Analytic Hierarchy Process & Genetic Algorithm Approach to reconfigure the Supply Chain Network

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Supply Chain Management (SCM) has attracted a lot of attention for most companies. Among them, to maintain their competitiveness is essential to reconfigure supply chain network (SCN) of existing. On the strategic level, however, even if we focus on the quantitative criterion such as cost, however, there are situations that it is not easy to aggregate various costs into the overall cost, because of their imprecision, indetermination and uncertainty. Furthermore, other qualitative criteria must be taken into account for evaluating the performance of supply chain network. In these complex situations, an heuristic approach which has been frequently used is the most suitable. However, general approach does not often include opinions and the intuition of the decision-maker. This paper is focused on the Analytic Hierarchy Process (AHP) with Genetic Algorithm (GA). It has been implemented in the evaluation of several reconfiguration alternatives of the warehouses distributed in a wide region. We utilize the AHP to calculate the weight of the decision-maker's opinion. And then, the weight from the AHP is adapted in a genetic algorithm. We expect that our approach has played a proper human-machine role in the real world decision-making.

Keywords: supply chain network, analytic hierarchy process, genetic algorithm, multi-criteria analysis

1. Introduction

Firms market be globalization, sourcing, manufacturing, regional specialization and the world needed a product strategy 'era of limitless competition in accordance with high quality, low price, timely delivery and the growing importance of 60% to 70% of the supply chain value is generated in a portion other than the manufacture, so that the entire line has been needed is manageable. Initially only an individual company has dealt the efficiency of distribution system. However, eventually, all the companies related to a specific product started adopting SCM to minimize the system wide costs while satisfying service level requirements.

One of the most advanced cases in SCM is the "direct" model, which gives Dell computer direct access to their final customers, by making use of information technology and unifying the production, distribution, and sales information. Further, a cross-docking system employed by Wal-Mart, a continuous replenishment program (CRP) developed by P&G, efficient consumer response (ECR) in the grocery industry and quick response (QR) in fiber-related industries have been successfully implemented.

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There are various SCM issues. One is the network configuration decision regarding the number, location, and capacity of warehouses and manufacturing plants. So far, mixed integer programming models have been widely used to configure facility locations, and improve overall operations (See, for instance, Shapiro [9]).

The reconfiguration of the existing supply chain network is essential to retain their competitive edges. On the strategic level, however, even if we focus on the quantitative criterion such as cost, it is not unusual that various costs involved in a supply chain network cannot easily be aggregated into the overall cost, because of their imprecision, indetermination and uncertainty. Furthermore, there are other qualitative criteria to evaluate the performance of a supply chain network. In theses complex situations, as an overall evaluation, for instance, a simple weighted sum of criteria is not adequate. Instead, the outranking analysis which has been frequently used is the most suitable. So far, various variants of the meta-heuristic algorithms, which are called Genetic Algorithm, Simulated Annealing, Tabu Search and others. These have, however, a weakness because of their arbitrariness at the same time and difficulty of coding.

These approaches are very logical and scientific, but the sensitivity of human (intuition, experience, advantage of in the mind) lacks in the context of decision-making to the real world. We adopted the AHP to complement these drawbacks. Then, We present a GA to decide an optimal a number of warehouses and optimal supply chain network with the weight form AHP. On an illustrative application, we conducted a Shapiro's data of the evaluation of various reconfiguration alternatives of the warehouses distributed all over wide region.

2. Genetic Algorithm: GA

The Genetic Algorithm (GA) is an adaptive heuristic search method based on population genetics. The basic concepts are developed by Holland (1975) [7], while the practically of using the GA to solve complex problems is demonstrated in Dejong (1975) [2] and Goldberg (1989) [4]. References and details about genetic algorithms can also be found for example in Alander (2000) and Muhlenbein (1997) respectively.

The creation of new generation of individuals involves primarily four major steps or phases: representation, selection, crossover (recombination), and mutation. The representation of the solution space consists of encoding significant features of a solution as a chromosome, defining an individual member of a population. Typically pictured by a bit string, a chromosome is made up of a sequence of genes, which capture the basic characteristics of a solution. The recombination or reproduction process makes use of genes of selected parents to produce offspring that will from the next generation. It combines characteristics of chromosomes to potentially create offspring with better fitness. As for mutation, it consists of randomly modifying gene(s) of a single individual at a time to further explore the solution space and ensure, or preserve, genetic diversity. The occurrence of mutation is generally associated with low probability. A new population replaces those from the old one. A proper balance between genetic quality and diversity is therefore required within the population in order to support efficient search.

