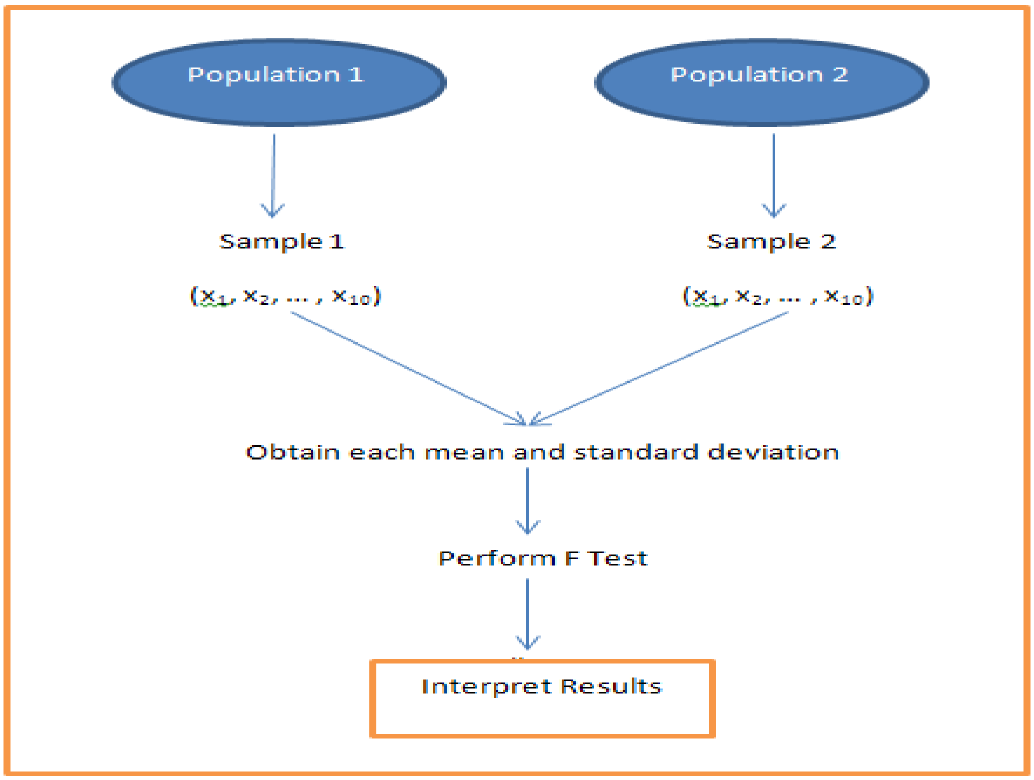

Figure 26 Steps needed to determine if the means of the two samples are statiscally different

The results of the experiment have been noted in the following table.

Table 10 Number of times the demands of the RHQ are met by the supplier as a function of the CSC status

CSC Network Status	Number of times RHQ need met by supplier (out of 1000 runs in each of the 10 trials) 1	2	3	4	5	6	7	8	9	10	Total	Average
0	87	96	79	99	99	88	88	89	88	98	911	92
1	952	941	947	954	947	939	949	946	940	951	9466	947

F-statistic

$F_0 = MS_{Treatments} / MS_{Error} = (3659401/1) / (635/18) = 103682.08$

Where $F_{critical} = F_{0.05,1,18} = 4.41$

Table 11 Summary of the ANOVA calculation to study the impact of CSC on #L3 - proximity to key suppliers

Source of Variation	Sum of Square (SS)	Degree of Freedom (df)	Mean Square (MS)	F_0
Treatments - CSC Status (Levels)	3659401	1	3659401	103682.08
Error	635	18	35	
Total	3660037	19		

Since, $F_o = 103682.08 > 4.41$, we reject the null hypothesis (H_0).

From Minitab results (shown in the following figure), we can conclude that we reject the null hypothesis because the P-value (0.000) is smaller than 0.05 and $F_o = 103682.08 > 4.41$. In other words, we accept the alternative hypothesis that the average number of times the demand of the RHQ gets met by the key supplier is more when cyber-supported collaboration network exists amongst the suppliers with information sharing to the RHQ in comparison to the level when no such CSC network exists.

One-Way Normal ANOM for Number of times of success

One-way ANOVA: Number of times of success versus CSC Status

```
Source       DF       SS       MS          F      P
CSC Status    1  3659401  3659401  103682.08  0.000
Error        18      635       35
Total        19  3660037

S = 5.941   R-Sq = 99.98%   R-Sq(adj) = 99.98%


                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level   N    Mean  StDev  -------+---------+---------+---------+--
0      10   91.10   6.61  (*
1      10  946.60   5.19                                      *
                          -------+---------+---------+---------+--
                               250       500       750      1000

Pooled StDev = 5.94
```

Figure 27 Results of ANOVA analysis to study the impact of CSC levels on the location decision factor #L3 using Minitab

So to summarize, we can say that there is no strong statistical evidence to prove our null hypothesis. Alternatively, we can say that with the existence of a cyber-supported collaboration network amongst suppliers, the significance of the factor #L3 – “Proximity to key suppliers” decreases in the decision-making process of RHQ location.

<u>Classification of the location models based on the relative impact of cyber-supported collaboration</u>

We have classified the 76 factors into three categories “A, B, or C” as shown in Table 11. This classification identifies the relative potential impact of CCT-based cyber-supported collaboration on each factor with A being clearly significant, B medium influence/importance/relevance and C being minor/sometimes influence.

NOTE FOR TABLES 14 and 15:

*Different governments may undergo collaboration to achieve a common goal

**Government(s) and enterprise(s) may undergo collaboration to attract business in a particular region. The government might have an incentive to uplift the living standards of the people through employment opportunities whereas enterprise(s) might get(s) attracted by tax deductions and other attractive government incentives to do business in the region.

