CHAPTER 7

MAXIMIZATION OF THE AGILITY DEPLOYING THE YEARLY BUDGET RESOURCES

The overall objective of any organisation is to maximize its supply chain agility (Saleeshya and Babu, 2011). The agility of supply chain will depend upon, how well supply chain managers deploy their input resources. To be agile, a supply chain manager has to quickly adjust its supply chain structure and operations in order to respond in a timely and effective manner to market volatility and other uncertainties. However, because change is costly and achieving agility often involves sacrificing efficiency (Teece, 2016), it is necessary for supply chain manager to maximize agility of supply chain deploying input resources. In view of this, an AHP-GP model is developed which will control the agility of supply chain by controlling the decision variables and by deploying input resources.

There are two methodologies which are used in this problem, first one is Analytic Hierarchy Process (AHP) and second one is Goal Programming (GP). Hence this model can be also called as the hybrid AHP-GP model. In hybrid AHP-GP model, the AHP provides the local and global weights of decision variables whereas GP model incorporates the AHP weights into model and restricts the value of these variables in order to optimize agility and other input resources. Local and global weights of decision variables are already calculated in previous chapter using AHP method. In this chapter AHP weights are used in GP model and this restricts the value of decision variables in order to optimize agility and other input resources. The use of the proposed AHP-GP model is illustrated in a real world case study.

7.1 Development of AHP-Goal Programming model

The framework for the development of hybrid AHP-GP model is shown in Figure 7.1. The first step of this framework is to identify and finalize selection criteria. For the present case the five selection criteria (competency, robustness, responsiveness, cost-effectiveness and quickness) are selected which are already shown in Chapter 6 (Table 6.1). In the next step, seven agility enablers are considered as decision alternatives (x_i). The global and local priority weights of the seven agility enablers with respect to each of the second level criterion are obtained through AHP analysis. These outcomes of AHP are embedded in GP to develop the AHP-GP model. Finally the combined AHP-GP model is developed by formulating objective function, resource limitation constraints, agility constraints and AHP weights constraints. The objective function of the combined AHP-GP model, given by equation (1), seeks to minimize the unwanted deviations from desired targets by taking into account the AHP scores.

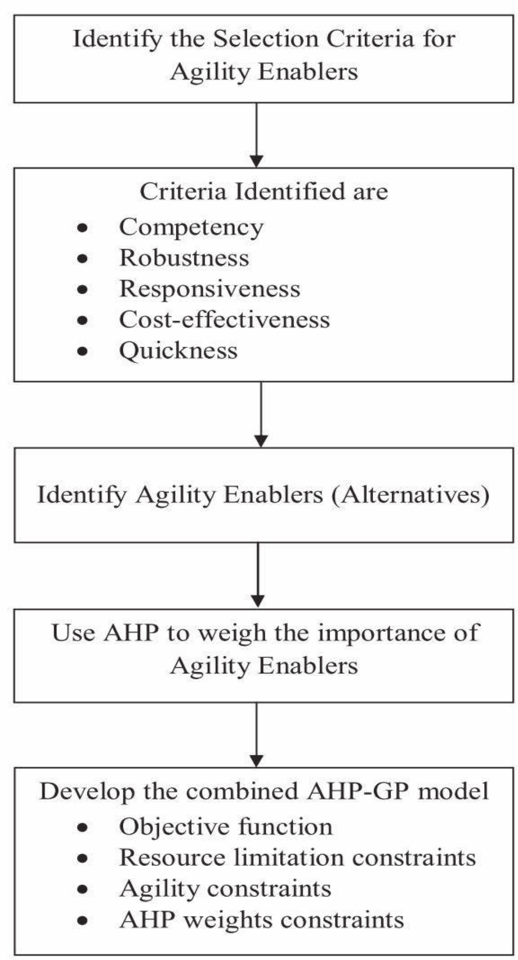

Figure 7.1: Illustrative diagram of the combined AHP-GP model development

Notations and indices used in this problem

i = enablers' index, i = 1 to 7.

j = criteria' index, j = 1 to 5.