Although theoretical results that characterize the behaviour of the GA have been obtained for bit-string chromosomes, not all problems lend themselves easily to this representation. This is the case, in particular, for sequencing problems, like vehicle routing problem, where an integer representation is more often appropriate. We are aware of only one approach by Thangiah (1995) [14] that uses bit string representation in vehicle routing context.

A basic scheme of a typical algorithm is as follows.

Randomly create an initial population
While not (**termination condition**)
    do
        Evaluate each member's fitness
        Kill the bottom x% elements of the population
            Let the fitness reproduce themselves
            Randomly select two members/parents (many other selection methods are also used)
                Perform crossover on the selected elements to generate two children (many variations of crossover exist)
                Perform mutation
Endwhile

3. Analytic Hierarchy Process

Since its invention, Analytic Hierarchy Process (AHP) has been a tool available to decision-makers and researchers and is one of the most widely used multiple criteria decision-making tools (Vaidya and Kumar 2006) [4] [11] [12]. It is designed to cope with both the rational and the intuitive of decision-maker's to select the best from a number of alternatives evaluated with respect to several criteria. In this process, the decision maker carries out simple pairwise comparison judgments, which are then used to develop overall priorities for ranking the alternatives (Saaty and Vargas 2001) [11]. The form of matrix of the pair-wise comparisons is as follows:

$$\boldsymbol{A} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} A_1 & A_2 & \cdots & A_n \end{array} \\ \begin{pmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_1/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{pmatrix} \end{array}$$

The comparisons are made using a scale that indicates the importance of one element over another element with respect to a given attribute. Table 1 shows the scale ranges from 1 for 'the least valued than' to 9 for 'the most important than'.

Table 1. 1-9 Scale for the pair wise comparison (Saaty 2001)

Linguistic term	Preference number
Equally important	1
Weakly more important	3
Strongly more important	5
Very strong important	7
Absolutely more important	9
Intermediate values	2, 4, 6, 8

In the basic structure of an Analytic Hierarchy presented in Figure 1, the goal is specified at the top, all the objectives or criteria are listed below the goal and all alternatives are presented at the last level.

Some key and basic steps involved in this methodology are;

Step 1. Determine the problem.

Step 2. Structure the decision hierarchy of different levels constituting goal, criteria, sub-criteria and alternatives.

Step 3. Compare each element at the related level and establish priorities.

Step 4. Perform calculations to find the normalized values for each criteria / alternative. Calculate the maximum Eigen value and C.I..

Step 5. If the maximum Eigen value, C.I. is satisfactory, then the decision is made based on the normalized values. If not, the procedure is repeated until the values lie in the desired range.

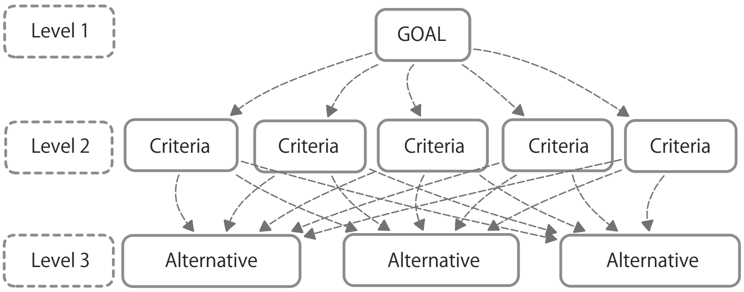


Figure 1. Basic structure of AHP

The consistency analysis is a part of the AHP method. It is to assure a certain quality level of the decision. The measure of inconsistency can be used to successively improve the consistency of judgments (Saaty and Vargas 2001) [13].