Table 12 Classification based on the level of significance of the factors as impacted by cyber-supported collaboration

Factor Number (L)	Location Factor	Significant Impact (A)	Medium Impact (B)	Minor/Low Impact (C)
1	Frequent and reliable international air flights	A		
2	Low travel and transportation costs	A		
3	Proximity to key suppliers	A		
4	Proximity to key clients	A		
5	High quality public infrastructure (utilities, roads, etc.)		B	
6	Proximity to local supporting and related industries	A		
7	Proximity to surrounding markets		B	
8	Availability of reliable suppliers	A		
9	Accessible central geographic location with region		B	
10	Free movement of capital and profits	A		
11	Easy access to local capital markets	A		
12	Freedom to control domestic firms			C

13	Access to local venture capital		B	
14	Access to local financial and commercial services	A		
15	Low cost of capital		B	
16	Access to regional financial and commercial services	A		
17	Efficient banking systems	A		
18	Efficient capital and foreign exchange markets	A		
19	Free movement of information	A		
20	Transparent regulatory environment	A		
21	Low level of bureaucracy			C
22	Ethical business environment (Low level of corruption)	A		
23	Flexible employment contracts			C
24	Low level of industrial / labor disputes		B	
25	Availability of home-country language-speaking staff			C
26	Availability of English-speaking staff			C
27	Availability of highly-skilled staff		B	
28	Competitively priced local staff			C
29	Presence of major multinational corporations		B	
30	Presence of major international organizations		B	
31	Presence of competing multinational corporations		B	
32	Presence of regional decision-making bodies	A		
33	High level of personal freedom			C
34	Available quality medical services		B	
35	Available quality residential housing			C
36	Available quality K-12 international schools		B	
37	Attractive personal tax rates			C
38	High cultural compatibility with home country culture			C
39	Low cost of living			C
40	Personal safety and protection of property			C
41	Convenient time zone location		B	

42	Attractive dividend withholding taxes**			C
43	Reliable protection of intellectual property rights	A		
44	Reliable protection mechanisms for foreign investors			C
45	Attractive government investment and start-up incentives**			C
46	Attractive government operating incentives**			C
47	Attractive corporate tax regulations**			C
48	Stable economy			C
49	High level of regional economic integration		B	
50	High level of global political integration			C
51	Availability of multilingual personnel			C
52	Cultural compatibility with countries in region			C
53	Multi-cultural environment			C
54	Membership in regional trading blocs (EU, NAFTA, etc.)			C
55	High level of global economic integration		B	
56	High level of regional political integration			C
57	Adherence to international accounting standards			C
58	Favorable image of/for business activity			C
59	Proximity to world class universities and research		B	
60	Proximity to tourist attractions			C
61	Proximity to cultural and recreational centers			C
62	Comfortable climate			C
63	High environment quality (low pollution, etc.)			C
64	Political stability*		B	
65	High level of country security			C
66	Efficient government*			C
67	Reliable justice system			C

68	High local market growth potential		B	
69	Large local market		B	
70	Proximity to manufacturing subsidiaries		B	
71	Proximity to R&D subsidiaries		B	
72	Proximity to marketing subsidiaries	A		
73	Low office rent		B	
74	Low operating costs		B	
75	High quality IT & telecommunication infrastructure	A		
76	Low telecommunication costs	A		

Table 12 lists the factors and the effect of CCT-based cyber-supported collaboration on the relative importance of those factors. In other words, whether the factor becomes more or less important relatively when CCT-based cyber-supported collaboration is applied.

Table 13 Impact of CCT-based cyber-supported collaboration on the 76 factors

Factor Number (L)	Location Factor	Increased with CCT	Unknown	Decreased with CCT
1	Frequent and reliable international air flights			With CCT for tele-presence and remote meetings, there is decrease in need for flights
2	Low travel and transportation costs			Same as #L1
3	Proximity to key suppliers			Need may decrease if cyber-supported collaboration measures exist

				between suppliers to meet client demands
4	Proximity to key clients			Need may decrease with better cyber-supported collaboration with subsidiaries
5	High quality public infrastructure (utilities, roads, etc.)			Need maybe decreased by cyber-supported collaboration since meetings can happen through video conferencing, e-learning, telemedicine, etc.
6	Proximity to local supporting and related industries			Effective collaboration measures decrease need
7	Proximity to surrounding markets			Need may decrease by effective collaboration with more remote markets in and near the region
8	Availability of reliable suppliers			Need decreases with better supplier selection from remote reliable suppliers, or if suppliers

				undergo collaboration to meet client demands
9	Accessible central geographic location with region			Need for physical access may be replaced by better cyber-supported collaborative interactions through tele-presence, etc.
10	Free movement of capital and profits	Significantly supported by CCT and improved by effective cyber-supported collaboration		
11	Easy access to local capital markets			e-financial services decrease need
12	Freedom to control domestic firms	Level decreases with shared responsibilities, information and resources in an effective collaboration. So it is necessary to identify division of responsibilities and control. Hence, factor's significance increases		
13	Access to local venture capital			e-financial

				services decrease need
14	Access to local financial and commercial services			e-financial services decrease need
15	Low cost of capital			CCT operations lower it
16	Access to regional financial and commercial services			e-financial services decrease need
17	Efficient banking systems			e-financial services decrease need
18	Efficient capital and foreign exchange markets	Significantly supported by CCT through e-financial services		
19	Free movement of information	Significantly supported by CCT		
20	Transparent regulatory environment	Significance increases with CCT as more monitoring is required on expanding collaborative networks		
21	Low level of bureaucracy		Unknown	
22	Ethical business environment (Low level of corruption)	Significance increases with CCT to prevent rising conflicts and errors with the collaborative network organizations		
23	Flexible employment contracts	Increased potential with		

