The value network optimization research based on Analytic Hierarchy Process method and the dynamic programming of cloud manufacturing

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[Abstract] Cloud manufacturing has experienced rapid development in the past several years. The research on its theories, technologies and applications still keeps attracting attentions from more and more researchers. One of the most important issues to its improvements and quality of manufacturing service is the optimization of value network. This paper researched the optimization method of cloud manufacturing value network based on the Analytic Hierarchy Process (AHP) method and the dynamic programming of business decisions computing model. According to the function of decision-making model, this paper used the AHP and dynamic programming method to establish the mathematical model of cloud manufacturing service value network for seeking the best value chain, and on this basis, established a different model to get the optimal result under the different conditions by time, cost and resources.

Keywords Optimization method. Cloud manufacturing. Analytic Hierarchy Process. Dynamic programming. Value network

1 Introduction

Cloud manufacturing is changing the way manufacturing enterprises organize production activities in that tangible and intangible manufacturing resources encapsulated as virtualized manufacturing services are provided to customers [1]. Currently, in order to realize the full-scale sharing, free circulation and transaction, on-demand-use of manufacturing resource and capabilities in modern enterprise systems, cloud manufacturing as a new service-oriented manufacturing paradigm has been proposed recently. The services that are managed in cloud manufacturing include not only computational software resource and capability service, but also various manufacturing resources and capability service. These various dynamic services make enterprises more powerful and reach at a higher-level of traditional services.

The typical research works on the value network are as follows: Adrian Slywotzky in"The Profit Zone" book first proposed the concept of "value network": The value network is a new business model, it will correct to the individual needs of customer and the increasing of sensitivity and high efficiency, low cost manufacturing methods and cooperate the providers together more quickly and easily to get solution[2].Suzanne Berger believed that the basic characteristics of the value network should be from the discrete forms of industrial organization, rather than to understand the scope of the linear scale external economic characteristics [3]. Sriniras regarded that the most important feature of these organizations was the various aspects of production activities consisting of different dynamic specialization members, which formed the topological spaces and the mobile value network [4]. Carney believed the network organization could achieve the dual purpose of maintaining flexibility and controlling the transaction costs [5]. David Porter put forward the main characteristics of the value network to integrate the network core equity and network capacity contract [6]. Zhou Xuan believed that the enterprise value network was based on customer value as a strategic starting point for consideration, the use of mergers and acquisitions, strategic alliances and other means to build value creation and value management system, the main network consisted of equity and contractual network[7].Changes in market conditions lead to changes in the main competition, and the rising customer demand was a combination of value contributed to the formation of a network relationship[8]. Li Yuan, Liu Yi regarded that the value of the network was the interaction between the stakeholders and the formation of value production, distribution, transfer, the use of relationship and the structure [9].

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The research on cloud manufacturing network mainly concentrated on the fixed number of resources or the established solutions to provide users without dynamic; like application service provider (ASP)[10]–[14], virtual manufacturing (VM)[15], global manufacturing (GM) [16], [17], manufacturing grid [18]–[19], intelligent manufacturing (IM) [20]-[26],agile manufacturing (AM) [27], [28], industrial system [29], [30], cloud manufacturing, and so on[31]-[32]. All these solutions did not realize the resources optimize allocation of cloud manufacturing. But optimize allocation of cloud manufacturing resources is the key technology of cloud manufacturing.

Fei Tao et al. investigated the applications of IoT technologies in cloud manufacturing in order to achieve intelligent perception and access of various manufacturing resources [33]. Liu et al. [34], [35] researched cloud manufacturing resource scheduling based on QoS and classified the resource scheduling processes into QoS-based resource search. Deng et al. [36] investigated a grid-based manufacturing resource scheduling system for virtual enterprises which was composed of an exterior grid and an interior grid in the architecture. Fei Tao et al. researched the formulation of service composition optima-selection in cloud manufacturing with multiple objectives and constraints, and then proposed a novel parallel intelligent algorithm [37]. Yingfeng Zhang presented a services encapsulation and virtualization access model for manufacturing machine by combining the Internet of Things techniques and cloud computing[38]. Existing work on service composition was concentrating on service composition framework [39], service composition validation [40] and service composition method, the optimization of service composition was a typical multi-objective combinatorial optimization problem as pointed out in [41]. Researchers also have developed a lot of intelligent algorithms to address it, such as genetic algorithms (GAs)[42], evolutionary programming (EP) [43], ant colony optimization (ACO)[44], particle swarm optimization (PSO) [45]and so on. Huang, B. designed chaos control optimal algorithm (CCOA) to address the cloud service composition optimal-selection problem in cloud manufacturing. The simulation results demonstrated that the proposed algorithm can search better solutions with less time-consumption[46].Kulvatunyou, B. described the deployment of the reference-ontology-based semantic mediation approach using Web Ontology Language[47]. If the services continue to grow and become dynamic, the above algorithms may need more iteration. For example, when using genetic algorithms, though it can make a global search and optimization to obtain the approximate optimal solution, but the initial parameters selection rely more on experience, if it is unreasonable, it will reduce the prime rate of global search algorithm.