Objective function

$$Z = P_1(d_c^+ + d_m^+ + d_e^+ + d_a^-) + P_2 d_{gw}^- + \sum_{j=1}^{5} P_3(w_j d_j^-) \tag{7.1}$$

Subject to constraints

Cost goal

$$\sum_{i=1}^{7} c_i x_i + d_c^- - d_c^+ = C \tag{7.2}$$

Management hour goal

$$\sum_{i=1}^{7} m_i x_i + d_m^- - d_m^+ = M \tag{7.3}$$

Employee hour goal

$$\sum_{i=1}^{7} e_i x_i + d_e^- - d_e^+ = E \tag{7.4}$$

Agility goal

$$\sum_{i=1}^{7} a_i x_i + d_a^- - d_a^+ = A \tag{7.5}$$

Global score constraint

$$\sum_{i=1}^{7} w_i x_i + d_{gw}^- - d_{gw}^+ = Q \tag{7.6}$$

Local score constraint

$$\sum_{i=1}^{7} w_{ij}x_i + d_j^- - d_j^+ = Q_j \qquad \text{(For } j = 1,2,\ldots\ldots,5) \qquad (7.7)$$

Where

P_1 , P_2 and P_3 : Priorities attached to each of the goals.

d_c^+ , d_m^+ and d_e^+ : Positive deviation from the available cost of operation, available management hours and available employee hours respectively.

d_c^- , d_m^- and d_e^- : Negative deviation from the available cost of operation, available management hours and available employee hours respectively.

d_a^+ : Positive deviation from the targeted agility level.

d_a^- : Negative deviation from the targeted agility level.

d_{gw}^+: Positive deviation from the targeted global weight.

d_{gw}^-: Negative deviation from the targeted global weight.

d_j^+ : Positive deviation of criterion *j* from targeted weight.

d_j^- : Negative deviation of criterion *j* from targeted weight.

w_j : Weight of the j^{th} criterion.

x_i : Decision variables used in problem.

c_i : Unit cost incurred for the variable x_i

m_i : Unit management hour incurred for the variable x_i

e_i : Unit employee hour incurred for the variable x_i

a_i : Unit agility score achieved for the variable x_i

w_i : Global score of the enablers *i*

w_{ij}: Local score of enabler *i* with respect to criterion *j*

Q : Targets defined for the constraint equation linked to the global score maximization

Q_j: Targets defined for the constraint equations linked to the local score maximization.

The objective function furnished in equation (1) comprises six goals. The goals are cost minimization, management hour minimization, employee hour minimization, agility maximization, global weights maximization, local weights maximization for each criterion.

The goal constraints are given in Equations (7.2) to (7.7). The goal constraints in Equations (7.2), (7.3) and (7.4) represent the availability of input resources. The right-hand side of each equation reflects availability of input resources, where *C* denotes available cost of operation, *M* available management hours, and *E* available employee hours. Equation (7.5) represents agility constraints in which *A* is the targeted agility level. The GP model is further linked to the global score maximization and local score maximization through Equation (7.6) and (7.7) respectively. Global score and local score of enablers are already derived in Chapter 6.

7.2 Application of the combined model

The combined AHP-GP model discussed in Section 7.1 is based on real life problem and it has been applied to maximize the agility of supply chain of a manufacturing company situated in North India. The data required for necessary analysis, were collected through the specific queries made to the experts from the case-organization.

7.2.1 Deriving the AHP weights

To derive the weights of enablers, a multilevel hierarchy model is developed in Chapter 6. To develop the model five selection criteria are used. The five selection criteria are competency, robustness, responsiveness, cost-effectiveness and quickness. The priority weights of enablers are obtained through AHP analysis. These outcomes of AHP are embedded in GP to develop the AHP-GP model.

7.2.2 The combined AHP-GP model

Goal programming provides desired level of agility to supply chain, deploying input resource limitations such as operating cost, management hour, and employee hour. Operating cost includes yearly cost of operation of particular enabler. It is for the cost of materials, postage, phone calls, printing, etc. Management hours are the total hour management personnel could devote for managerial activities of particular enabler (i.e. decision making activities) in a year. Employee hours are the total hours used for data collection and clerical activities of particular enabler in a year. With the help of combined model a decision maker can decide the degree of focus of the seven agility enablers in designing the agility control system. Seven decision variables x_1, x_2, x_3, x_4, x_5, x_6 and x_7 (representing significant agility enablers) and summary of yearly input resources and agility level of the each agility enablers are shown in Table 7.1. Agility levels of enablers are taken from Chapter 5. Since agility index are in fuzzy form, it is necessary to convert it to real number. Centroid method is used to convert the fuzzy numbers to real numbers.