4. Supply Chain Network Reconfiguration Problem

The business entity has many warehouses and agents generally in the every corner. There is a long demand chains of the business entity's products consisting of construction dealers, agents, business offices, enterprises, and plants / factories. The distribution process of the business entity is illustrated in Figure 2. As shown in Figure 2, logistics network of the business entity is one-stage distribution system, where the warehouses are supplied from factory. Such as the business entity has to secure one-day delivery service, warehouses are distributed in local regions. Since, there are many restrictions (capacity of warehouses, variety of demand, etc.), it is a difficult and impractical process to store all items in the warehouses. In some cases the business entity has a problem, how many warehouses are needed.

Figure 2. Business entity's distribution process

Problem Formulation

We are examining the effectiveness of merging some warehouses distributed all over the region. Some of the advantages of merging are as follows:

(a) to reduce the safety inventory.

(b) to reduce the operating cost.

Cost

It is difficult to aggregate distribution, handling and storage cost, into an overall cost, because it is difficult to estimate precisely cost values due to time and cost constraints. Therefore, we have decided to look at all these costs separately.

Total inventory

Estimate the warehouses stock/inventory.

Since lesser the inventory stock, the better, this is a minimization criterion.

Restrictions

Consider capacities of warehouses and agencies

Each agency can receive the products form just one warehouse

Numerical Study

Our numerical experiments were run on an Intel Core i5-2GHz Processor, Windows 7 Operating System using the Program Language C++. We tested two methods; AHP-Genetic Algorithm, and Branch & Bound method, so as to evaluate the performance treating a data of Shapiro. It is well known that the setting of the parameter of GA reacts to the convergence of the solution sensitively. However, the computational study on set of benchmark problems indicated that our GA-based heuristic is capable of generating optimal solutions for small-size problems as well as high-quality solutions for large-size problems. The algorithm outperforms any of the previous heuristics in terms of solution quality. The computational times of the algorithm are very reasonable for all problem instances from the heuristic viewpoint. In addition, the numerical experiment used a delivery plan problem, which is shown as Table 2.

Table 2. Cost of delivery from warehouse to agency & Capacity of each warehouse

	fixed cost		a	b	c	d	e	f	g	h
A	134	**A**	148.5828	169.287	113.022	130.4688	256.128	112.29	63.6528	25.05
B	140	**B**	156.6288	154.9092	72.8364	53.7972	103.2516	13.002	29.904	207.414
C	160	**C**	197.3952	176.7078	79.2948	38.124	22.4112	73.284	22.8552	324.648
D	225	**D**	389.4264	349.2414	213.486	196.1268	275.3376	261.222	62.7984	576.15
E	142	**E**	284.292	273.1782	165.7656	152.496	212.9064	156.615	39.3024	317.634
F	285	**F**	54.1764	11.595	49.8732	114.7956	308.154	180.255	93.984	347.694
G	140	**G**	292.8744	256.4814	139.932	108.8652	123.2616	169.026	34.176	470.94
H	280	**H**	344.9052	339.9654	238.602	258.8196	443.4216	286.635	103.1688	374.748
		demand	894	773	598	706	1334	985	356	1670

i	j	k	l	m	n	o	p	q	r	s	t	Capacity
28.812	56.1516	28.5768	42.4848	52.632	102.8016	203.3838	263.4	332.2752	397.9764	101.088	101.9472	7500
85.848	129.2256	50.5764	42.6852	94.248	139.0512	171.7902	279.204	255.9252	249.246	64.3968	87.3144	6000
120.54	172.6854	72.576	55.5108	119.952	163.4064	186.9288	298.1688	220.4988	164.2572	54.4752	80.7216	6500
189.924	295.7574	107.5032	73.7472	151.776	169.3536	178.3722	218.0952	14.0484	189.5904	74.5056	23.6376	8000
110.25	135.3792	44.4528	18.2364	82.2528	96.5712	12.5058	146.4504	164.3052	266.4072	86.8608	53.7072	6800
114.954	183.0696	105.0084	101.0016	137.088	202.7712	375.174	434.0832	437.3328	446.1912	90.2304	136.68	7200
162.582	220.3758	95.256	67.5348	144.9216	179.832	188.2452	285.5256	133.7652	26.1504	34.8192	59.8176	5500
104.958	105.3804	60.5556	58.5168	45.7776	7.9296	219.1806	128.5392	342.6588	529.5456	145.08	89.7264	4500
490	641	378	334	408	472	1097	878	1018	1362	312	268	

*. A~H : warehouse, a~t :agency

5. AHP & GA Approach

In this paper, we utilized a simple AHP and matrix-form coding method to control lethal gene in GA process. The Process is the first, AHP is utilized to get the weight of decision maker's then the weight is used in GA process. The next, GA suggests the warehouse to be left including decision maker's opinions.