However, the above studies most are still concentrated in the framework to explore about the value network, theoretical methods and research of the cloud manufacturing without resources allocation optimization, and the existing algorithms were lack of dynamic. In order to effectively optimize the allocation of cloud manufacturing resources and reduce the cost of manufacturing. With the consideration of the above cloud manufacturing algorithm, an intelligent algorithm, namely the Analytic Hierarchy Process (AHP) method combined with the dynamic programming is designed. Based on the description of optimization allocation problem for cloud manufacturing resources, considering the actual impact on time and cost for all the cloud manufacturing production activities{product design, raw material procurement, production, processing, storage, packaging, logistics and transportation, sales}, construct the optimal allocation of resources model for cost and time minimized, quality optimization, use the dynamic programming method to solve the multi-stage decision problem, take a practical example to show the effectiveness of the model and algorithm.

2 The value network optimization problems of cloud manufacturing

Take the cloud manufacturing production activities represented as a collection {product design, raw material procurement, production, processing, storage, packaging, logistics and transportation, sales}; the contribution of the different enterprise value nature of the different aspects is different, how to make collaboration with corporate resources to optimize the allocation of cloud manufacturing resources is the key problem of value network optimization for cloud manufacturing. As shown in Fig. 1.

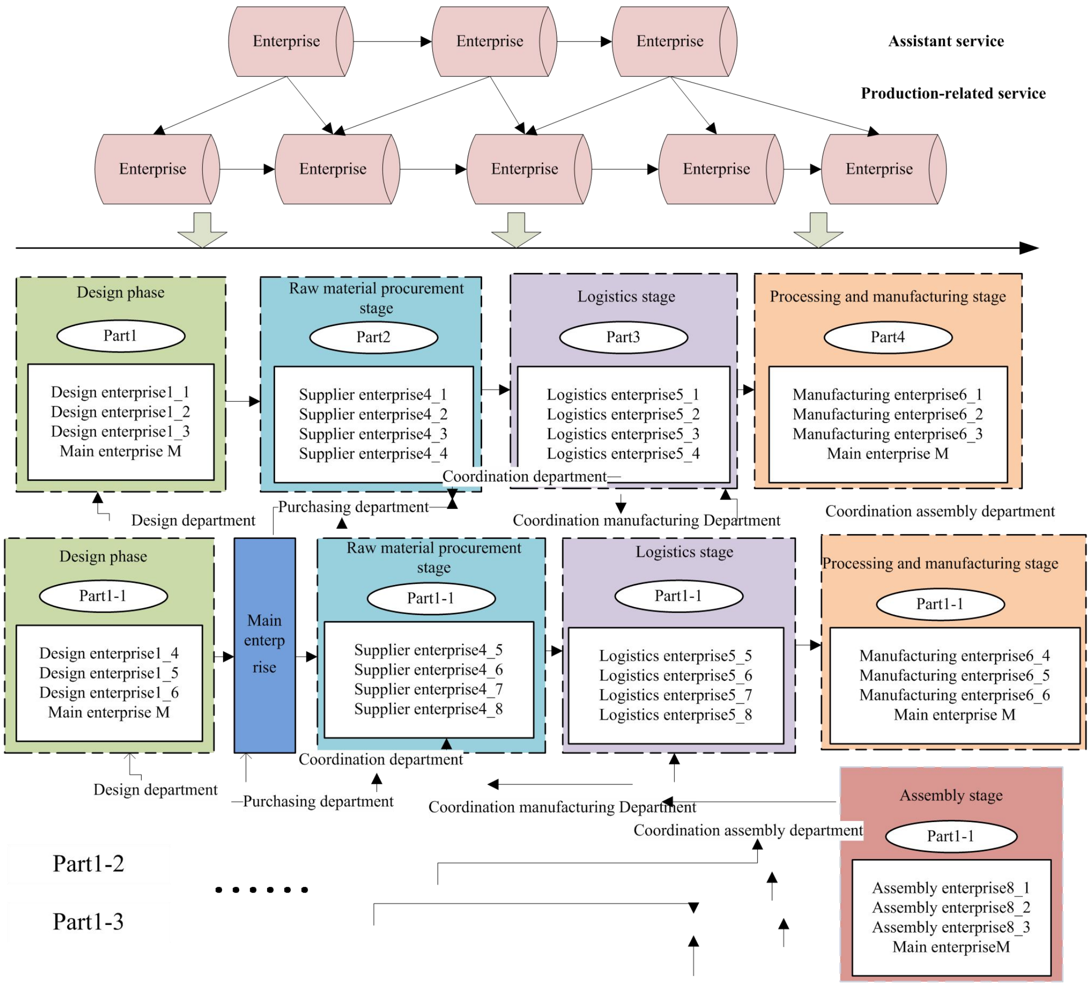

Fig. 1 The value network optimization of cloud manufacturing

The factors affecting the different stages are not the same, the main are location, the degree of closely related, the degree of knowledge exchange, etc.

The best path for solving the global strike is a lowest cost path, so the conceptual model is expressed as:

Function {global cost function C (product cost + customer satisfaction); production sectors M, enterprise capacity factor A, activity costs P};

Seeking the shortest path that is the each following problem's answer:

