Relationship Network Analysis of Manufacturing System Limited by Business Lines

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Abstract
It is a common problem of manufacturing enterprise limited by business line, which optimized its resources allocation to increase productivity, but now the researches are very weak in relationship mapping and network analysis method in the world. Aimed to the demands, proposed a resource allocation method limited by business line of manufacturing system based on the relational mapping of production system, manufacturing model of hierarchical network based on business line and node degree are been established. Defined the data structure of node on hierarchical network, simplified the network computing by dividing it to three parts - orders assignment, accomplish feedback and pure information exchange. Analyzed the distributing of network degree, established an equation of power law which has two limited parameters of node degree and side weight to automatic compute the amounts of resources of new order. Case study shows that the network analysis method limited business line proposed in the paper can give us an important reference frame of resources assignment.

Keywords: Resources Allocation; Network Analysis; Manufacturing Network; Business Line

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1. Introduction
Manufacturing is the process of transforming material to product or semi finished product, it integrates all the business activity information from generating order to delivering product. In the process, the manufacturing efficiency is decided by the resources allocating levels of manpower, raw materials and other resources. Throughout the well-known international manufacturing company, the resources allocation beat good fitting with its production process. Statistics show that China is already a big country in manufacturing industry, but is also very weak innovative ability. One reason is that the level of resource allocation and process management are still a wide gap between our manufacturing enterprises to the first-class foreign companies. For example, the production efficiency of SAIC (China) is less than half that of Toyota (Japan) [1]. In order to improve the effectively of resources allocating, some researches are carried out at home and abroad. Based on integrating the workshop business process model, organizational model, functional model, information model and object model, Dr. Shang Wen-li built a resource-based workshop model framework [2]. The push and pull control method of job shops is proposed by Li Hong-xin [3]. Zhou Ke studied the collaborative optimization methods of the manufacturing tasks' decomposition and allocation in manufacturing unit-level resource [4]. Zheng Jun-ling studied the optimization scheduling method of printing and dyeing job shop [5]. Yan Ping developed a service-oriented workshop manufacturing process information integration system to settle the problem of multi-information fusion in workshop [6]. Zhang Lian-cheng studied the quick response digital capacity based on space complexity manufacturing system [7]. LIU Fu-yun built a product family commonality analysis method based on complex network [8].

Those researches are developed some adjective theories, methods, product and system, and significantly boosted the level of manufacturing resources allocation. However, the resource allocation in manufacturing system must take into account the constraint factors of their business processes such as the order processes, machining processes, machines or workers' status, manage scheduling method. It is very difficult to optimize the allocation of resources if
ignore those factors. So, we map the resource allocation problem to the optimization of constraint network, and proposed a novel resource allocation method limited by business lines.

2. The BL Network Model

To build the network from a complex manufacturing system directly is very difficult because it troubled from some factors such as time, space, personnel, materials, orders and so on. We must sort out the main problem, and focus on the key factors. Firstly, some definitions should define as follow:

Definition 1: BL network is a manufacturing network limited by business lines, node \( R \) is an entity, side \( L \) is a line between one node to another node which have business relationship.

Definition 2: degree \( K \) is the amount of sides connected to the node directly. In-degree is the side connecting to the node, out-degree is the side departing from the node. In this paper, we measure the distribution using in-degree.

Based on definition 1, we may define personnel, machines, steps, workshop, department as node, and define the generalized information flows behaving orders, production progress information, logistics flow, cash flow, decision-making flow, so, a manufacturing network model is built as Figure 1.

The manufacturing network model has the following characteristics from Figure 1.

2.1 the hierarchical structure of BL network

Because of the business lines, thought the manufacturing network is very complex, we may divide the manufacturing network as assignments, feedback and the other information networks. A assignment network may constitute by some process, such as marketing orders, process the department of design, production scheduling, shop floor scheduling, machine processing, QC, quality control, product storage and other links. There is a strict priority and significant business line from \( R_1 \) to \( R_8 \) as Figure 1. There is a forward process in assignment network from market department, technology department, production department, workshop, machine, QC to the warehouse; on the contrary, the information is a reversing flow in the feedback network. In addition, there is also horizontal information beside the above-mentioned two types of information, and the informations constitute the pure information network.

