Information-sharing mechanism of synergistic incentive among EPC subjects of energy efficiency retrofitting of existing buildings against COVID-19

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Abstract

The pandemic situation of COVID-19 blocks many traditional information exchange paths, intensifies the information asymmetry in the implementation of the energy efficiency retrofitting project of existing building and seriously affects the decision-making effect of the energy performance contracting (EPC) subject. Therefore, based on the information-sharing platform, this paper constructs the synergistic incentive framework; designs the computational experimental models from the aspects of system information structure, system organization structure, synergistic communication strategy and subject knowledge structure; and analyzes the influence mechanism and evolution law of information on synergistic incentive performance from the two dimensions of the influence of the synergy cycle on the incentive performance and the influence of the incentive cycle on the synergy degree. The results show that increasing the information redundancy length and the information redundancy width can improve the synergy degree and incentive validity. The concentration of subject number or information dimension in a certain information area can quickly improve the synergy degree and incentive utility in the early stage of the synergistic incentive cycle, but the above situation is opposite in the later stage. Increasing the information communication path is beneficial to the effective information dissemination among subjects and can improve the efficiency of the decision-making of the subjects. Lastly, considering the background of COVID-19 epidemic situation, this paper puts forward the remedial methods and coping strategies make up for the lack of synergistic incentive information between EPC subjects. Research results can provide strong support for the design of synergistic incentive mechanism of EPC subjects.

Keywords: the information-sharing mechanism; synergistic incentive; EPC subjects; COVID-19

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1. INTRODUCTION

As global energy consumption and carbon emissions increase [1], and the phenomenon of greenhouse is exacerbated [2], energy saving and emission reduction and energy management have not only been a slogan but also a policy and an important goal of economic reform [3]. Buildings use a lot of energy, which nearly accounts for 40% of the world's energy consumption [4]. Among them, more than 80% of energy consumption [5] and 36% of CO₂ emissions [6] occur in the construction and operation stage, which makes buildings the third energy-consuming sector after transport and industry [7]. Under this situation, it is of great significance to carry out energy efficiency retrofitting of existing buildings. The retrofitted buildings tend to be more airtight and more thermally insulated [8], significantly reduce energy consumption [9], reduce carbon emissions, drive the relevant
industrial chain and increase employment [10]. Overall, energy efficiency retrofitting of existing buildings would facilitate China’s goals of energy saving and emission reduction [11].

In China, most of the owners entrust the energy services company (ESCO) to implement energy efficiency retrofitting of existing buildings by means of energy performance contracting (EPC). Among them, the ‘energy efficiency sharing’ contract is the EPC type that is strongly supported by the government. The system revenue of energy efficiency retrofitting of existing buildings comes from the energy-saving effect and operation cycle after the retrofitting, which depend on the engineering quality in the retrofitting stage. Therefore, improving the quality of energy efficiency retrofitting project is the primary goal of EPC management, and the synergistic incentive among EPC subjects is an important measure to realize this goal effectively.

Under the traditional management mode, the incentive among EPC subjects is mostly the owner as the core, whose main focus is the realization of the contract goal then the synergistic incentive of the government, the owner, the ESCO, subcontractor and the supplier. During EPC implementation—with the increase of project complexity, the improvement of social influence and the renewal of energy-saving technology—the EPC contract objective is generally diversified, the contract terms are gradually refined and the contractual duties and obligations are increasingly improved, which urges EPC subjects to pay attention not only to their own target income, but also to EPC project implementation quality, environmental protection, construction safety, contract risk and other objectives. The multi-objective decision-making process of the project has strong information dependence, timing sensitivity, thinking integration and random dynamics. It is necessary for EPC subjects to have comprehensive professional knowledge, perfect cognitive ability and systematic information communication system in order to accurately grasp the goal, essence and law of EPC project decision-making. All in all, knowledge architecture, professional attainment and cognitive ability of EPC subjects are the main factors that affect the decision-making results.