1. How effectively specialization of the value network can make the entire value chain added.

2. How to control the degree of specialization, namely the participation of other cloud manufacturing enterprise.

3. The collaborative competition with the same value of the cloud manufacturing enterprise and the overall size of the value network makes the value maximize.

2.1 Cloud manufacturing production costs

First, obtain the cost of a certain production activities in a certain stage of cloud manufacturing production, such as the cost of spare parts required in the design phase, a data set of cost value is: {design enterprise offers cost data, the required design costs for main business of their own (cost data of the previous design), the design costs of supplier}; there are external factors of the production activities, for example, the choice of third-party logistics, not only consider the shipping costs, but also consider the impact of geographic location close degree, knowledge exchange factors for supplier evaluation to select the lowest-cost solution.

2.2 Costs of activities convergence

Between before and after the production activities are usually the allocation of different enterprise resource, so it will produce fees when the convergence of events, how to choose the company's resources in order to make the convergence cost less is also the optimization problem which needs to be considered. At this level, the principle of allocation resources is the overall situation of the cost which takes the total cost of the entire value chain as the goal. Secondly, consider the cost contact between the different cloud manufacturing production activities, try to reduce the information processing costs during different cloud manufacturing enterprise resource, because of the cloud manufacturing production activities are in the configuration process.

2.3 The global costs

After the costs of various production and the convergence of the upper and lower activities calculated, then obtain the value of the overall cost, Calculate the cost of each path, which the minimum cost is the minimum path to link the selected node which is about to obtain the minimum cost for the sum of the individual, the path is the one we want to get the best value chain, which can be represented as shown in Fig.2:

