

Research on Decision-making of Main Manufacturer-supplier Participating in Complex Equipment Based on Time Coupling

Feng Chen

School of Management Science and Engineering
Nanjing University of Finance and Economics
Nanjing, China

Yongbo Cheng

School of Management Science and Engineering
Nanjing University of Finance and Economics
Nanjing, China

Abstract—Based on the process of information exchange and accumulation between the main manufacturer and the supplier, this paper puts forward the cumulative function of information exchange and knowledge. Based on Ohm's law in physics, Ohm's law of knowledge is put forward to construct knowledge potential, knowledge flow and knowledge transfer quantity to maximize the overall benefit. This paper also explores the intervention time of supplier's involvement in R&D of complex equipment, the frequency of information exchange between the two sides and provides reference for the development process of aviation complex equipment.

Keywords—*complex equipment; information exchange frequency; Supplier R&D Intervention Time; knowledge accumulation function*

I. INTRODUCTION

Aviation complex equipment is a concentrated embodiment of high-tech and a symbol of a country's industrialization level and comprehensive national strength. Aviation industry has high-end technology and all-round design in many industrial fields. It can not only promote the technological development of high-tech industry and general industry, but also is the strategic industry to enhance national strength and the main pillar to ensure the security of national defense. The development of complex equipment products has higher difficulty, higher technical requirements, higher investment and management, higher risks, higher concentration of knowledge density and higher concentration and integration of resources, reflecting the country's highest level of technical manufacturing capacity. According to statistics, the manufacture of an aircraft such as the Boeing 747 series requires approximately 4.5 million components, which are from 1,500 large companies and 15,000 SMEs (Small and Medium-sized Enterprises) in six countries. Similarly, the R&D of complex equipment also requires a large number of manufacturers and suppliers. Due to the particularity of the R&D of complex equipment, the manufacturers and suppliers can be divided into main manufacturers and subordinate suppliers according to their attributes. Therefore, they have become the "main manufacturer-supplier" collaborative R&D model. Manufacturers are in the core position, have certain control

over all levels of suppliers, all levels of suppliers and the main manufacturers have dependence.

Since the production of complex aviation equipment involves the main manufacturers and suppliers at all levels, product design faces many complexities, and it is absolutely necessary for manufacturers to communicate with suppliers coordinating information. This paper mainly deals with the two stages of product design and process design, transforming information about products between the main manufacturer and supplier into knowledge transfer and accumulation, so that the research in this paper has certain guidance and auxiliary effects on the production design of the product. Through the analysis of the model, it is beneficial to the choice of decision-making basis between the main manufacturer and the supplier.

II. LITERATURE REVIEW

The complex equipment R&D process generally refers to the process of complex equipment development. It is an integrated and parallel design of equipment and related processes. The overall goal is to shorten the product R&D cycle, improve product quality, and reduce production costs. Parallel engineering is to manage and control the integration process from the perspective of global optimization, and to improve and promote the existing product R&D process (PDP, Product Development Process). In this paper, the information exchange between the main manufacturer and supplier on the R&D of complex products is a parallel engineering method analyzing how to exchange information and knowledge transfer in the production process, how to model, and how to benefit the global benefit in detail.

The management scientist Teece first proposed the concept of knowledge transfer. He believed that knowledge transfer is the process of sending and receiving knowledge between the sender and the receiver [1]. As the research on knowledge transfer gradually matures, the definition of knowledge transfer from the perspective of knowledge transfer effect is gradually accepted. And knowledge transfer subjects and recipients from this perspective can provide better benefits. As a kind of resource, knowledge can affect the resource transaction efficiency and transaction cost