		improved and efficient collaboration		
24	Low level of industrial / labor disputes			Significance may decrease through the use of efficient conflict and error resolution protocols in collaborative network organizations
25	Availability of home-country language-speaking staff	Increased potential for effective collaborative measures		
26	Availability of English-speaking staff			May decrease in cases of English-speaking staff having tele-presence
27	Availability of highly-skilled staff			Decreases with effective cyber-supported collaboration through e-manage and e-training programs
28	Competitively priced local staff			Need may decrease with CCT due to sharing of responsibilities and resources
29	Presence of major multinational corporations			May decrease the need by

				improved and efficient collaboration and intense cyber-supported interactions
30	Presence of major international organizations			May decrease the need through effective cyber-supported collaboration measures
31	Presence of competing multinational corporations			May decrease with effective and improved collaboration with non-competing organizations against the competing ones, or amongst themselves to gain mutual benefits
32	Presence of regional decision-making bodies	Increased potential for better quality distributed and local decisions		
33	High level of personal freedom		Unknown	
34	Available quality medical services			Telemedicine services may decrease need
35	Available quality residential housing		Unknown	
36	Available quality K-12 international schools			e-learning may decrease need

37	Attractive personal tax rates		Unknown	
38	High cultural compatibility with home country culture		Unknown	
39	Low cost of living			Need may decrease resulting from business organizations which are part of a collaborative network collaborate with other affiliates and the government to bring down prices (eg. Wal-Mart prices)
40	Personal safety and protection of property		Unknown	
41	Convenient time zone location			Need may decrease by effective cyber-supported collaborative interactions with members of the collaborative network in the other time zones, thereby, sharing work, responsibilities, resources and information
42	Attractive dividend withholding taxes**	Increased potential for promoting		

		collaboration		
43	Reliable protection of intellectual property rights	Fundamental for effective cyber-supported collaboration		
44	Reliable protection mechanisms for foreign investors	Fundamental for CCT as cyber-supported collaboration requires information security and support		
45	Attractive government investment and start-up incentives**	Increased potential with improved and efficient collaboration between organizations and government(s)		
46	Attractive government operating incentives**	Same as #L45		
47	Attractive corporate tax regulations**	Same as #L42		
48	Stable economy	Increased potential if there is improved and effective collaboration between entities		
49	High level of regional economic integration	Level improved by effective collaboration		
50	High level of global political integration*	Level may increase if		

		governments undergo collaboration		
51	Availability of multilingual personnel			Need may decrease with access to information in multiple languages through cyber-supported collaboration
52	Cultural compatibility with countries in region		Unknown	
53	Multi-cultural environment	Improved through cyber-supported collaborative interactions with entities from different cultures		
54	Membership in regional trading blocs (EU, NAFTA, etc.)	Promoted through improved and effective collaboration with regional and remote trading bloc members		
55	High level of global economic integration	Level increased by improved and effective collaboration		
56	High level of regional political integration	Same as #L50		
57	Adherence to international accounting standards	Essential for expanding collaborative networks with		

		increasing transparency and visibility		
58	Favorable image of/for business activity	Increased potential with improved and efficient collaborative activities		
59	Proximity to world class universities and research			Decreases through better cyber-supported collaboration with remote research centers through e-learning and e-training
60	Proximity to tourist attractions		Unknown	
61	Proximity to cultural and recreational centers			Physical proximity may be of less importance because of e-entertainment, etc.
62	Comfortable climate		Unknown	
63	High environment quality (low pollution, etc.)	Increased potential with effective and improved collaboration to respect higher quality standards (eg. European Union member nations and their high		

		respect for environmental quality standards)		
64	Political stability*	Increased potential for stability with governments or competing parties undergoing effective collaboration		
65	High level of country security	Improved potential when governments collaborate effectively and efficiently with each other (eg. European Union members)		
66	Efficient government*	Significance increases for effective and improved collaboration to work		
67	Reliable justice system	Fundamental for resolving conflicts and errors and intellectual property crimes in collaborative network organizations		
68	High local market growth potential			Need may decrease by better

				collaboration with remote and local markets
69	Large local market			Need may decrease with effective CCT measures giving access to local and global markets
70	Proximity to manufacturing subsidiaries			Need may decrease if remote and proximate subsidiaries engage in effective cyber-supported collaboration (eg. e-manufacturing)
71	Proximity to R&D subsidiaries			Need may decrease by better cyber-supported collaboration with remote R&D subsidiaries
72	Proximity to marketing subsidiaries			Need may decrease by efficient collaboration with remote and proximate subsidiaries
73	Low office rent			e-operations and e-manage decrease need through effective cyber-

				supported collaboration
74	Low operating costs			e-operations decrease need through effective cyber-supported collaboration
75	High quality IT & telecommunication infrastructure	Fundamental for CCT, and may be justified and expanded by it		
76	Low telecommunication costs	Fundamental for effective cyber-supported collaboration, and maybe justified and expanded by it		

Influences that may be significant under certain conditions might not be significant under others. In the table on the previous page, for example, collaboration can exist between enterprises or between governments or between the government and an enterprise.

In this chapter, we studied the impact of CCT-based cyber-supported collaboration on one of the location factors with the help of an example. ANOVA analysis was performed on the results of an experiment, and it was found that cyber-supported collaborations decreases the significance of the factor requiring the location of RHQ close to key suppliers. The analysis was then followed by a list of the potential impact of cyber-supported collaboration on the 76 location factors for a RHQ. The following chapter provides the reader with a summary of results, along with direction for future work that could be done.

CHAPTER 5 CONCLUSIONS & FUTURE WORK

The impact of CCT-based cyber-supported collaboration on the 76 location decision factors has been discussed in this study. With the help of an experiment, it was found that in the presence of cyber-supported collaboration, the location decision factor – proximity of RHQ to key suppliers is not significant.