2.2 the Matthew characteristics of BL network

Similar products usually follow the same processing line, more experience, the greater the possibility of processing similar follow-up products. A few nodes bring together most of the
sides, but another nodes’s sides are less. Some node processing the information takes a long time, but other nodes require less time to complete the information processing. For example, the degree of R3 is eight, but the degree of R1 is 5, obviously, the BL network has the characteristics of Matthew.

3. The resources allocation method in BL network

In order to analyze the network better, a data structure is defined to represent the relationship of nodes in BL network:

Definition 3: the relationship between node i and j is defined to:

\[ L_{i,j} = \{c \cdot P[k], A[k], N[k], U[k], S[k], D[k], j \} \]

where:
- i, j is the serial number of node, \( i,j=1,2, \ldots, N \);
- c: the serial number of order, \( c=1, 2, \ldots, m \);
- \( P[k] \) is the degree distribution of node i in order k;
- \( A[k] \) is the property of task k in order c, there:
  - \( A(k)=0 \) is the pure information exchange in task k, it have no task assignment or task feedback;
  - \( A(k)=1 \) is the information flow of task assignment;
  - \( A(k)=2 \) is the information flow of task feedback;
- \( N[k] \) is the amount of task;
- \( U[k] \) is the resource consumption of per unit of product;
- \( S[k] \) is the total resources of nodes;
- \( D[k] \) is the description of task.

3.1 The task assignment network

According to the manufacturing business lines, marketing departments send a new order information to the technology departments firstly, two nodes are connected through a directed line segment as Figure 1, where, marketing departments are sources, and technology departments are destinations. Technology departments issue the order to production departments while they complete the technology material designing, and connect the two nodes together. Production departments assign the manufacturing task information to workshops, workshops assign to sections, to machines, to operators, to QC departments, to storages and so on, they all connect together and form a network diagram using directed line segment as the priorities of the order. In a real production plan (\( A(k)=1 \)), the nodes and the data structure \( L_{i,j} \) in the network are instantiated according the relationship.

3.2 The task feedback network

Units in the network produce the production plan after task assignment, feedback the information and other information according their production schedule to the task delivery department, the units those request communication are sources, the task delivery department are destinations and the direction of the arrow point to the destinations. The nodes and \( L_{i,j} \) are instantiated while \( A(k) = 2 \). All the nodes connect together and form a task feedback network.

3.3 The pure information network

The units exchange other informations in the producing process too, though those information do not act as the action as tasking and feedback, they are very important to the manufacturing system. The sending nodes are sources, the recipients are destinations, connect them together and direct from the sources to the destinations when \( A(k)=0 \).

The manufacturing network is integrated by those three network intact. In addition, those above network may be simplified if it needs. In production plan, task assignment and feedback are the main process, other information have nothing to do with the task scheduler. By this way, the network should be simplified as case \( A(k)=1 \) and \( A(k)=2 \), and Figure 1 may be simplified as Figure 2. the allocation amount of resources \( T[k] \) in order k can be expressed as the follow:

\[ T[k] = N[k]U[k] - S[k] \]
Formula (1) sets up a resource allocation formula $T[k]$ in node $j$, where $S[k]$ can be computed according to needs, $U[k]$ may sets by experience, how to arrive the amount of the resource allocation? It depends on the ability to obtain resources of node $j$, in other words it depends on the degree of node $j$.

![Figure 2. the manufacturing network simplified](image)

4. Network degree distribution compute methods based on business lines

Network characteristics of power-law. The authors analyzed the characteristics of the network based on Matthew in their previous study [9]-[12], and proposed a serial formulas to compute the distribution of nodes as follow:

$$P_i = \frac{k_i}{\sum_{j=1}^{n} k_j}$$  \hspace{1cm} (2)

where:  $\sum_{i=1}^{n} P_i = 1$, $n$ is the total amount of nodes.

$$P(k) = \frac{2n(n+1)}{k(k+1)(k+2)} \propto 2n^2k^{-3}$$  \hspace{1cm} (3)

Formulas (2) and (3) show that the degree distribution of manufacturing network is followed power law, and it has an index of 3. The degree distribution changes of power-law network is much slower than it in network with Poisson distribution. It shows that the importance of node is not equal, most of the nodes have a smaller degree, but a few nodes have more side and act as important actions in the network.