Table 7.1: Input resources data of each agility enablers

Resource items		Decision alternatives (supply chain agility enablers)							Total budgeted yearly resources
		x_1	x_2	x_3	x_4	x_5	x_6	x_7	
Estimated cost (Rs.)	(c_i)	410*10^5	390*10^5	350*10^5	310*10^5	320*10^5	350*10^5	420*10^5	C = 1660*10^5
Management hour (hr)	(m_i)	2320	2290	2210	1990	2200	2225	2350	M = 10160
Employee hours (hr)	(e_i)	8050	7900	7850	7650	7900	7910	8250	E = 36760
Agility level	(a_i)	7.56	7.01	7.40	6.97	7.65	6.88	6.97	A = 35

The unit cost incurred by enablers x_1, x_2, x_3, x_4, x_5, x_6 and x_7 are 410*10^5, 390*10^5, 350*10^5, 310*10^5, 320*10^5, 350*10^5 and 420*10^5 (in rupees) respectively and the total available cost is C = 1660*10^5 (Rs.). The management hours incurred by enablers x_1, x_2, x_3, x_4, x_5, x_6 and x_7 are 2320, 2290, 2210, 1990, 2200, 2225 and 2350 respectively and the available management hours are M = 10160. The employee hours incurred by enablers x_1, x_2, x_3, x_4, x_5, x_6 and x_7 are 8050, 7900, 7850, 7650, 7900, 7910 and 8250 respectively and the available employee hours are E = 36760. The agility level of enablers x_1, x_2, x_3, x_4, x_5, x_6 and x_7 are 7.56, 7.01, 7.40, 6.97, 7.65, 6.88 and 6.97 respectively and the targeted agility level of supply chain is set to A = 35.

The significance of the unit costs given in respect of each enabler can be explained as follows. If the value of x_1 is one, then the cost incurred by enabler x_1 is Rs. $410*10^5$. This means that if the degree of focus of enabler x_1 is one then the system would incur a cost of Rs. $410*10^5$, implying that the enabler x_1 is deployed to an extent equivalent to index value 1. Similarly the other unit costs are related to x_2 to x_7. Similar explanation can be given for the other two resource constraints *i.e.* management hour and employee hour also. For the case of agility constraints if enabler x_1 takes values 1, then the contribution of the corresponding enabler to the overall agility is 7.56. Similar explanation can be given for the other enablers x_2 to x_7 also. It must be noticed that all input resources data for each agility enabler presented in Table 7.1 are not exact; Sometimes they are approximated by senior executive of the case-organization 'ABC' for the sake of developing the model.

In addition to these, it is also necessary for decision maker to ensure the importance of each enabler. To determine the importance of enablers five agility measures are identified in Chapter 6. These five agility measures can also be called as selection criteria. The priority weights of each enabler with respect to each criterion and overall AHP weights of the agility enablers are already calculated in Chapter 6 which is presented in Table 6.14 and Table 6.16 respectively. The derived priorities of enablers with respect to each of the five criteria will be used in the combined model to serve as the contribution that each criterion makes to each enabler.

P_1 , P_2 and P_3 are priorities attached to each of the goals. Here priorities attached to input recourses goals and agility goal are considered first, followed by global weight maximisation goal and local weight maximisation goal. Hence P_1 is given first priority,

P_2 is given second priority and P_3 is given third priority. The values of P_1, P_2 and P_3 are calculated using rank sum weight method, which are obtained as 0.50, 0.33 and 0.17 respectively.

7.2.3 Formulation of the model

The objective function will attempt to minimize the overall deviations in each of the goal constraints. The goal constraints include resource limitation constraints, agility constraint as well as desired agility measure goals:

$$Z = P_1(d_c^+ + d_m^+ + d_e^+ + d_a^-) + P_2 d_{gw}^- + P_3(0.285d_1^- + 0.475d_2^- + 0.084d_3^- + 0.078d_4^- + 0.078d_5^-) \quad (7.8)$$