Since November 2019, a serious form of pulmonary illness has quickly engulfed a majority of the world [12]. This pneumonia outbreak was attributed to a novel corona virus that has not been previously identified in humans [13], the disease caused by the virus was termed coronavirus disease 2019 (COVID-19) [12]. It was characterized by World Health Organization (WHO) as a global pandemic on 11 March 2020. Countries worldwide are implementing various preventive measures to contain the spread of the infection such as travel and trade restrictions, closure of educational institutions and shops and curfew implementation as some took more strict measures [13]. Against the background of COVID-19, many traditional information communication channels are blocked, and EPC subjects cannot communicate in time to obtain correct information, which results in the shortage of decision-making information. At the same time, EPC subjects often have information defects such as insufficient cognitive ability and one-sided professional knowledge, and each subject also has the characteristic of independent decentralized decision-making. The individual abilities, preferences and heterogeneity of decision-makers in interest demands, strategy choices, effort degree, business philosophy, management objectives and so on will lead to communication lack and difficult to form a synergistic decision-making mechanism among EPC subjects; At the same time, the recessive factors such as knowledge and technology invested by each EPC subject are difficult to measure, and the advantages of information resources among subjects cannot be effectively integrated. The above situation will lead to such bad phenomena as cost overrun, time delay, safety accidents, and ultimately affect the management performance and the effect of energy efficiency retrofitting of existing buildings.

Synergistic incentive, as an integrated management method based on information-sharing platform, can make up for the lack of information aggravated by COVID-19 epidemic situation, overcome the loose—or even antagonistic—organizational relationship among EPC subjects and then strengthen the contractual relationship of EPC subjects to adapt to the overall value-added objectives of the EPC project. The synergistic incentive among EPC subjects can break the ‘information island’ phenomenon caused by lack of knowledge, cognitive ability and information; eliminate the obstacles of independent and decentralized decision-making; effectively avoid the moral hazard caused by adverse selection of EPC subjects under the condition of asymmetric information, establishing an incentive mechanism for effective decision-making among the subjects; enhance the initiative and behavior synergy of the subjects participating in energy efficiency retrofitting; and urge all parties to change from repeated confrontation relationship to cooperative relationship in order to adapt to the optimal allocation of market resources [14], to achieve multi-win and EPC project overall value-added goal [15].

Knowledge sharing [16], knowledge brokering [17] and the perceived information literacy [18] are able to act as the cognitive bridge among different types of knowledge. Information technology helps the subject search for relationships in the collaborative innovation process [19]. However, there is an abundance of conflicting, implausible, misleading and unauthorized information spread throughout various information resources [20]. If the categories of information cannot be distinguished, decision-makers are often overwhelmed by the abundance of information [21]. Kumaraswamy et al. believe that the diversity objectives of the project participants need complete information to achieve optimal decisions [22], such as knowledge on energy-saving performance could contribute to EPC investment decisions [23]. For this reason, Mei et al. designed a network information system, which can integrate the views of project subjects from different cultural backgrounds to achieve the goal of collaborative decision-making [24]. Hurwicz [25] take the economic mechanism as an information transmission system to detect the information exchange and find that in order to realize the effective allocation of resources under the condition of individual rationality, incomplete information, free choice and decentralized decision-making, economic people need to strengthen communication and obtain a certain amount of correct information, so as to put forward the concept of ‘incentive compatibility’, in order to solve the
incentive problem in the process of economic activity. The ‘incentive compatibility’ proposed by the Hurwicz refers to the following: in the market economy, every rational economic person has a self-interest side, and his personal behavior is to act according to the rules of self-interest. If there can be an institutional arrangement to promote the pursuit of individual interests that coincides with the maximizing goal of the enterprise collective value, then this institutional arrangement is ‘incentive compatibility’. Modern economic theory and practice show that carrying out the principle of incentive compatibility can effectively solve the contradiction and conflict between individual interests and collective interests and make the behavior mode and behavior result of the actor conform to the maximizing goal of collective value, that is, the individual value and collective value can be consistent.