among organizations, and thus affects the realization effect of alliance knowledge transfer. Therefore, it is of great significance to study the knowledge transfer utility and knowledge transfer efficiency of supply chain collaboration. Kedia et al. [2] believe that benefit is the degree of achievement of the goal, while efficiency is the amount of resources invested by unit output. Knowledge transfer and knowledge usefulness can be used to describe the utility of knowledge transfer, and the speed of knowledge absorption and cost are used to describe the efficiency of knowledge transfer. Rebecca Clemons et al. [3] in the context of supply chain disruption believe that knowledge transfer will affect the order and quality of enterprises, thus affecting the profits of enterprises and suppliers. Constantin Blome et al. [4] found that the internal and external knowledge transfer has a positive impact on supply chain flexibility and is also an important manifestation of the company's ability to maintain market competitiveness. Sharath Sasidharan [5] defined the knowledge network, emphasized the importance of learning, and analyzed the impact of knowledge patterns and intensity on firm performance. Sung Yul Ryoo et al. [6] believes that corporate performance is influenced by the degree of knowledge complementation, and knowledge exchange has a positive effect on corporate performance. Angeloantonio Russo et al. [7] studied the relationship between knowledge resources and knowledge alliances in order to reasonably understand the configuration of the company and internal knowledge. Mohamed Hamdoun et al. [8] found that knowledge transfer has a positive effect on corporate quality and environmental management through structural equation modeling. Mário Franco et al. [9] found knowledge transfer firms meet market needs, through the creation of new products or technology developed by the researchers. Dong et al [10] constructed a knowledge transfer mechanism model from three stages: technology transfer, R&D joint, and co-construction entity, and obtained the decisive factors of knowledge transfer efficiency, and explored countermeasures to improve knowledge transfer efficiency. For the knowledge Ohm's law to be analyzed in this paper, the information exchange and knowledge transfer between the main equipment manufacturer and supplier of complex equipment needs further exploration and analysis.

The premise that manufacturer and supplier can transfer knowledge is that there is a difference in the amount of knowledge, so knowledge can be transmitted. In the law of knowledge Ohm, the essence of knowledge transfer is the potential difference, which is called the knowledge potential difference in this paper. Liao et al. [11] deeply studied the influence and mechanism of knowledge potential difference on knowledge transfer performance, and had certain influence on decision-making subject knowledge input and transfer strategy; De Jong et al. [12], [13] and other scholars believe that the input of absorptive capacity affects the relationship between knowledge potential and absorptive capacity. If the investment in absorptive capacity is increased, it will help to enhance the understanding of knowledge and promote cooperation between subjects.

In summary, the existing researches believe that knowledge transfer, knowledge potential, and the ability of

the research subject to absorb knowledge will have a certain impact on business performance. This paper takes the development of complex equipment as the research background, and uses the knowledge Ohm's law to establish a collaborative manufacturing model with higher transmission efficiency, which provides a reasonable decision-making basis for the development of the main manufacturer and supplier.

III. AVIATION COMPLEX EQUIPMENT MAIN MANUFACTURER-SUPPLIER TIME COUPLING RESEARCH

The main manufacturer and supplier analogy to the two poles of Ohm's law, the manufacturer is the positive pole of the power supply, the supplier is the negative pole of the power supply, the information flow is transmitted from the relatively sufficient manufacturer to the relatively scarce suppliers of information, and the knowledge transfer between the two parties. The process is equivalent to the flow of knowledge. Since the whole life cycle of aviation complex equipment involves the economic, complexity, risk control, quality assurance and other aspects of the system, there will always be some obstacles in the production and development process. This paper refers to the various factors that hinder knowledge transfer between upstream and downstream activities as knowledge resistance, and the product of knowledge flow and time in the process of knowledge transfer is called knowledge transfer quantity. The knowledge accumulation function and design rework function are used to describe the communication between the main manufacture and supplier in complex equipment development. The communication provides a reasonable time for the supplier to participate in the R&D.

A. Basic Hypothesis

Considering the complexity and variable characteristics of aerospace complex equipment production, for the convenience of analysis, the paper makes the following assumptions:

Hypothesis 1: According to Ohm's law, the current flows from a place where the potential is high to a place where the potential is low. Although the communication of information is two-way, the knowledge transfer generated by the main manufacturer and supplier in the process of information exchange should also be mutual. It is assumed that the knowledge flow is transmitted from the main manufacturer to the supplier and the information flow is processed in one direction.