Future work involves exploring the exact relationship between the major factor groups and the models discussed. For example, the group "Attractive Standard of Living" has a functional relationship with Tec-Ed's Virtual Teams Model, but the exact mathematical relationship is still unknown. Consequently, further work needs to be done in determining the exact mathematical functional relationship that exists between the two. Some major groups are dependent on many models. It would be interesting to find out the correlations between these models and it's respective effect on the related major groups.

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Appendix

JAVA code for the experiment to study the impact of cyber-supported collaboration amongst suppliers with information sharing to RHQ on the location decision factor #L3 – Proximity to key suppliers

The package comprises of the following four classes:

Main.java
KeySupplier.java
SupplierCollaborativeNetwork.java
Supplier.java

Main.java

```
import java.util.Scanner;
import java.util.Random; //to generate random RHQ coordinates for the
simulation

public class Main {

	/**
	 * @param args
	 */
	public static void main(String[] args) {
		// TODO Auto-generated method stub
	  int quantity, dOD, x, y, numberOfIterations;
	  int counter = 0;

	  /*KeySupplier kSupp = new KeySupplier();
	  //double price;

	  //create a scanner object to read the input
	  Scanner keyboard = new Scanner (System.in);

	  //Enter data
	  System.out.println("Enter client's x-coordinate: ");
	  x = keyboard.nextInt();
	  System.out.println("Enter client's y-coordinate: ");
	  y = keyboard.nextInt();
	  System.out.println("Enter Quantity: ");
	  quantity = keyboard.nextInt();
	  System.out.println("Enter number of days the product is needed
from today: ");
	  dOD = keyboard.nextInt();
	  System.out.println("Enter key supplier's x-coordinate: ");
	  int ksX = keyboard.nextInt();
	  kSupp.setKSxCoordinate(ksX);
	  System.out.println("Enter key supplier's y-coordinate: ");
	  int ksY = keyboard.nextInt();
```

```
        kSupp.setKSyCoordinate(ksY);
        System.out.println("Enter number of iterations: ");
        numberOfIterations = keyboard.nextInt();
        //System.out.println("Enter Price: ");
        //price = keyboard.nextDouble();

        //Send the client (RHQ) information to its key supplier
        System.out.println("FinalResponse = " +
kSupp.checkAbilityToSupply(x, y, numberOfIterations)); */

        //Auto-generated simulation loop begins here
        for (int count=1; count<=1000; count++)
        {
            //Create a Random object
            Random randomNumber = new Random();

            //Get a random number
            x = 0;//= randomNumber.nextInt(71);
            y = 0;//= randomNumber.nextInt(71);
            int ksX = -6 + (int)(Math.random() * ((6 - (-6)) + 1));
//Range for x-coordinate of supplier is -6<x<6
            int ksY = -6 + (int)(Math.random() * ((6 - (-6)) + 1));
//Range for y-coordinate of supplier is -6<y<6
            //int ksX = randomNumber.nextInt();
            //int ksY = randomNumber.nextInt(71);
            KeySupplier kSupp = new KeySupplier();
            kSupp.setKSxCoordinate(ksX);
            kSupp.setKSyCoordinate(ksY);
            numberOfIterations = count;
            counter = counter + kSupp.checkAbilityToSupply(x, y,
numberOfIterations);
        }
        System.out.println("Out of 1000, total number of successful
scenarios = " + counter);
      }

}
```