Therefore, based on the information-sharing platform among EPC subjects, this paper constructs the synergistic incentive framework; designs the computational experimental model from the four aspects of system information structure, system organization structure, synergistic communication strategy and subject knowledge structure; analyzes the mathematical relationship between synergy and incentive; studies the influence mechanism and evolution law of information on synergistic incentive performance from the two dimensions of the influence of the synergy cycle on the incentive performance and the influence of the incentive cycle on the synergy degree; and puts forward strategies to make up for the lack of information communication, which provides a strong support for the design of synergistic incentive mechanism among EPC subjects.

2. PROBLEMS DESCRIPTION AND THEORETICAL MODEL

2.1. Information-sharing system of synergistic incentive among EPC subjects

EPC subject’s decision-making process is the process of obtaining, processing, discriminating and innovating all kinds of information resources. Only by mastering a large number of information resources can the subject make a comparative judgment and make the best choice of various schemes. Both theoretical research and practical analysis of engineering management show that subject decision-making mainly depends on its long-term accumulated experience in engineering management, psychological expectation and other private information for subjective judgment. Synergistic incentive between subjects requires mastering recursive information such as interest demands, fair cognition, goal setting, etc. These psychological and behavioral private information lead to high sensitivity and reversibility in the decision-making and synergistic incentive process of EPC subjects, which requires continuous coordination and communication among subjects in order to match the information of the EPC project system and the information needed for synergistic incentive and to meet the needs of synergistic incentive among subjects.

The complexity and variability of the engineering environment also affects the strategy selection and synergistic incentive effect of the subject. It is necessary for multiple subjects to share hidden information and transform private information into important resources of system decision-making and synergistic incentive so as to continuously track and adjust incentive strategies among subjects and further realize the innovation of knowledge and technology while achieving incentive compatibility. Besides, when the subject chooses the strategy according to the various incentive clauses in the EPC contract, he not only pays attention to his own income and expenses, but also compares the other subjects’ income and expenses, that is, there is a psychology of fairness cognition. This social psychology makes the subject become a finite rational person, and often misjudge in decision-making, which requires the use of other information such as professional knowledge, engineering experience to assist and correct the decision-making process. As a whole, the decision-making of subject and the synergistic incentive of subjects need multiple types of supporting information.

Information sharing refers to the exchange of information between multiple subjects of the project system through various channels to enhance the application value of information and produce new knowledge or ideas. Information sharing is a division as well as cooperation system among the members of the project system based on the heterogeneity of information resources. It can be used to eliminate the barriers of information heterogeneity, technical compatibility, knowledge one-sidedness and behavior independence between the subjects in the operation of the project system and to increase the synergy and cultural complementarity of project subjects in choosing management objectives. The information shared includes not only dominant expertise, such as design and construction technology, energy consumption measurement methods, market policy, weather and environmental conditions, but also recessive private information, such as engineering experience, cultural characteristics, fairness preference, psychological activities, etc. All information intersects and forms a flow of information that can be transmitted through different paths. These paths include meetings, dinners, letters, telephone calls, videoconferences, e-mail and so on. All project subjects, information, communication path and so on are constructed into decision-making and synergistic incentive information system among EPC subjects, as shown in Figure 1.

2.2. Framework system of synergistic incentive among EPC subjects

The diversity goal of engineering stakeholders needs complete information to make optimal equilibrium decision. When faced with the multi-objective decision-making problem of energy efficiency retrofitting project of existing buildings under the EPC mode, the group decision-making based on information sharing among the government, the owner, the ESCO, the subcontractors and suppliers becomes an important decision-making mode, and synergistic incentive is an important measure to realize and optimize the decision-making mode.
According to the synergy theory, energy efficiency retrofitting project in EPC mode is a complex operating system, which relies on the joint action of many subsystems. The synergistic effect produced by the interaction of many subsystems is the driving force of EPC implementation. The incentive theory studies how to arouse people's enthusiasm; it thinks that work efficiency is directly related to the work attitude of the subject and work attitude depends on the satisfaction degree and incentive factor of the subject's needs. The incentive theory provides effective way to solve the problem of subject's enthusiasm through specific methods and management system. The synergistic incentive mechanism is the behavior mode between subject and object through a series of incentive factors to promote and restrict each other in order to achieve individual goal and collective goal. Figure 2 shows the relationship between synergy and incentive of EPC subjects.