Hypothesis 2: There is a main manufacturer and n suppliers in the supply chain. In the synergy between the main manufacturer and the supplier, the main manufacturer is at the core and coordinating the entire supply chain; it is assumed that n suppliers are independent of each other and have the same subject status. That is, each supplier is engaged in research and development cooperation in a certain aspect independently of the main manufacturer.

Hypothesis 3: Assume that at the time when the main manufacturer's development activities proceed to $t_0 \geq 0$, the

supplier begins to participate in the collaborative development process of aviation complex equipment, and the information exchange interval between the main manufacturer and the supplier is discrete. The supplier has n times of information exchange with the main manufacturer during the $(T - t_0)$ time period, where $n > 1$, the time interval of each information exchange is $\Delta t = \frac{T - t_0}{n - 1}$, and the unit information exchange cost of the main manufacturer and supplier are known.

According to the above-mentioned assumptions, through the knowledge flow and knowledge intensity under time coupling, the overall benefit is maximized, the key problems in the collaborative development process of the complex equipment manufacturer's supplier are improved, and the supplier's early intervention time is clarified, and provide reasonable planning and decision-making for supplier participation.

B. The Main Manufacturer-supplier Collaborative Development of Knowledge Transfer

The essence of collaborative development between the main manufacture and supplier is the process of knowledge exchange and accumulation among the participating entities. Considering the full life cycle of complex equipment product development, the early participation of supplier has certain risks. If the intervention is too early, the information between the two parties will be imperfect, and there will be a large design rework, which will increase the cycle and cost of product development; if the intervention is too late, it will cause delay in knowledge. Considering the parallel product development cycle, establish a time-coupled map of the main manufacturer-supplier information exchange as shown in "Fig. 1".

supplier and the main manufacturer conducted n information exchanges. According to Hypothesis 3, the time interval of each information exchange is $\Delta t = \frac{T - t_0}{n - 1}$, and the R&D subjects learn more and more through continuous communication, and the time taken for product design rework is gradually reduced. Therefore, the collaborative R&D time schedule between the above-mentioned main manufacturer-supplier is in line with the actual situation.

C. Main Manufacturer-supplier Activity Knowledge Potential Function

Due to the development of complex equipment involving customers, main manufacturer, suppliers at all levels, under the strong promotion of high technology, the development of complex equipment faces many challenges and requires the management of global supply chain. Therefore, the introduction of complexity parameters k ($0 \leq k \leq 1$), indicating technical challenges in the development of complex equipment. Since the main manufacturer has certain supervision and guidance to suppliers at all levels, the propulsion parameter w ($0 \leq w \leq 1$) is introduced according to its own management ability and the ability to promote product development. According to Hypothesis 3, considering that the time interval of information exchange is uniform, the knowledge transfer activity only occurs at the beginning of each communication, so the knowledge potential function only studies the knowledge potential at each moment of knowledge transfer. The knowledge potential function the of the main manufacturer activity A is:

$$\varphi_A(t_i) = \frac{k}{w} \times \left(\frac{t_i}{T}\right)^\alpha + \left(1 - \frac{k}{w}\right) \quad (1)$$

Where $\varphi_A(t_i)$ is the knowledge potential of the i -th Δt at the beginning of the main manufacturer activity $1 - \frac{k}{w}$. $\frac{k}{w} \times \left(\frac{t_i}{T}\right)^\alpha$ indicates that the main manufacturer has a knowledge base when developing new products, and does not need to communicate and cooperate with other entities at all levels. w indicates the amount of new knowledge that the main manufacturer has when developing products at t_i . $t_i = t_0 + (i - 1)\Delta t$, $0 \leq t_i \leq T$, t_i is the i -th initial moment of

$i = \left\lceil \frac{t - t_0}{\Delta t} \right\rceil + 1 (i = 1, 2, \dots, n)$, α represents the cumulative evolution path index of knowledge of the main manufacturer's activities.