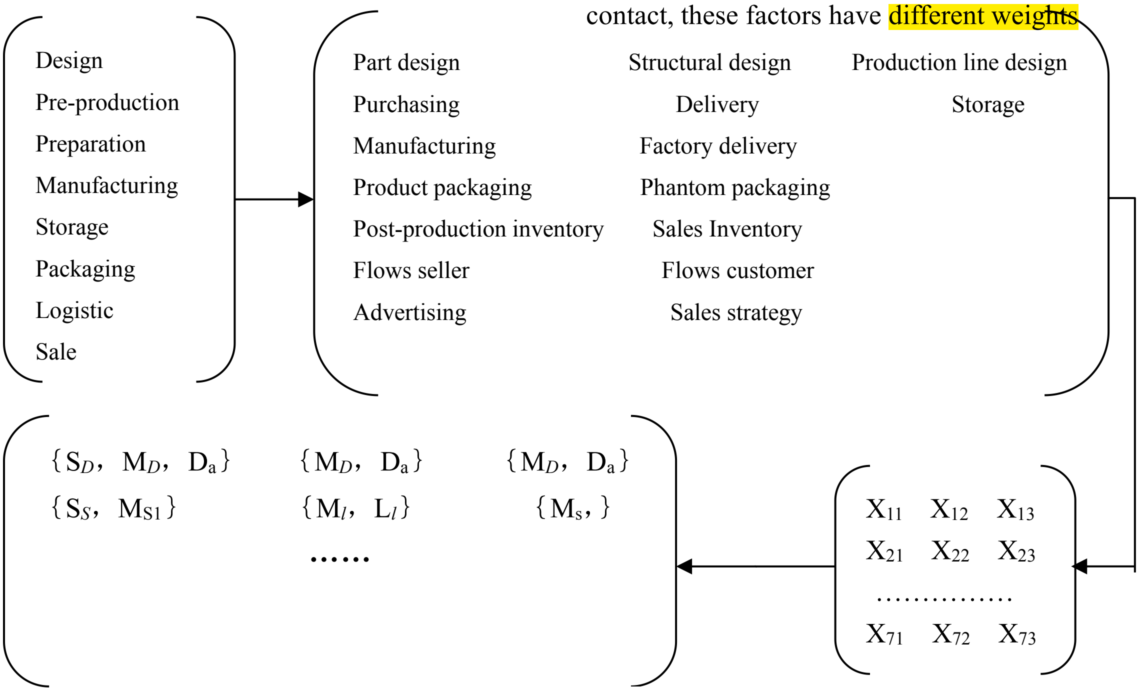

Fig. 2 The mathematics representation of the value path problem

In Figure 2: x_{ij} represents the costs of j activity among the i production process, Ss represents the quotes from suppliers for certain parts of the design costs, M_d represents the design costs of main business for this component design, D_a represents the cost quote of the parts design of professional design companies; and other symbols are as shown in the above analogy.

The cost value of each path for cloud manufacturing can be expressed as:

$$C = \sum_{i=1,j=1}^{m,n} x_{ij} \tag{1}$$

$x_{ij} \rightarrow (S, M, D)$, obtain the optimal allocation of resources, which is the best one value chain, the shortest path is:

$$C_p = \min \sum_{i=1,j=1}^{m,n} x_{ij} \tag{2}$$

x_{ij} is the cost required to complete a corporate production activities, which is related not only with the bare cost (the cost of required business just completed an productive activities), but also with the business location, knowledge of cross-frequency, delivery time, degree of contact, these factors have different weights

Impact on x_{ij} , how to evaluate the selection of cloud manufacturing resources depends on the value of x_{ij} . How to select the x_{ij} and how to calculate the cost of production activities is an important problem to solve the global cost, due to the computing calculated cost is affected with qualitative and quantitative factors. Therefore, it needs to make the right way to calculate the cost affecting by the different weight of factors. AHP as a method of qualitative and quantitative analysis can solve this problem.

3 The Optimization Model of cloud manufacturing

Depending on the needs of cloud manufacturing, respectively establish the optimal path model based on time, costs and locations these three basic cloud manufacturing resources, as follows:

The best time model is: $\sum_{i=1}^{m} opt_i T_{11,nn}(s_{11},t_{11},s_{12},t_{12}\cdots s_{nn},t_{nn})$ (3)

The optimal cost model is: $\sum_{i=1}^{m} opt_i U_{11,nn}(s_{11},u_{11},s_{12},u_{12}\cdots s_{nn},u_{nn})$ (4)

For the optimal location model, the first step is to select a critical path g of the longest production activities, use AHP method to strike the cost g_k under different customer benefits and economic weights, then use the dynamic programming model to strike the optimal value on the critical path, for non-critical path it just strike the cost optimal model.

Therefore, the optimal location model is as follows:

$$optG_{11,nn}(s_{11},g_{11},s_{12},g_{12}\cdots s_{nn},g_{nn})+\sum_{i=1,i\neq g}^{m} opt_i U_{11,nn}(s_{11},u_{11},s_{12},u_{12},\cdots s_{nn},u_{nn}) \quad (5)$$

Where: m represents the type number of components, s_{kl} represents the time of k production activity l enterprise needs to complete, u_{kl} represents the cost of k production activity l enterprise needs to complete, g_{kl} represents the cost weight of k production activity l enterprise needs to complete on the critical path.

3.1 Dynamic Programming

Using the dynamic programming method to solve the multi-stage decision problem, first take the practical problems into dynamic programming model, the used concept are: stage, status, decision and strategy, state transition equation, index function [48-50].