Equations (7.9) to (7.11) are resource constraints that represent the availability of limited resources. Resource constraints are needed to reduce resource wastage by selecting the best set of values of enablers between 0-1. The three resource limitation constraints will have deviation variables associated with them, and will attempt to minimize the positive deviations by adding deviation variables to the overall objective function. The case organization 'ABC' allocated a maximum yearly operating budget limitation of Rs. $1660*10^5$ for the cost of materials, postage, phone calls, printing, salaries of workforce etc for the activities of all enablers. Maximum yearly number of hours that management personnel could devote to the managerial activities for all the enablers is set to 10160 hours, and the maximum yearly number of hours that employee could devote for data collection, interviews and other clerical activities for all the enablers is set to 36760 hours.

$$410*10^5x_1 + 390*10^5x_2 + 350*10^5x_3 + 310*10^5x_4 + 320*10^5x_5 + 350*10^5x_6 + 4200*10^5x_7 + d_c^- - d_c^+ = 1660*10^5 \quad (7.9)$$

$$2320x_1 + 2290x_2 + 2210x_3 + 1990x_4 + 2200x_5 + 2225x_6 + 2350x_7 + d_m^- - d_m^+ = 10160 \quad (7.10)$$

$$8050x_1 + 7900x_2 + 7850x_3 + 7650x_4 + 7900x_5 + 7910x_6 + 8250x_7 + d_e^- - d_e^+ = 36760 \quad (7.11)$$

Equation (7.12) is agility constraint which controls the agility of supply chain by controlling the decision variables (*i.e* enablers) and by deploying input resources. Decision maker can set the desired agility level, and this agility level can be obtained by selecting the best set of values of enablers between 0-1.

$$7.56x_1 + 7.01x_2 + 7.40x_3 + 6.97x_4 + 7.65x_5 + 6.88x_6 + 6.97x_7 + d_a^- - d_a^+ = 35 \quad (7.12)$$

In addition to these four constraints the management of the case organization 'ABC' also wants to add the importance of enablers in the present model. The Importance of enablers can be obtained through AHP analysis. One goal constraint is needed to ensure that the enablers with the highest weights obtained from the AHP analysis will be selected. This goal constraint will attempt to maximize the weights by selecting the enablers with the highest priorities. Equation (7.13) shows the overall priority weight maximization of the enablers.

$$0.224x_1 + 0.134x_2 + 0.088x_3 + 0.087x_4 + 0.217x_5 + 0.181x_6 + 0.069x_7 + d_{gw}^- - d_{gw}^+ = 0.622 \quad (7.13)$$

Remaining five constraints (7.14 -7.18) shows the maximization of priority weights of enablers with respect to each of the criterion. The AHP priority weights for each enabler with respect to each of the criterion will be used to determine the ability of the enablers to measure each of the five criteria presented in Table 6.1.

The right-hand-side values for global (Eq. 7.13) and local (Eq. 7.14 - 7.18) weights constraints seek to select agility enablers (x_i) with the highest scores. In other words, the best set of three agility enablers was chosen for each of the five criteria. Though the right-hand side of Eq 7.13 to Eq 7.18 could be set at any level, however for this case it is simply derived by summing the best three weights of enablers. The model seeks to select the best or perfect set of agility enablers, for each of the selected criteria:

$$0.349x_1 + 0.196x_2 + 0.037x_3 + 0.037x_4 + 0.196x_5 + 0.093x_6 + 0.092x_7 + d_1^- - d_1^+ = 0.741 \quad (7.14)$$

$$0.107x_1 + 0.099x_2 + 0.064x_3 + 0.113x_4 + 0.288x_5 + 0.280x_6 + 0.049x_7 + d_2^- - d_2^+ = 0.681 \quad (7.15)$$

$$0.347x_1 + 0.068x_2 + 0.211x_3 + 0.068x_4 + 0.042x_5 + 0.132x_6 + 0.132x_7 + d_3^- - d_3^+ = 0.690 \quad (7.16)$$

$$0.214x_1 + 0.154x_2 + 0.294x_3 + 0.048x_4 + 0.188x_5 + 0.061x_6 + 0.041x_7 + d_4^- - d_4^+ = 0.696 \quad (7.17)$$

$$0.363x_1 + 0.177x_2 + 0.081x_3 + 0.177x_4 + 0.081x_5 + 0.064x_6 + 0.054x_7 + d_5^- - d_5^+ = 0.717 \quad (7.18)$$

7.2.4 Solution of the combined model

Results of AHP-GP model are obtained through M.S. Solver package after using the input resources data of the case-organization ‘ABC’. Table 7.2 shows the combined AHP-GP model solution. The results include the optimal values of seven agility enablers x_1, x_2, x_3, x_4, x_5, x_6 and x_7, deviation of each goal constraints and optimized value of objective function. The optimal values of enablers are the degree of focus which supply chain manager has to give to each enabler.