KeySupplier.java

```
//This class represents the key supplier.
//The RHQ sends its requests here.
//It acts as a manager for the collaborative network of suppliers

import java.util.Random; //needed for random class

public class KeySupplier {
private int posResponse;
private int negResponse;
private int ksXcoord;
private int ksYcoord;
private int distance; //distance from client
```

```
//Default constructor to initialize values
public KeySupplier ()
{
       posResponse = 1;
       negResponse = 0;
       ksXcoord = 0;
       ksYcoord = 0;
       distance = 0;
}

//Constructor to initialize private variables with user specified
values
public KeySupplier (int pResp, int nResp)
{
       posResponse = pResp;
       negResponse = nResp;
}

//methods to set Key Supplier coordinates
public void setKSxCoordinate(int ksX)
{
       ksXcoord = ksX;
}

public void setKSyCoordinate(int ksY)
{
       ksYcoord = ksY;
}

//methods to get Key Supplier coordinates
public int getKSxCoordinate()
{
       return ksXcoord;
}

public int getKSyCoordinate()
{
       return ksYcoord;
}

//method for validation process between key supplier and client (RHQ)
public int ksValidation (int clientX, int clientY)
{
       distance = calculateDistanceFromClient(clientX, clientY);
    System.out.println("Distance of Key Supplier from client =
"+distance);
       int response = 0;

       //call the exponentially decaying probability function to
determine the success rate based on the x and y coordinates with
probability being 1 closest to the client site
       double pdfXY = expoDecayFunction(getKSxCoordinate(),
getKSyCoordinate(), clientX, clientY, 2, 1, 0.5);
```

```
        //if probability > 40% then it is a successful negotiation and
the key supplier can meet the demand, else not
        if (pdfXY*100 > 40)
        {
              System.out.println("Key Supplier response: YES");
              response = 1;
        }
        else
        {
              System.out.println("Key Supplier response: NO");
              response = 0;
        }

        /*
        //Create a Random object
        Random randomNumber = new Random();

        //Get a random number
        int randomPCNum = randomNumber.nextInt(100);

        if (distance>=0 && distance<=100)
        {
              System.out.println("Distance between 0 and 100 ");
              if (randomPCNum<=90)
              {
                    //Then 90% probability of key supplier able to meet
RHQ demand
                    System.out.println("Key Supplier Response = YES ");
                    response = posResponse;
              }
              else
              {
                    //10% chance of not meeting demand
                    System.out.println("Key Supplier Response = NO ");
                    response = negResponse;
              }
        }
        else if (distance>100 && distance<=200)
        {
              System.out.println("Distance between 100 and 200 ");
              if (randomPCNum<=60)
              {
                    //Then 60% probability of key supplier able to meet
RHQ demand
                    System.out.println("Key Supplier Response = YES ");
                    response = posResponse;
              }
              else
              {
                    //40% chance of not meeting demand
                    System.out.println("Key Supplier Response = NO ");
                    response = negResponse;
              }
        }
        else if (distance>200 && distance<=300)
```

```
        {
                System.out.println("Distance between 200 and 300 ");
                if (randomPCNum<=30)
                {
                        //Then 30% probability of key supplier able to meet 
RHQ demand
                        System.out.println("Key Supplier Response = YES ");
                        response = posResponse;
                }
                else
                {
                        //70% chance of not meeting demand
                        System.out.println("Key Supplier Response = NO ");
                        response = negResponse;
                }
        }
        else if (distance>300)
        {
                System.out.println("Distance above 300 miles ");
                if (randomPCNum<=5)
                {
                        //Then 10% probability of key supplier able to meet 
RHQ demand
                        System.out.println("Key Supplier Response = YES ");
                        response = posResponse;
                }
                else
                {
                        //90% chance of not meeting demand
                        System.out.println("Key Supplier Response = NO ");
                        response = negResponse;
                }
        }*/
        return response;
}

//method to calculate distance from client
public int calculateDistanceFromClient(int clientX, int clientY)
{
        int x1 = getKSxCoordinate();
        int y1 = getKSyCoordinate();
        int squareSum = (x1-clientX)*(x1-clientX) + (y1-clientY)*(y1-
clientY);
        int distanceFromClient = (int)(Math.sqrt(squareSum));
        //System.out.println("sumSq: "+squareSum);
        System.out.println("Distance: "+distanceFromClient);
        return distanceFromClient;
}

/*If key supplier is unable to meet demand on time, it searches the 
collaborative database (hence acts as a DBA) to find the nearest 
supplier with highest CPI. This method provides this search feature*/
public int checkAbilityToSupply (int clientX, int clientY, int 
numOfIterations)
{
```

```
        int ksResponseCheck = ksValidation(clientX, clientY);
        int finalResponse = 0;

        //This code segment is to be used in case of NO cyber-supported
collaboration amongst suppliers
        finalResponse = ksResponseCheck;

        /*///The following code segment is to be used ONLY when cyber-
supported collaboration exists between the suppliers
        if (ksResponseCheck == 0)
        {
              SupplierCollaborativeNetwork scn = new
SupplierCollaborativeNetwork();
              finalResponse = scn.setSCN(clientX, clientY,
numOfIterations);
        }
        else finalResponse = ksResponseCheck;

        if (finalResponse==1)
              finalResponse = 1;
        else finalResponse = 0; */
        return finalResponse;
}

//Exponentially decaying probability function
        /*
         * % multinorm(x,y,0,0,2,1,0.5); % where  -6 < x,y < 6
function f = multinorm(x,y,mu_x,mu_y,sig_x,sig_y,rho)
         */
        public double expoDecayFunction(int x, int y, int clientX, int
clientY, int sigX, int sigY, double rho)
        {
              double k2 = 1/(2*(1-rho*rho));
              double kX = ((x-clientX)/sigX)*((x-clientX)/sigX);
              double kY = ((y-clientY)/sigY)*((y-clientY)/sigY);
              double kXY = 2*rho*(x-clientX)*(y-clientY)/(sigX*sigY);
              double a = -1*k2*(kX+kY-kXY);
              double f = Math.exp(a);
              System.out.println("Probability value for x = "+x+"; y =
"+y+" is: "+f+"\n");
              return f;
        }
}
```