3.1.1The dynamic programming model

The dynamic programming model can be described as follows:

$$optV_{1,n}(s_1,u_1,s_2,u_2\cdots s_1,u_1)$$

$$\begin{cases} s_{k+1}=T(s_k,u_k) \\ s_k\in S_K \\ u_k(s_k)\in D_k(s_k) \\ k=1,2,\cdots,n \end{cases}$$

To solve and obtain the dynamic programming problem under the constraints:

Where: s_k represents the state variables of k phase, $u_k(s_k)$ represents the decision variables of k phase s_k, $D_k(s_k)$ represents the allowed the decision collection of k phase s_k.

（1） The optimal strategy is:

$$\{u_1^*,u_2^*,\cdots u_n^*\}$$

（2） The optimal route, the sequence states of optimal strategy execution $\{s_1^*,s_2^*,\cdots s_n^*\},s^*_{k+1}=T_k(s^*_k,u^*_k)$

（3） The optimal index function value, the value of $f_1(s_1)$

3.1.2 The basic equation of dynamic programming

In the n stage decision-making process, when the indicator function satisfies $V_{k,n}=\sum_{j=1}^{n} v_j(s_j,u_j)$, if the state s_k of phase k is $s_{k+1}=T(s_k,u_k)$ after execute arbitrary selection decisions u_k. At this point, according to the principle of optimization, take the optimal strategy on the sub-process of phase $k+1$, because after effect the index function, the indicator function value of the implementation of the selected sub-process stage k is:

$$v_k(s_k,u_k)+f_{k+1}(s_{k+1}) \quad (6)$$

According to the definition, the optimal value function is:

$$f_k(s_k)=\underset{uk\in D_k(s_k)}{opt}\{v_k(s_k,u_k)+f_{k+1}(s_{k+1})\} \quad (7)$$

3.3 AHP analysis

Analytic Hierarchy Process (AHP) is always decompose the elements which are related to the decision-making into goals, guidelines, programs and other levels, and on this basis to make decision for qualitative and quantitative analysis.

3.3.1 The basic steps of AHP analysis

1) Establish the hierarchy model

Based on the depth analysis of the actual problem, divide the various factors into several levels according to different attributes from top to bottom, the factors in the same layer belong to the upper layer or affect the upper layer, also dominate the next layer or is affected by the underlying. The upper one is the target layer, usually only one factor, the lowest level for the program or the object layer, the middle can have one or several levels, usually as a criterion or indicator layer. When the guidelines are too many (for example more than nine) should be further decomposed to sub-criterion level.

Thus, the structural model of the cost calculation for production activities regard to the AHP can be expressed as shown in Fig.3:

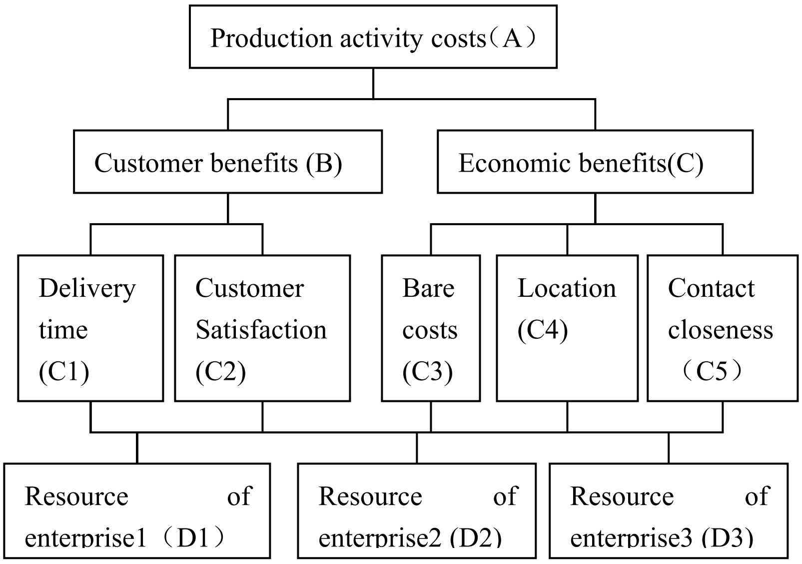

Fig. 3 The hierarchical model of cloud manufacturing enterprise activity costs

2) Construct the comparison matrix

From the second level in the hierarchy model, each factor of subordinate (or influence) the last layer, use the pairwise comparison method and 1~9 compare scale to construct the comparison matrix until the lowest level. As shown in Table 1.