Table 7.2: The combined AHP-GP model solution

(a) Decision variables			
Name of the decision variables	Notations (x_i)	Values	
Virtual Enterprises	x_1	0.492	
Collaborative Relationship	x_2	0.558	
Use of Information Technology	x_3	0.958	
Market Sensitivity	x_4	0.401	
Customer Satisfaction	x_5	0.598	
Adaptability	x_6	0.789	
Flexibility	x_7	0.746	
(b) Deviations in resource limitation constraints			
Constraints	Usage	Total available	Deviation (d)
Estimated cost (Rs.)	$1659.78*10^5$	$1660*10^5$	22000
Management hours (hr.)	10158.66	10160	1.34
Employee hours (hr.)	36076.44	36760	683.56
(c) Agility score constraints			
Agility score	Obtained	Target	Deviation (d)
	32.72	35	2.28
(d) Deviation in AHP constraints			
	Obtained	Target	Deviation (d)
	0.620	0.622	0.002
(e) Deviation in selection criteria constraints			
Constraint	Obtained	Target	Underachievement
Competency	0.591	0.741	0.150
Robustness	0.644	0.681	0.037
Responsiveness	0.666	0.690	0.024
Cost-effectiveness	0.683	0.696	0.013
Quickness	0.565	0.717	0.152
(f) Objective function			
z = 68062.631			

The enabler use of information technology (x_9) is identified with the maximum degree of focus 0.958 and the enabler market sensitivity (x_4) with the minimum value 0.401. Other enabler's degree of focus is lies between these two. Results presented in Table 7.2 also show the deviations obtained for all goal constraints. From results it can be seen that, targeted agility level is almost achieved within the available resource limitations. The targeted agility level of supply chain is set to 35 and agility level obtained is 32.72 which is almost closer to desired level with negative deviation of 2.28. The total available yearly operating cost is Rs. $1660*10^5$ and the amount utilised is $1659.78*10^5$ only, which gives the value of negative deviation d_c^- = Rs. 22000. Similarly the values of negative deviations for management hour and employee hour constraints are obtained as 1.34 and 683.56 respectively. Deviation in criteria constraints shows that there are negligible deviation of robustness, responsiveness and cost-effectiveness whereas competency and quickness are under-achieved. It means that robustness, responsiveness and cost-effectiveness are achieved significantly, whereas competency and quickness are not achieved significantly. The value of objective function (z), which is the weighted sum of the all deviations from their respective goals, is obtained as 585.274.

7.3 Sensitivity analysis

A sensitivity analysis determines how different values of independent variables affect particular dependent variables. To identify the suitability and to check the sensitivity of the model, the similar exercises have been carried out with varying values of independent variables. Mainly two experiments have been carried out. In the first experiment the model is tested by changing the priorities weights (P_1, P_2 and P_3) and second experiment is carried out by changing the value of available recourses (C, M, E, and A).

7.3.1 Sensitivity of the variations in P_1, P_2 and P_3

P_1, P_2 and P_3 are priorities attached to each of the goals. Here priorities attached to input recourses goals and agility goal are considered first, followed by global weight maximisation goal and local weight maximisation goal. Hence P_1 is given first priority,

P_2 is given second priority and P_3 is given third priority. The values of P_1, P_2 and P_3 are calculated using rank sum weight method, which are obtained as 0.50, 0.33 and 0.17 respectively. The summation of all three priorities is one. Any variations in any priority will change the values of other two priorities.

Increment in the value of priority P_1 will gives the high increment in objective function because of high deviations of input resources. Similarly decrement in the value of input resource priority P_1 will gives the high decrement in objective function. Increment in the values of priority P_2 and P_3 will give decrement in the objective function but at lower rate. It is due to the reasons that as the value of P_2 and P_3 will slightly increase the value of P_1 will decrease simultaneously which will result in the decrement in objective function. Similarly decrement in the values of priority P_2 and P_3 will give an overall increment in the objective function but at lower rate because as the value of P_2 and P_3 will decrease the value of P_1 will increase.