When $0 < \alpha < 1$, the knowledge of the main manufacturer is accumulated rapidly. In the later stage of production, the main manufacturer needs to invest a lot of

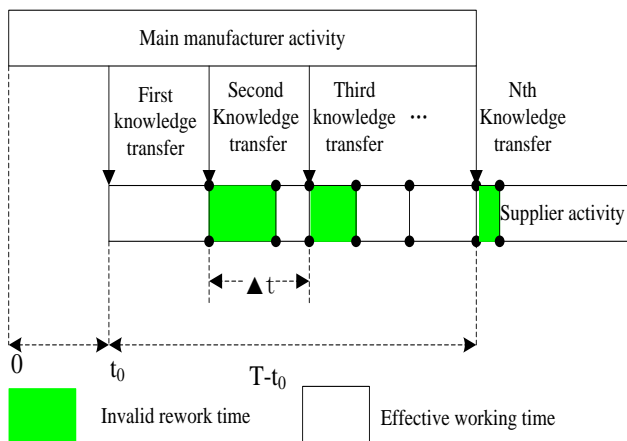


Fig. 1. Collaborative development progress diagram.

The starting time of the main manufacturer is 0, and its expected completion time is T. When the development time starts to t_0 ($0 \leq t_0 \leq T$), the supplier begins to participate in the process of information exchange and transformation of complex product development. During the T-t0 period, the

resources. After multiple processes, the transition from raw material state to finished product state is realized, and the cycle is long. Therefore, the knowledge accumulation is relatively slow, forming an upper convex line.

When $\alpha = 1$, it means that the knowledge accumulation is uniform growth type.

When $\alpha > 1$, it means that the amount of new knowledge is gradually decreasing, and the knowledge accumulation is slower and faster.

At the i -th initial moment of Δt , the knowledge potential function of supplier activity B is:

$$\varphi_B(t_i) = \frac{k}{w} \left(\frac{t_i - t_0}{T - t_0} \right) + \left(1 - \frac{k}{w} \right) \quad (2)$$

The supplier participates in the process of complex equipment development. The information flow of the product development is transmitted from the main manufacturer to the supplier, and then the supplier processes the information and feeds it back to the manufacturer, thus forming an effective closed loop, as shown in "Fig. 2":

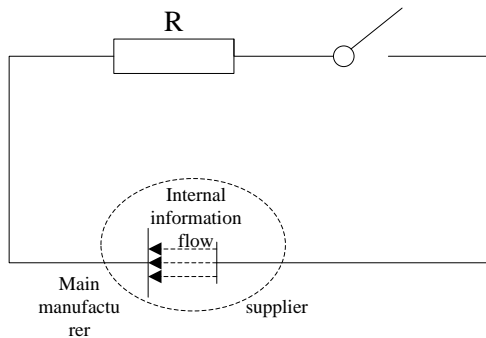


Fig. 2. The main manufacturer-supplier information flow diagram.

This paper defines various factors affecting knowledge transfer as knowledge resistance, denoted by R . As the number of information exchanges between the main manufacturer and the supplier increases, the learning ability and the correctness of knowledge transfer between the two parties will gradually increase, so the resistance is gradually reduced. At this time, the knowledge resistance function can be expressed as:

$$R_i = R_1 i^{-\lambda} \quad (3)$$

Where R_i is the knowledge resistance of the i -th knowledge transfer process; R_1 is the knowledge resistance of the first knowledge transfer process; i is the frequency of knowledge transfer; λ is the learning index; $\lambda = -\lg S_R / \lg 2$; $S_R = R_{2i} / R_i = 2^{-\lambda}$ indicates the rate of self-learning between the main manufacturer and the supplier during the knowledge transfer process.

As the supplier will feedback information about the products, the knowledge transmitted by the main manufacturer and the knowledge required for the actual development of the product are subject to errors in the development stage of complex equipment. The probability that error caused by the main manufacturer in information transfer is defined as $P_A(t)$.