Table 1 The judgment matrix

A	B1	B2
B1	1	1
B2		1

B1	C1	C2
C1	1	1/3
C2		1

B2	C3	C4	C5
C3	1	7	7
C4		1	1
C5			1

C1	D1	D2	D3
D1	1	3	3
D2		1	1
D3			1

C2	D1	D2	D3
D1	1	3	1
D2		1	1/3
D3			1

C3	D1	D2	D3
D1	1	1/3	1/2
D2		1	1/2
D3			1

C4	D1	D2	D3
D1	1	3	1
D2		1	1/3
D3			1

C5	D1	D2	D3
D1	1	3	2
D2		1	2
D3			1

3) Calculate the weight vector and take the consistency test

For each pairwise comparison matrix calculate the maximum characteristic root and the corresponding feature vectors, use the consistency index, random consistency index and consistency ratio to make consistency check. If the test is passed, the feature vector (normalized) is the weight vector; if failed, need re-structure the comparison matrix.

The formula of the level computing weight vector is[51]:

$$w_t = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{i=1}^{n}a_{ij}} \tag{8}$$

Consistency check, when determine the order of the matrix structure, it is often difficult to meet the consistency matrix. However, the judgment matrix deviate the consistency condition should have a degree, therefore, there must determine whether a matrix is acceptable for identification which is the connotation of the consistency check.

Calculate the consistency index: $C.I$ (consistency index)[52]:

$$C.I = \frac{\lambda_{\max} - n}{n-1} \tag{9}$$

Second, look up the table to determine the appropriate average random consistency index $R.I$ (random index), for the fifth-order judgment matrix, $R.I$ =1.12. As shown in Table 2.

Finally, calculate the consistency ratio $C.R$ (consistency ratio)[53]:

$$C.R = \frac{C.I}{R.I} \tag{10}$$

When $C.R < 0.1$, consider the consistency of judgment matrix is acceptable.

Table2 The RI standard values of mean random consistency index

	1	2	3	4	5	6	7	8
$R.I$	0	0	0.52	0.89	1.12	1.26	1.36	1.41
	9	**10**	**11**	**12**	**13**	**14**	**15**	
$R.I$	1.46	1.49	1.52	1.54	1.56	1.58	1.59	

According to calculations, all the $C.R$ of the single ordering matrix are close to 0.0000, so consider the consistency of each judgment matrix is acceptable. As shown in Table 3.

Table3 The table of level computing power and the result of test vector

A		**B1**		**B2**	
B1	0.5000	C1	0.2500	C3	0.7778
B2	0.5000	C2	0.7500	C4	0.1111
				C5	0.1111
C1		**C2**		**C3**	
D1	0.6000	D1	0.4286	D1	0.1667
D2	0.2000	D2	0.1428	D2	0.5000
D3	0.2000	D3	0.4286	D3	0.3333
C4		**C5**			
D1	0.4286	D1	0.5454		
D2	0.1428	D2	0.1818		
D3	0.4286	D3	0.2727		

4) The total level of sorting and inspection

Assumed that the weight $w^{(k-1)} = (w_1^{(k-1)}, w_2^{(k-1)}, \dots w_m^{(k-1)})$ for m elements of the first K-1 layer respected to the overall goal have been calculated, the single sort weights for n elements of the K layer to the upper layer of the j element is $p_j^{(k)} = (p_{1j}^{(k)}, p_{2j}^{(k)}, \dots p_{nj}^{(k)})$, the weight of j element which is not dominated zero. $p^{(k)} = (p_1^{(k)}, p_2^{(k)}, \dots p_n^{(k)})$ represent the ordering of element of K layer the first of K-1 layer element, so the total sort of the element for the K layer to the overall goal is:

$$w^{(k)} = (w_1^{(k)}, w_2^{(k)}, \dots w_m^{(k)}) = p^{(k)} * w^{(k-1)} \tag{11}$$

Similarly, there also needs consistency test for the results of overall sort.

$$C.R^{(k)} = \frac{C.I^{(k)}}{R.I^{(k)}}$$

When $C.R$ <0.1, consider that the overall consistency of judgment matrix is acceptable.