SupplierCollaborativeNetwork.java

```
import java.util.Random;

/*
 * This class forms the supplier collaborative network.
 * The related operations are also performed here.
 */
public class SupplierCollaborativeNetwork {
```

```
	private int numOfSuppliers; //variable to set number of suppliers 
in the collaborative network
	private String[] name = {"S1", "S2", "S3", "S4", "S5", "S6", 
"S7", "S8", "S9", "S10", "S11", "S12", "S13", "S14", "S15", "S16", 
"S17", "S18", "S19", "S20"};
	//private int[] x = {-24, 209, 249, 259, -48, 126, 135, -215, -
32, 184, -139, 127, 115, -246, -187, 290, -83, -87, -215, 12};
	//private int[] y = {252, -287, 264, 263, -266, 10, -117, 184, -
76, -202, -150, 169, -217, -294, 60, -22, -148, -161, -42, -8};
	//private int[] x = {6, 4, 4, 0, -1, 5, 2, -6, -4, 5, -3, 0, 6, -
5, -4, 5, -2, -1, -5, 0};
	//private int[] y = {0, -4, 6, -3, 6, -1, 0, 1, -3, -1, -2, 6, 0, 
-3, 6, 0, -1, 1, -6, -1};
	//private int[] y = {-5, -6, 4, 4, -4, 1, -4, 3, -6, -3, -2, -6, 
-5, -5, 6, 3, -2, -6, 2, 0};
	private int[] x = {-1, 4, 4, 5, -1, 2, 2, -5, -1, 3, -3, 2, 2, -
5, -4, 5, -2, -2, -5, 0};
	//private int[] y = {0, -6, 6, 5, -6, 0, -1, 6, -2, -4, -2, 4, -
5, 6, 2, -1, -2, -4, -1, 5};
	private int[] y = {5, -6, 5, 5, -6, 0, -3, 3, -2, -5, -3, 3, -5, 
-6, 1, -1, -3, -4, -1, -1};
	//private static Supplier[] supplier = new 
Supplier[numOfSuppliers];
	//private static double[] arrayCPI = {0, 0, 0, 0, 0, 0, 0, 0, 0, 
0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0};
	//private static String[] name2 = 
{"","","","","","","","","","","","","","","","","","","",""};
	//private static int[] x2 = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 
0, 0, 0, 0, 0, 0, 0, 0};
	//private static int[] y2 = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 
0, 0, 0, 0, 0, 0, 0, 0};
	//private static int[] dist = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 
0, 0, 0, 0, 0, 0, 0, 0, 0};
	//private static int[] check = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 
0, 0, 0, 0, 0, 0, 0, 0, 0};
	//Default constructor
	public SupplierCollaborativeNetwork()
	{
		numOfSuppliers = 20; //excluding the key supplier
	}
	
	//constructor to set number of Suppliers if specified by user
	public SupplierCollaborativeNetwork(int supplierNumber)
	{
		numOfSuppliers = supplierNumber;
	}
	
	//method to set number of suppliers
	public void setNumberOfSuppliers(int number)
	{
		numOfSuppliers = number;
	}
	
	//method to get number of suppliers value
```

```
	public int getNumberOfSuppliers()
	{
		return numOfSuppliers;
	}

	//Create Supplier Collaborative Network based on proximity to
client
	public int setSCN(int clientX, int clientY, int
networkIterationCounter)
	{
		Supplier[] supplier = new Supplier[numOfSuppliers];

		//first create the supplier objects as they reference to
null right now. However, do this only on the first trial of the mega
1000 runs
		//if (networkIterationCounter==1)
		//{
		  //Supplier[] supplier = new Supplier[numOfSuppliers];
		    for (int index=0; index<supplier.length; index++)
		          supplier[index] = new Supplier();
		//}
		//else
		//{
		//    for (int index=0; index<supplier.length; index++)
			//    supplier[index] = new Supplier(name2[index],
x2[index], y2[index], arrayCPI[index], dist[index], check[index]);
		//}
		for (int index=0; index<supplier.length; index++)
		{
			//Only for the very first iteration, the coordinates
are assigned to memory and relative CPI is set to 100 for all supplier
units
			//if (networkIterationCounter==1)
			//{
				supplier[index].setSupplierName(name[index]);
				supplier[index].setX(x[index]);
				supplier[index].setY(y[index]);
				//supplier[index].setRelCPI(50);
				//set the CPI value of each supplier based on
the proximity goodwill
				if (networkIterationCounter == 1)
				{
					double pdfXY =
expoDecayFunction(x[index], y[index], clientX, clientY, 2, 1, 0.5) *
100;

					supplier[index].setRelCPI(pdfXY);
					//displaySCN(supplier);
				}

			//}

			//Find the distance of the supplier from the client
			supplier[index].setDistance(clientX, clientY);

		}
```

```
            //call method to sort the suppliers in the collaborative
network based on CPI of supplier with key supplier
            sortSuppliers(supplier);

            //From the sorted list based on relative CPI values, find
the supplier with the next highest CPI value and the closest distance
to client
            int indexNearestSupHighestCPI =
getIndexOfNearestSupplierWithHighestCPI(supplier, 0);
            int supResponse = 0;
            while (indexNearestSupHighestCPI != -1 && supResponse != 1
&& supResponse != -1)
            {
                  indexNearestSupHighestCPI =
getIndexOfNearestSupplierWithHighestCPI(supplier, 0);
                  supResponse = listSearchNetwork(supplier, clientX,
clientY);
            }
            //saveCPI(supplier);
            return supResponse;
      }

      //Method to Sort suppliers in SCN based on relative CPI value of
supplier with key supplier
      public static void sortSuppliers(Supplier[] supplierArray)
      {
            int startScan, index, minIndex;
            Supplier minValue = new Supplier();
            for (startScan=0; startScan<(supplierArray.length-1);
startScan++)
            {
                  minIndex = startScan;
                  minValue = supplierArray[startScan];
                  for (index=startScan+1; index<supplierArray.length;
index++)
                  {
                        if (supplierArray[index].getRelCPI() >
minValue.getRelCPI())
                        {
                              minValue = supplierArray[index];
                              minIndex = index;
                        }
                  }
                  supplierArray[minIndex] = supplierArray[startScan];
                  supplierArray[startScan] = minValue;
            }
      }

      //Method to find the nearest supplier with the highest CPI value
      public int getIndexOfNearestSupplierWithHighestCPI(Supplier[]
supplier, int startSearchAtIndex)
      {
      Supplier selectSupplier = new Supplier();
      int supplierIndexTracker;
```

```
        int index = startSearchAtIndex;

        if (supplier[index].getChecked()==0)
        {
              selectSupplier = supplier[index]; //set dummy variable to
the next highest CPI supplier in the search process
            supplierIndexTracker = index;
              for (int subindex=index+1; subindex<supplier.length;
subindex++)
            {
              if
(selectSupplier.getRelCPI()==supplier[subindex].getRelCPI() &&
supplier[subindex].getChecked()==0)
              {
                    if
(selectSupplier.getDistance()>supplier[subindex].getDistance())
                    {
                          selectSupplier = supplier[subindex];
                          supplierIndexTracker = subindex;
                    }
              }
            }
              return supplierIndexTracker;
        }
        else
              {
                 System.out.println("\nList search complete. No supplier
found in the SCN!!!!");
                 return -1;
              }
        /*
        if (index<supplier.length-1)
        {
              selectSupplier = supplier[index]; //set dummy variable to
the next highest CPI supplier in the search process
            supplierIndexTracker = index;
              for (int subindex=index+1; subindex<supplier.length;
subindex++)
            {
              if
(selectSupplier.getRelCPI()==supplier[subindex].getRelCPI() &&
supplier[subindex].getChecked()==0)
              {
                    if
(selectSupplier.getDistance()>supplier[subindex].getDistance())
                    {
                          selectSupplier = supplier[subindex];
                          supplierIndexTracker = subindex;
                    }
              }
            }
              return supplierIndexTracker;

        }
        else if (index==supplier.length-1){
```

```
            System.out.println("Last supplier in CNO left");
          return index;

      }
      else
            {
               System.out.println("/nList search complete. No supplier
found in ");
               return -1;
            } */
      }

      //Selected supplier validates with client/collaborative supplier
whether or not it can meet client demand
      public int selectedSupplierValidation (int distanceFromClient,
String supplierName, int x, int y, int clientX, int clientY)
      {
            int distance = distanceFromClient;
            int response = 0;
            String name = supplierName;

            //call the exponentially decaying probability function to
determine the success rate based on the x and y coordinates with
probability being 1 closest to the client site
            double pdfXY = expoDecayFunction(x, y, clientX, clientY, 2,
1, 0.5);
            System.out.println("\n"+ name + ": ");
            System.out.println("Distance from client = "+distance);
            //if probability > 95% then it is a successful negotiation
and the key supplier can meet the demand, else not
            if (pdfXY*100 > 45)
            {
                  //Let's assume that even if the supplier is nearby
due to price, date of delivery negotiations, etc. there is only 40%
probability that the supplier can make the demand on time
                  //Create a Random object
                  Random randomNumber = new Random();
                  //Get a random number
                  int randomPCNum = randomNumber.nextInt(100);
                  if (randomPCNum<=75)
                  {
                      System.out.println("Supplier "+name+" response:
YES");

                      response = 1;
                  }