The network characteristics analysis based on business lines. It has the same rate in the network discussed above, in a real manufacturing system, the rate of side is different because it may troubled by order processes, machining processes, status of machines or workers, manage scheduling method and so on. For example, although the QC in business lines is redundant, but it is the essential part of manufacturing system, so, it should be given a heavier weighting factor. If $r$ is the rate of $L_{i,j}$, $t$ is an adjustment coefficient between degree of nodes and rate of sides, the probability of connecting node $i$ can be deined as formula (4).
\[ P_i = \frac{k_i^tr_i^{1-t}}{\sum_{j=1}^{n}(k_j^tr_j^{1-t})} \]  

(4)

where:

\[ \sum_{j=1}^{n} P_i = 1, \ 0 \leq t \leq 1; \]

\( k \) is the degree distribution of node \( r \) and \( r \) is the rate of side \( i-j \).

The most efficient allocation of new processing tasks from node \( i \) to node \( j \) is asigned as \( P_i \) descend order. \( t \) is the adjustment coefficient between degree of nodes and rate of sides, its value depends on the needs of network. Biger rate means that the side is more important, the node \( i \) and \( j \) have more correlation.

So, formula (3) must be corrected as formula (5):

\[ P(k,r,t) \approx 2n^2(k^r r^{1-t})^{-3} \]  

(5)

Formular (5) shows that the network is still a power law network, and its degree distribution is an exponential equation.

From formula (4) and (5) told us the following fact: though the new tasks tend to connect to node with bigger degree, decentralized connection is also a common phenomenon because it disturb by the rate of sides. The degree of node acts no action when \( t=0 \), rate of sides play a decisive role, the case may happen in key business lines. On the contrary, the importance of nodes in the network depends on the degree of the nodes when \( t=1 \), for example, the tasks usually assigns to the experienced workers in section. The degree of nodes and rate of sides act together when \( 0<t<1 \), the degree of nodes tend to enable the convergence, but the rate of sides reduce the dependence on the rich nodes, and form more than one center, so, the task may config to different workers and equipment along different processing line automatically.

The task in production is decided by the amount of product \( m \) and the degree \( P_j \) of node \( j \):

\[ N[k] = \lfloor mP_j \rfloor \]  

(6)

\[ T[k] = \lfloor mP_j \rfloor U[k] - S[k] \]  

(7)

5. Case study

Plant X has the produce processes as Figure 2, and obtained an order for processing Y-Gear 1000 piece, the processed history of Y-Gear is shown in Table 1.

| Table 1. The processed history of Y-Gear |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| k5              | k9              | k11             | R5              | R9              | R11             |
| 0.5             | 0.3             | 0.2             | 0.2             | 0.6             | 0.2             |
| Support \( S[k] = 0 \), the resource can be computed as following:

\[ P_5 = \frac{k_5^tr_5^{1-t}}{\sum_{j=1}^{n}(k_j^tr_j^{1-t})} = 0.3854 \]

\[ N[5] = \lfloor mP_j \rfloor = \lfloor 1000 \times 0.3854 \rfloor = 385 \]
Similarly can be obtained:


\[ P_9 = \frac{\sum_{j=1}^{n} (k_j r_j^{-1-t})}{n} = 0.5171 \]

\[ N[9] = |mP_9| = 517 \]


\[ P_{11} = \frac{\sum_{j=1}^{n} (k_j r_j^{-1-t})}{n} = 0.0975 \]


So, the resource allocation scheme for the processing plant is that 385 sets allocate to operator 1, 517 sets allocate to operator 2 and 98 sets allocate to operator 3.

6. Conclusion

It is a general problem that the resource allocation troubled by business lines. Aiming at the problem, a relationship network analysis method of manufacturing system limited by business lines is proposed in the paper. Built a hierarchical network according business lines to map the real manufacturing system, the network is devided to task assignment network, task feedback network and pure information network. Proposed a power law equation limited by the degree of nodes and rate of sides, the adjustment coefficient between degree of nodes and rate of sides can optimize the allocation of resources. Case studies show that the method is sound.

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