In the framework of synergistic incentive relationship of EPC subjects, the roles of each subject are defined first, then task is determined, and then the trust relationship among subjects is established through communication to realize the information sharing of synergistic incentive of subjects. Division of labor and cooperation relationship of EPC subjects is shown in Table 1.

In the framework of synergistic incentive relationship of EPC subjects, there is a need for the flow of information among subjects, among subjects and incentive inducing factor and among subjects and synergetic connecting factors. The communication and dissemination of information, especially recessive information (private information), can unify the thought and behavior of EPC subjects and establish good interpersonal relationship, which is the premise and foundation of synergistic incentive of EPC subjects. The starting point of the synergistic incentive framework of EPC subjects is to meet the needs of each subject, to arouse the enthusiasm and behavioral synergy of EPC subjects to participate in the energy efficiency retrofitting project and to induce the decision direction of the subject through the incentive measures, that is, incentive compatibility should be achieved at low cost, while the objective of each subject and the overall objective of the EPC project should be achieved. The information flow always runs through the synergistic incentive mechanism of EPC subjects in the process of EPC project implementation and endows the soul with the synergistic incentive system of EPC subjects. The synergistic incentive framework of EPC subjects based on information sharing is shown in Figure 3.

2.3. Information-sharing model of synergistic incentive among EPC subjects

This paper uses a multi-dimensional information stock \( I \) to represent the information system needed by the synergistic incentive of EPC subjects, as shown in Equation (1):

\[
I = I_1 + I_2 + I_3 + \cdots + I_j + \cdots + I_S
\]

In Equation (1), \( I_1, I_2, I_3, \ldots, I_S \) represent different categories of information, such as the subject's psychological activity, engineering practice experience, design and construction technology, energy consumption verification methods, management models,
etc. There are $S$ categories, among them

\[
\begin{align*}
I_1 &= i_{11}, i_{12}, i_{13}, \ldots, i_{1n_1} \\
I_2 &= i_{21}, i_{22}, i_{23}, \ldots, i_{2n_2} \\
& \quad \quad \quad \ldots \\
I_k &= i_{k1}, i_{k2}, i_{k3}, \ldots, i_{kn_k} \\
& \quad \quad \quad \ldots \\
I_j &= i_{j1}, i_{j2}, i_{j3}, \ldots, i_{jn_j} \\
& \quad \quad \quad \ldots \\
I_S &= i_{S1}, i_{S2}, i_{S3}, \ldots, i_{Sn_S}
\end{align*}
\]

In Equation (2), there are $n_1$ dimensional information stock in information $I_1$, $n_2$ dimensional information stock in $I_2$, $\ldots$, $n_j$ dimensional information stock in the $I_j$ and $n_S$ dimensional information stock in the $I_S$. Any 1D information can be expressed as $i_{uv} \in (-1, 0, 1)$, where $u \in (1, S)$, $v \in (1, n_S)$. The information system $I$ has $m = n_1 + n_2 + n_3 + \cdots + n_j + \cdots + n_S$ dimension information composition—the larger the $m$, the more information factors are considered when the subject makes the decision.