Table 7.3: Sensitivity of the variations in P_1, P_2 and P_3

Varying Parameter and their effect				
(P_1, P_2 and P_3 in %), increasing P_1	50, 33, 17	60, 28, 12	70, 23, 7	80, 18, 2
Objective function (Z)	68062.631	75945.298	81307.648	84265.105
(P_1, P_2 and P_3 in %), increasing P_2	50,33,17	45,43,12	40, 53, 7	35, 63, 2
Objective function (Z)	68062.631	65845.325	63132.845	59325.745
(P_1, P_2 and P_3 in %), increasing P_3	50,33,17	45,28,27	40,23,37	35,18,47
Objective function (Z)	68062.631	65185.365	61324.405	58678.541
(P_1, P_2 and P_3 in %), decreasing P_1	50, 33, 17	40, 38, 22	30, 43, 27	20, 48, 32
Objective function (Z)	68062.631	61156.462	55845.587	48985.412
(P_1, P_2 and P_3 in %), decreasing P_2	50,33,17	55,23,22	60, 13, 27	65, 3, 32
Objective function (Z)	68062.631	69524.236	71236.745	72865.265
(P_1, P_2 and P_3 in %), decreasing P_3	50,33,17	55, 38, 7	60, 40,0	60, 40, 0
Objective function (Z)	68062.631	69236.287	70236.412	70236.412

7.3.2 Sensitivity of the variations in C, M, E, and A

In the second experiment the sensitivity of the model is tested by changing the values of goal constraints only while varying one parameter and keeping others constant. For constraints one to four the RHS values have been varied one by one by keeping other constraints constant. These changes have been made independently and hence for four different cases the results were obtained. Analysis of the results revealed expected but interesting facts. In first three cases when Operating cost (C). Management hours (M) and Employee hours (E) were varied keeping others constant, the Objective function (Z) varied in a direct proportion. It is very well expected since the deviations corresponding to these parameters were positive. The interesting fact is as these parameters deviate more from the optimal value the deviation in objective function becomes larger and larger and thus showing a non linear dependence, the study of which is out of scope of the thesis but it can definitely be a potential research direction. Likewise since the parameter Agility score (S) shows a negative deviation, its effect on objective function (Z) seems to be inverse and it is quite evident from this analysis.

Table 7.4: Sensitivity of the variations in C, M, E, and A

Varying Parameter and their effect							
Variation in C keeping M, E, A constant	$1060*10^5$	$1260*10^5$	$1460*10^5$	$1660*10^5$	$1860*10^5$	$2060*10^5$	$2260*10^5$
Objective function (Z)	57452.165	59820.984	63420.512	68062.631	72863.234	77192.762	83089.583
Variation in M keeping C, E, A constant	9560	9760	9960	10160	10360	10560	10760
Objective function (Z)	66345.521	66894.524	67485.624	68062.631	68795.524	69652.624	70562.785
Variation in E keeping C, M, A constant	35260	35760	36260	36760	37260	37760	38260
Objective function (Z)	64862.651	65752.236	66725.653	68062.631	69098.129	70351.865	71985.652
Variation in A keeping C, M, E constant	20	25	30	35	40	45	50
Objective function (Z)	69136.526	68795.256	68482.523	68062.631	67625.652	670256.256	66785.625

7.4 Concluding remarks

The agility of any organisation will depend upon, how well effective management of input resources like operating cost, management hour and employee hour are available to implement agility in the supply chain. However, the existing literature on maximization of agility has failed to sufficiently address the relevant perspectives. In this problem a hybrid AHP-GP model is developed to maximize agility of supply chain deploying the input resource limitations. In AHP-GP model the overall agility scores of each enabler is linked with the input resource limitations such as operating cost, available management hours and available employee hours. The AHP is first used to prioritize the seven agility enablers along with the five criteria in a consistent manner. The outcomes of AHP are embedded in GP to develop the hybrid AHP-GP model. Specific set of input resources data for each enabler and total yearly budgeted resources are taken from the case-organization 'ABC' to solve the problem. With the help of this model, degree of focus of the all seven enablers is identified in order to achieve targeted agility level of supply chain deploying the input resources. The proposed combined model has saved input resources of case-organization by restricting the resources.