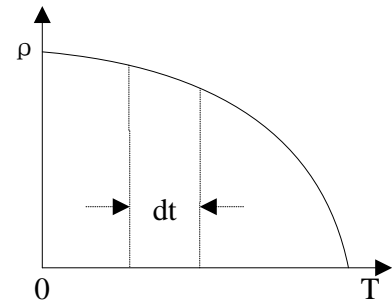


Fig. 3. Main manufacturer information transfer error rate function.

$$P_A(t) = \rho \left[1 - \frac{t}{T} \right]^\tau \quad (4)$$

Where $0 < \rho \leq 1$, denoting the maximum error rate of knowledge transfer by main manufacturer, $0 \leq t \leq T$; $\tau > 0$ determining the shape and trend of the main manufacturer error rate function curve (as is shown in "Fig. 3").

In the R&D process, the possibility that the supplier activity B obtains insufficient information from the main manufacturer activity A and there is a design modification is called the supplier knowledge rework rate function, which is recorded $P_{AB}(t)$:

$$P_{AB}(t) = mP_A(t) = m\rho \left[1 - \frac{t}{T} \right]^\tau \quad (5)$$

Where $0 \leq m \leq 1$, denoting the degree of information dependence of supplier activity B on main manufacturer activity A. Due to the complex equipment design rework time is invalid information exchange time. Thus, according to Fig. 1, due to overlapping tasks, the invalid working time of the i -th and $i+1$ th information exchanges between the main manufacturer and the supplier are expressed:

$$T_{Re\ work} = \int_{t_i}^{t_{i+1}} P_{AB}(t) dt = -\frac{m\rho T}{\tau + 1} \left[\left(1 - \frac{t_{i+1}}{T} \right)^{\tau+1} - \left(1 - \frac{t_i}{T} \right)^{\tau+1} \right] \quad (6)$$

IV. MODEL SOLUTION

According to Ohm's law, the main manufacturer and supplier have the following knowledge potential difference and knowledge flow in the process of knowledge transfer:

$$I_{AB} = \frac{U_{AB}}{R_i} = \frac{\varphi_A(t_i) - \varphi_B(t_i)}{R_i} = \frac{kt_0(n-i)}{wR_1 i^{-\lambda} T(n-1)} \quad (7)$$

Note: For convenience, the knowledge cumulative evolution path index $\alpha = 1$ of the main manufacturer activity indicates that the knowledge of the main manufacturer has grown linearly.

During the Δt period, the amount of knowledge that the main manufacturer delivers about complex equipment R&D is Q each time information is exchanged.

$$Q_i = I_{AB}\Delta t = \frac{kt_0(T - t_0)(n - i)}{wR_1 i^{-\lambda} T(n - 1)^2} \quad (8)$$

In the Δt time period of i -th, the amount of invalid knowledge transfer is Q_i^r .

$$Q_i^r = I(t_i)T_{Re work} = \frac{kt_0(n - i)m\rho(T - t_0)^{\tau+1}}{wR_1 i^{-\lambda}(\tau + 1)(n - 1)^{\tau+2}T^{\tau+1}} [(n - i)^{\tau+1} - (n - i - 1)^{\tau+1}] \quad (9)$$

Therefore, during the Δt period, the effective knowledge transfer of the main manufacturer and supplier for complex product development is Q_i^e .

$$Q_i^e = Q_i - Q_i^r = \frac{kt_0(T - t_0)(n - i)}{wR_1 i^{-\lambda} T(n - 1)^2} \left\{ 1 - \frac{m\rho(T - t_0)^{\tau}}{(\tau + 1)(n - 1)^{\tau}} [(n - i)^{\tau+1} - (n - i - 1)^{\tau+1}] \right\} \quad (10)$$

When the main manufacturer and supplier exchange information n times, the amount of knowledge of the transferred product development is π . For convenience, let $\tau = 1$, denoting the main manufacturer error rate function is linearly monotonically decreasing.