                  else
                  {
                        System.out.println("Supplier "+name+" response:
NO");

                      response = 0;
                  }
            }
            else
            {
                  System.out.println("Supplier "+name+" response: NO");
```

```
                        response = 0;
                }
                /*
                //Create a Random object
                Random randomNumber = new Random();

                //Get a random number
                int randomPCNum = randomNumber.nextInt(100);

                System.out.println("\n"+ name + ": ");
                if (distance>=0 && distance<=100)
                {
                        System.out.println("Distance between 0 and 100:
"+distance);
                        if (randomPCNum<=90)
                        {
                                //Then 90% probability of key supplier able to
meet RHQ demand
                                System.out.println("Supplier "+ name +"
Response = YES ");
                                response = 1;
                        }
                        else
                        {
                                //10% chance of not meeting demand
                                System.out.println("Supplier "+ name +"
Response = NO ");
                                response = 0;
                        }
                }
                else if (distance>100 && distance<=200)
                {
                        System.out.println("Distance between 100 and 200:
"+distance);
                        if (randomPCNum<=60)
                        {
                                //Then 60% probability of key supplier able to
meet RHQ demand
                                System.out.println("Supplier "+ name +"
Response = YES ");
                                response = 1;
                        }
                        else
                        {
                                //40% chance of not meeting demand
                                System.out.println("Supplier "+ name +"
Response = NO ");
                                response = 0;
                        }
                }
                else if (distance>200 && distance<=300)
                {
                        System.out.println("Distance between 200 and 300:
"+distance);
                        if (randomPCNum<=30)
```

```
                  {
                        //Then 30% probability of key supplier able to
meet RHQ demand
                        System.out.println("Supplier "+ name + "
Response = YES ");
                        response = 1;
                  }
                  else
                  {
                        //70% chance of not meeting demand
                        System.out.println("Supplier "+ name + "
Response = NO ");
                        response = 0;
                  }
            }
            else if (distance>300)
            {
                  System.out.println("Distance above 300 miles:
"+distance);
                  if (randomPCNum<=5)
                  {
                        //Then 10% probability of key supplier able to
meet RHQ demand
                        System.out.println("Supplier "+ name + "
Response = YES ");
                        response = 1;
                  }
                  else
                  {
                        //90% chance of not meeting demand
                        System.out.println("Supplier "+ name + "
Response = NO ");
                        response = 0;
                  }
            }*/
            return response;
      }

      //method to reset i.e. set them equal to zero all "checked"
attribute values of supplier objects
      public void resetSupplierCheck(Supplier[] supplierUncheck)
      {
            for (int index=0; index<supplierUncheck.length; index++)
            {
                  supplierUncheck[index].setChecked(0);
            }
      }

      public int listSearchNetwork (Supplier[] supplier, int clientX,
int clientY)
      {
            //From the sorted list based on relative CPI values, find
the supplier with the next highest CPI value and the closest distance
to client
```

```
                        int indexNearestSupHighestCPI =
getIndexOfNearestSupplierWithHighestCPI(supplier, 0);
                        int selSupResponse = 0;
                        if (indexNearestSupHighestCPI != -1)
                        {
                              //check if selected supplier can meet the
date of delivery demand of the client or not
                              int selectedSupplierResponse =
selectedSupplierValidation(supplier[indexNearestSupHighestCPI].getDista
nce(), supplier[indexNearestSupHighestCPI].getSupplierName(),
supplier[indexNearestSupHighestCPI].getX(),
supplier[indexNearestSupHighestCPI].getY(), clientX, clientY);
                              double rCPI =
supplier[indexNearestSupHighestCPI].getRelCPI();
                              //if negotiation is a success, return
result(supplier's index) to key supplier and update CPI value, else
continue search and update CPI value for this supplier
                              if (selectedSupplierResponse==1)
                              {
                                    //update supplier CPI value by +2
units

      supplier[indexNearestSupHighestCPI].setRelCPI(rCPI+2);
                                    //Select the winning supplier and
save its information
                                    Supplier winSupplier =
supplier[indexNearestSupHighestCPI];
                                    //Display this information to the
client
                                    System.out.println("\nSupplier: " +
winSupplier.getSupplierName() + " can supply.");
                                    //reset all supplier attribute
values of checked variable
                                    resetSupplierCheck(supplier);
                                    //sort the collaborative supplier
list to reflect updated CPI value
                                    sortSuppliers(supplier);
                                    //return positive response
                                    selSupResponse = 1;

                                    //display supplier network
                                    displaySCN(supplier);
                              }
                              else
                              {
                                    //update supplier CPI value by -1
unit

      supplier[indexNearestSupHighestCPI].setRelCPI(rCPI-1);
                                    //To prevent the supplier from
being asked again, set its checked value to 1

      supplier[indexNearestSupHighestCPI].setChecked(1);
                                    //First check another supplier with
next highest CPI value
```

```
                                    //Sort the collaborative supplier 
list to reflect updated CPI value
                                    sortSuppliers(supplier);
                                    selSupResponse = 0;

                                    //display supplier network
                                    displaySCN(supplier);
                              }

                        }
                        else
                        {
                              System.out.println("\nList search is 
complete. No supplier found. ");
                              selSupResponse = -1;
                        }
                        return selSupResponse;
      }

      //This method can be called to print the collaborative network 
supplier list and all related information at any time
      public void displaySCN(Supplier[] supplierArray)
      {
            System.out.println("\nFollowing is the collaborative 
supplier list: ");
            String info = "";
            for (int index=0; index<supplierArray.length; index++)
            {
                  info = "Name: " + 
supplierArray[index].getSupplierName() + " Distance: " + 
supplierArray[index].getDistance() + " CPI: " + 
supplierArray[index].getRelCPI() + " Check: " + 
supplierArray[index].getChecked();
                  System.out.println(info);
            }
      }

      //Exponentially decaying probability function
      /*
       * % multinorm(x,y,0,0,2,1,0.5); % where  -6 < x,y < 6
function f = multinorm(x,y,mu_x,mu_y,sig_x,sig_y,rho)

%K1 = 1/(2*pi*sig_x*sig_y*sqrt(1-rho^2));
K2 = 1/(2*(1-rho^2));
Kx = ((x-mu_x)/sig_x)^2;
Ky = ((y-mu_y)/sig_y)^2;
Kxy = 2*rho*(x-mu_x)*(y-mu_y)/(sig_x*sig_y);


f = exp(-K2*(Kx+Ky-Kxy));
end
       */
      public double expoDecayFunction(int x, int y, int clientX, int 
clientY, double sigX, double sigY, double rho)
      {
```

```
            double k2 = 1/(2*(1-rho*rho));
            double kX = ((x-clientX)/sigX)*((x-clientX)/sigX);
            double kY = ((y-clientY)/sigY)*((y-clientY)/sigY);
            double kXY = 2*rho*(x-clientX)*(y-clientY)/(sigX*sigY);
            double a = -1*k2*(kX+kY-kXY);
            double f = Math.exp(a);
            System.out.println("Probability value for x = "+x+"; y =
"+y+" is: "+f);
            return f;
      }

      //method to save CPI list for each iteration
      /*public void saveCPI(Supplier[] supplier)
      {
            for (int index=0; index<arrayCPI.length; index++)
            {
                  arrayCPI[index]=supplier[index].getRelCPI();
                  name2[index]=supplier[index].getSupplierName();
                  x2[index]=supplier[index].getX();
                  y2[index]=supplier[index].getY();
                  dist[index]=supplier[index].getDistance();
                  check[index]=supplier[index].getChecked();
            }
      }*/
}
```