Therefore, the total sort and test results of C-level are as shown in Table 4,5:

Table4 The total order of C level ($C.R$ = 0.0000)

C1	C2	C3	C4	C5
0.1250	0.3750	0.3889	0.05555	0.05555

Table5 The total order of D level ($C.R$ = 0.0000)

D1	D2	D3
0.3547	0.2910	0.3543

Therefore, we can draw the D1 cloud manufacturing enterprise is the best suited for receiving production tasks, D3 is second, D1 is the final.

For different production activities, the determinants of its impact are different weights. According to the actual situation as well as the historical data, list the weight value of the above factors for each productive activities. As the following table 6:

Table 6 The factor weights of the production activity

Production activities / factors	Delivery time C1	Customer Satisfaction C2	Bare cost C3	Location C4	Contact closeness C5
Part Design	0.2234	0.2125	0.3334	0.0000	0.2307
Structural Design	0.2212	0.3120	0.2341	0.0000	0.2327

Production line design	0.2120	0.2345	0.2145	0.0000	0.339
Purchase	0.2561	0.2391	0.3541	0.1002	0.0505
Transport	0.2781	0.1535	0.4512	0.1106	0.0066
Inventory	0.2524	0.1015	0.3623	0.2625	0.0213
Manufacturing	0.2241	0.2194	0.5036	0.0213	0.0316
Product packaging	0.2113	0.1454	0.5465	0.0316	0.0652
Phantom packaging	0.2912	0.1721	0.4651	0.0465	0.0251
Inventory after production	0.3214	0.0765	0.3165	0.1720	0.1136
Sales Inventory	0.2910	0.0105	0.3852	0.2130	0.1003
Flows seller	0.2213	0.1526	0.3926	0.1414	0.0921
Flow customers	0.2114	0.1477	0.4112	0.1276	0.1021
Advertising Planning	0.1003	0.3692	0.5163	0.0000	0.0142
Retail	0.0812	0.2178	0.3352	0.2352	0.1306

4 The best path solution for cloud manufacturing enterprise value network

According to the above processes and methods of dynamic programming and AHP, calculate the value x_{ij} among each production activities and the value of each company, the value x_{ij} is the ability element , link the enterprise competency elements which are pointed by the value of x_{ij} during all activities, there is the shortest path needs to be found.

List the enterprise features which meet the production requirements in the table, determine the ability of enterprises through the state system of analysis to complete the capacity factors of production activities, and transferred into the optional status. Calculate each enterprise capacity elements x_{ij} using the logical computing of AHP.

Through the calculation of x_{ij} and connect the of enterprise capabilities elements through the point connection of x_{ij} (the most appropriate elements of enterprise capabilities), the path is the best value chain, also is the best resource allocation path. As shown in Fig.4

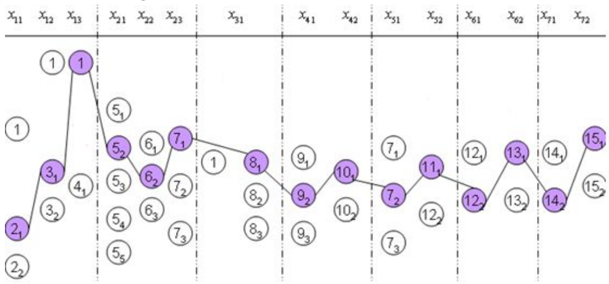

Fig. 4 The optimal path of the production capacity

By seeking the shortest path, we can learn the best allocation of cloud manufacturing resources are not only related with the problem of capacity factor for each enterprise, but also in the overall grasp of the premise, respectively obtain the optimal resource of every aspects, and take the max use of resources as the principle, use up the remaining capacity to catch the requirements for maxing the value under the minimal costs.

5 Conclusion

Resource service composition and optimal-selection is critical to the realization of a real cloud manufacturing system. In this paper an algorithm combined dynamic programming with AHP was proposed according to time, cost and resources three different conditions to maximize the reliability of cloud manufacturing resource service composition paths. The case study and performance simulations results demonstrate that the proposed method finds out a good solution to cloud manufacturing enterprise resource allocation problem. The use of the non-critical path cost can strike the optimal model, and finally calculate the cost of the optimal value, list the selected code and output its related information of cloud manufacturing enterprise resource. A recommended future work includes the complexity of the relationship between resources and how to develop standards and protocols to solve the optimization allocation problem. Some effectiveness research of description methods and standards, or operational complexity and rationality need further research and verify. AHP combined with dynamic programming, which factors influence each other should be further verified.

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