$$Q_i^e = \frac{kt_0(T - t_0)(n - i)}{wR_1 i^{-\lambda} T(n - 1)^2} \left\{ 1 - \frac{m\rho(T - t_0)(2n - 2i - 1)}{2T(n - 1)} \right\} \quad (11)$$

$$\pi = \sum_{i=1}^{n-1} Q_i^e = \sum_{i=1}^{n-1} \frac{kt_0(T - t_0)(n - i)}{wR_1 i^{-\lambda} T(n - 1)^2} \left[1 - \frac{m\rho(T - t_0)(2n - 2i - 1)}{2T(n - 1)} \right] \quad (12)$$

In order to enable suppliers to participate in collaborative development in advance and maximize the overall revenue of the supply chain, that is, when the amount of knowledge

transfer is the maximum, the R&D manufacturing system is optimal at this time.

$$\max(\pi) = \sum_i^{n-1} Q_i^e \quad (13)$$

$$s.t. \begin{cases} n > 1 \\ 0 \leq t_0 \leq T \\ 0 \leq t_i \leq T \\ R_1 > 0 \\ 0 \leq k \leq 1 \\ 0 \leq w \leq 1 \\ 0 < \rho \leq 1 \\ i = 1, 2, 3, \dots, n - 1 \end{cases}$$

When the knowledge transfer amount is optimized, the general calculation method is more complicated for solving the above formula (13). Therefore, this paper uses MATLAB to solve the problem. At the same time, we will further analyze the utility function that is, when the amount of knowledge transfer both sides of the main manufacturer and supplier of π optimal, the impact of product R&D complexity and propulsion on the optimal intervention time of the supplier.

V. NUMERICAL SIMULATION

In the design process of the aircraft airborne system, the main manufacturer is mainly involved in the design of the core components of the complex airborne system. The supplier is mainly responsible for the design of the small parts in the system, affecting the operation of the aircraft airborne system.

This section mainly analyzes the above model by numerical examples. The values of each parameter are shown in "Table I".

TABLE I. MODEL PARAMETER SETTING

Symbol	Parameter name	Parameter value
k	Product R&D complexity	0.8
w	Product R&D propulsion	0.8
R_1	Knowledge resistance of the first knowledge transfer process	0.7
m	Degree of information dependence of supplier on main manufacturer	0.6
ρ	Maximum error rate of knowledge transfer by main manufacturer	0.1
T	Product R&D cycle	90
λ	Learning index	0.32

Under the conditions of the above table parameters, according to the simulation results, it can be seen that with the increase of n , the amount of knowledge transfer between the main manufacturer and supplier on the R&D of complex equipment is increasing, and the frequency of information exchange between the two sides is constantly increasing, so that the accuracy of information transmission is more accurate. Considering the frequency of information exchange will affect the budget of the cost, according to the actual situation of information exchange, it is determined that $n = 10$. According to “Fig. 4”, the optimal intervention time of the supplier is $t_0 = 29$ days, which corresponds to the maximum amount knowledge transfer $\pi = 182.7$ and the

$$\Delta t = \frac{T - t_0}{n - 1} = 6.7 \approx 7$$

interval of each transfer

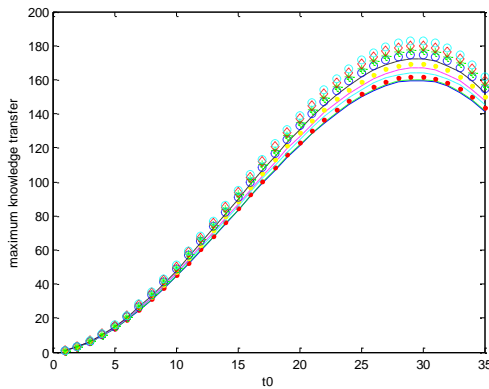


Fig. 4. Supplier intervention in R&D time.

As shown in “Fig. 5”, when the product R&D complexity is in $[0, 0.1]$, as the complexity increases, the R&D of the main manufacturer will be limited and delayed, and the time for the supplier to intervene will be delayed. When the complexity is in the range of $[0.1, 1]$, as the complexity of product development increases, the time for suppliers to participate in the development is unchanged. The main reason for this result is that manufacturers and suppliers are not sensitive to the complexity of product R&D. Even if obstacles are encountered during the information exchange, they will be overcome.