Supplier.java

```
/*This class represents the supplier and its attributes, along with
methods
 *to use those attributes
 */


public class Supplier {

      private String supplierName;
      private int x, y; // x and y coordinates of the supplier w.r.t.
RHQ (0,0)
      private int distance; //distance of supplier from RHQ rounded to
nearest mile
      private double relCPI; //Collaborative Performance Index value of
the supplier w.r.t. the key supplier
      private int checked; //variable to avoid revisiting during search
for suppliers if the search index has already visited it once. If value
is '0', then checking allowed else not

      //default constructor
      public Supplier()
      {
            supplierName = "";
            x = 0;
            y = 0;
```

```
            distance = 0;
            relCPI = 50;
            checked = 0;
      }

      public Supplier(String name, int x2, int y2, double relativeCPI,
int dist, int check)
      {
            supplierName=name;
            x=x2;
            y=y2;
            distance = dist;
            checked = check;
            relCPI = relativeCPI;
      }

      //methods to set variable values
      public void setChecked(int value)
      {
            checked = value;
      }

      public void setSupplierName(String name)
      {
            supplierName = name;
      }

      public void setX(int xCoord)
      {
            x = xCoord;
      }
      public void setY(int yCoord)
      {
            y = yCoord;
      }
      public void setDistance(int clientX, int clientY)
      {
            //distance = dist;
            //calculate the distance between the client(x,y) and this
supplier using the distance formula
            int x1 = getX();
            int y1 = getY();
            int squareSum = (x1-clientX)*(x1-clientX) + (y1-
clientY)*(y1-clientY);
            //int squareSum = (getX()-clientX)^2 + (getY()-clientY)^2;
            distance = (int)(Math.sqrt(squareSum));
      }
      public void setRelCPI(double relativeCPI)
      {
            relCPI = relativeCPI;
      }

      //methods to get variable values
      public int getChecked()
      {
```

```
            return checked;
        }

        public String getSupplierName()
        {
            return supplierName;
        }

    public int getX()
        {
            return x;
        }
        public int getY()
        {
            return y;
        }
        public int getDistance()
        {
            return distance;
        }
        public double getRelCPI()
        {
            return relCPI;
        }
}
```