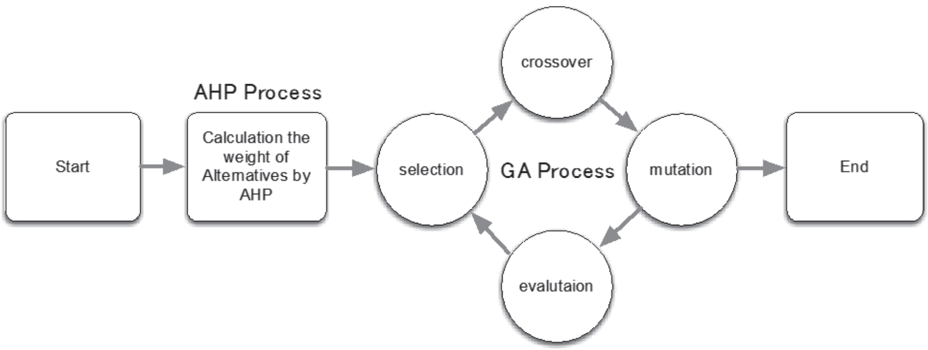


Figure 3. AHP-GA Process

Model Formulation

We have the following variables: For each warehouse $i \in m$ and agency $j \in m$, d_{ij} is the cost from warehouse i to agency j. From each arc (i, j), the decision variable x_{ij} is equal to 1 if arc (i, j) is used (delivered) and 0 others, and variable y_j indicates that warehouse j will be held or not it. Furthermore, f_j indicates a fixed cost of warehouse, w_j is demand of agency, a_j is weights form AHP and C_j is capacity of warehouse. We minimize the total cost that consist of travel or time cost and a fixed cost. The object is, firstly minimize total cost and then decide decision variable y_j.

These objective function and constraints will be used as the fitness function in the Genetic Algorithm process.

$$\text{Min} \quad \sum_{i}^{m} \sum_{j}^{n} d_{ij} x_{ij} a_j + \sum_{j}^{n} f_j a_j y_j$$

$$\text{s.t.} \quad \sum x_{ij} = 1$$

$$\sum w_i x_{ij} \leq C_j y_j$$

$$x_{ij} = \begin{cases} 1 & : \text{deliver warehouse } j \text{ agent } i \\ 0 & : \text{not deliver warehouse } j \text{ agent } i \end{cases}$$

$$y_{ij} = \begin{cases} 1 & : \text{hold warehouse } j \\ 0 & : \text{not hold warehouse } j \end{cases}$$

Simulation

We present a GA to decide an optimal a number of warehouses and optimal supply chain network with the weight form AHP. Using genetic algorithms for SCN is similar to the TSP or Job Shop Scheduling Problem, as it often involves the use of order or position dependent genomes, since the optimum or best sequence of activities is sought. Hence, an illegal solution may have the same value multiple times in the genome ("superposition") and be missing other values. Technique that is preventing creation of these 'lethal' individuals is important for the efficient execution of a GA, and is presented as a matrix-form coding method.

We tested two methods; AHP-GA, and Branch & Bound, so as to evaluate the performance treating a data of Shapiro.

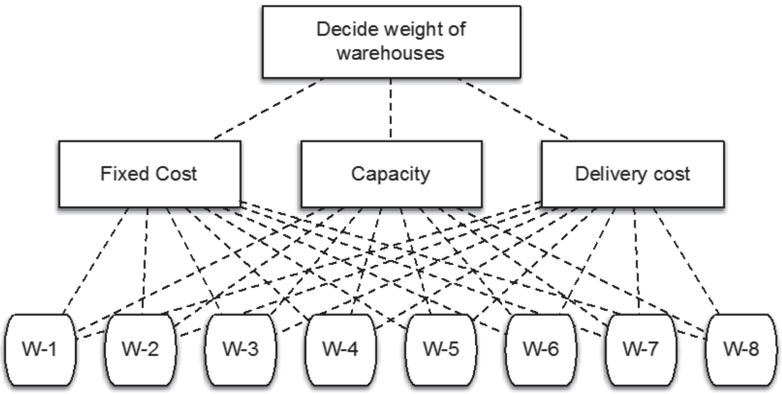
Table 3. Result of Branch & Bound Method