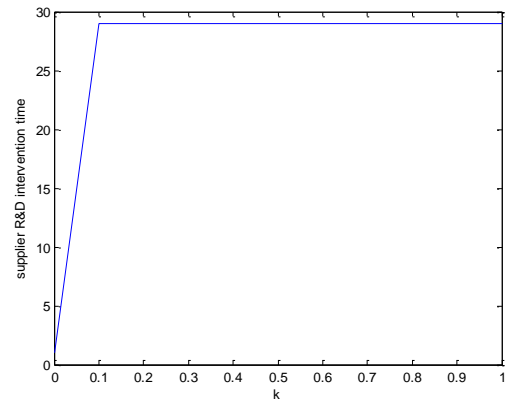


Fig. 5. The relationship between t_0 and k .

The relationship between the development of complex equipment projects, the dependence of suppliers on manufacturers and the time of supplier development interventions show the same trend.

According to “Fig. 6”, in the range of $[0, 0.1]$, when the propulsion of complex equipment projects continues to increase, the supplier intervention time t_0 also increases. In the range of $[0.1, 1]$, the progress of the project is stable, and the supplier's R&D intervention time will not be changed with the increase of the propulsion.

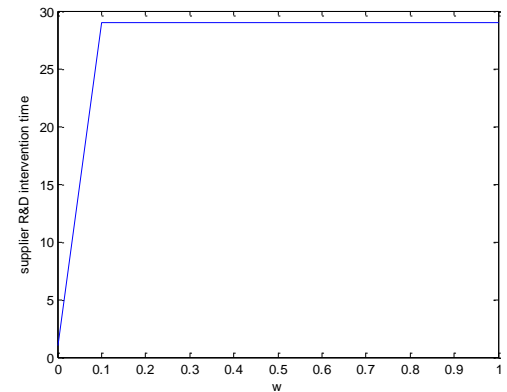


Fig. 6. The relationship between t_0 and w .

According to “Fig. 7”, the supplier's dependence on the manufacturer is increasing within the range of $[0, 0.1]$, and remains unchanged in the range of $[0.1, 1]$. In the R&D process of manufacturer and supplier, the accumulated knowledge of products has been increasing, and the R&D of products has become more perfect. Therefore, information is effectively utilized in communication.

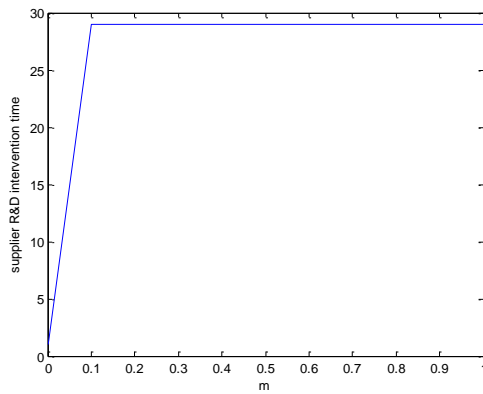


Fig. 7. The relationship between t_0 and m .

In general, in the information overlap phase, the transfer of knowledge will make R&D easier. Therefore, the relationship between supplier development intervention time and product development complexity, propulsion and information dependence are only obtained in the early stage of product development. In fact, there is no clear quantitative relationship in the later stage of development.

VI. CONCLUSION

This paper analyzes the contribution of the main manufacturer and supplier to the development of complex products by means of the R&D of aviation complex equipment.

Based on the knowledge Ohm's law, this paper constructs the knowledge potential function and knowledge resistance function of the main manufacturer and supplier activities, obtains the knowledge flow intensity function in the process of knowledge transfer, and constructs an overlapping time function model that maximizes the global benefit. And use the simulation to solve the model.

Although this paper proves the validity and feasibility of the method in the R&D stage of complex equipment, in the hypothesis 1, we have made a strong one-way processing hypothesis for information, and did not consider the feedback of the information when the two sides exchange information errors. It is also the focus of further improvement and research in the next step.

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