Y_j	X_{ij}	a	b	c	d	e	f	g	h	I	j	k	l	m	n	o	p	q	r	s	t
1	A	1	1	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0
0	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	C	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	E	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1
0	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0
0	H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Demand	894	773	598	706	1334	985	356	1670	490	641	378	334	408	472	1097	878	1018	1362	312	268

	TOTAL COST
Objective function	1843.2672

		Capacity	
Restrict	5254 <	7500	7500
	0 <	6000	0
	3979 <	6500	6500
	0 <	8000	0
	3049 <	6800	6800
	0 <	7200	0
	2692 <	5500	5500
	0 <	4500	0

The best result from branch & bound method is Table 3. These table indicates that the warehouse A, C, E, G are should be kept in the all warehouses. We designed AHP-tree that consisted with 3 criteria and 8 alternatives as below Figure 4..



*. *w-1, w-2, ..., w-8 indicate the number of warehouses*

Figure 4. AHP Hierarchy

We performed numerical experiments according to designed AHP-hierarchy in Figure 4. The total evaluation results form AHP is shown in below Table 4.

Table 4. Total Evaluation of AHP

Criteria		Alternatives							
	Criteria weight	W-1	W-2	W-3	W-4	W-5	W-6	W-7	W-8
Fixed Cost	0.36	0.11	0.21	0.22	0.03	0.18	0.07	0.15	0.03
Capacity	0.21	0.16	0.05	0.19	0.21	0.06	0.03	0.19	0.11
Delivery Cost	0.43	0.11	0.10	0.18	0.08	0.23	0.14	0.09	0.07
Total Weight		0.1205	0.1291	0.1965	0.0893	0.1763	0.0917	0.1326	0.0640

Table 5. represents the parameters setting for GA approach in this research. The fitness function used the model that is mentioned in "model formulation" with the value of weighs from AHP.

Table 5. Setting of GA-parameters

GA-parameters	
Crossover Probability	0.3
Mutation Probability	0.1
Selection Method	Roulette wheel Strategy
Population Size	20
Generations	1,000

Finally, The results from all process are summarized in below Table 6.

Table 6. Result of GA

chromosome	warehouse
0 1 0 0 1 0 0 1 1 0 1 0 1 0 0 1 0 0 0 0 → 1	A
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 → 0	B
1 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 0 → 1	C
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 → 0	D
0 0 0 0 0 0 1 0 0 0 0 0 0 1 1 1 1 0 0 0 → 1	E
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 → 0	F
1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 → 1	G
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 → 0	H

・Minimum Cost :1832.18
・Generation :1072 th.

A GA contains operators called crossover and mutation, the ones that specially affect performance of GA. Therefore, it is very important to specify the GA's parameter for getting a good performance. However it is very troublesome to identify GA-parameters. In the present paper, we use Experimental Design Method to setup GA parameters proposed by HAN [5] and then set up as Table 5. Validation of an analytical method through a series of experiments demonstrates that the method is suitable for its intended purpose.

6. Concluding remarks

Even if the result of alternatives do not seem to provide enough insight on decision making, by carrying out a genetic algorithm method, we can derive the overall solution by making the best use of them. In general, the relative importance of criteria is ambiguous and the scores are imprecise. It suggests that, in such cases, a genetic algorithm method is useful.

In this research, a Supply chain Network model has been proposed using Analytic Hierarchy Process & Genetic Algorithm approach. Our approach was used to synthesize the opinions of the decision makers to identify the weight of each alternative. This research demonstrated the advantage of being able to capture decision maker's opinion and intuition in solving the research problem through a structured manner and a simple process.

Further development of this approach could be the improvement in the determination of the weights of each alternative and to handle uncertainty level of the decision-making problem by using hybrid approach, like the neural network.

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