The information stock of different EPC subject is concentrated on different knowledge structure, such as ESCO information stock is mainly energy saving technology and EPC. When the subject $k$ not only has $j$ kinds of information stock, but also has other types of information stock, it indicates that the subject $k$ has information redundancy in addition to the $j$ kinds of professional fields. If the maximum dimension $n_s$ is taken as the standard and the stock dimensions of other information category is less than


| Table 1: Division of labor and cooperation of EPC subjects. |
|----------------------------------------------------------|
| Subject | Planning | Design | Management | Construction |
|---------|----------|--------|------------|--------------|
| Owner   | Evaluate the functionality of the scheme | Provide normative standards | Develop incentive policies for project participants | Solve related interference |
| ESCO    | Determine the target range of energy-saving and demand | Propose rational proposal of energy efficiency retrofitting | Audit, optimize and improve construction scheme | Solve uncertainties and monitor processes |
| Subcontractor | Propose rational proposal of energy efficiency retrofitting | Choose goals, develop management strategies | Develop incentive policies for project participants | Optimize construction scheme |
| Supplier | Propose rational proposal of material equipment | Develop incentive policies for project participants | Design and manufacture special equipment and components | Manufacture and transport |

Suppose the willingness intensity of the member subject’s willingness to disseminate information and to accept information. The subject’s willingness to exchange information includes subject spreading information and learning to absorb information, which are unique and compatible. The dissemination effect of information exchange can be quantified by the willingness of the subject to communicate. Each kind of information exchange among the subjects is affected by two factors: one is the path of information dissemination and the other is the willingness of the subject to accept information. The subject’s willingness to exchange information includes the subject’s willingness to disseminate information and to accept it. Suppose the willingness intensity of the member subject is $w_{ij}$, which complement the dimension with 0 at the corresponding position, then the information stock of the member subject $k$ within the category $j$ (that is, category $j$ subjects) can be expressed as matrix form of the $x$ row and $n_x$ column, as shown in Equation (3):

$$I_{uv}^k = \begin{pmatrix}
  i_{11}^{jk} & i_{12}^{jk} & \cdots & i_{1n_x}^{jk} \\
  i_{21}^{jk} & i_{22}^{jk} & \cdots & i_{2n_x}^{jk} \\
  \vdots & \vdots & \ddots & \vdots \\
  i_{x1}^{jk} & i_{x2}^{jk} & \cdots & i_{xn_x}^{jk}
\end{pmatrix}$$

In Equation (3), $u \in (1,x), v \in (1,n_x), x \in (1,S)$, any 1D information stock $I_{uv}^k \in (-1,0,1)$. When $i_{uv}^k = i_{uv}$, it means that the $uv$ dimension information stock of the subject $k$ is matched with the information stock needed for synergistic incentive, i.e. $i_{uv} = 1$. When $i_{uv}^k = -i_{uv}$, it means that the $uv$ dimension information stock of the subject $k$ is not matched with the information stock needed for synergistic incentive, i.e. $i_{uv}^k = -1$. There is no equal relation of the above two kinds, indicating that the subject $k$ lacks the $uv$ dimension information stock, i.e. and $i_{uv}^k = 0$.

Information redundancy in different dimensions can be measured from two perspectives of information redundancy length and information redundancy width. The number of information dimension $i_{uv}$ that the subject $k$ has in addition to the $j$ professional field is called the information redundancy length $L$, as shown in Equation (4). In addition to the $j$ information structure type of the subject $k$, the number of information structure types in other fields is called the information redundancy width $W$, which is expressed by Equation (5):

$$L = \frac{1}{m-n_j} \sum_{x=1}^{x} \sum_{u=1,u\neq j}^{n_x} \sum_{v=1}^{S} |i_{uv}^k|$$

$$W = \frac{\lambda_u}{S-1}$$

The process of synergistic incentive cannot be separated from the information exchange among the subjects. Through mutual learning and communication, the subjects can constantly update their knowledge level, improve their cognitive ability and eliminate the misdirection of wrong information on strategy selection. The effect of information exchange is mainly affected by two factors: one is the path of information dissemination and the other is the willingness of the subject to communicate. Each kind of information corresponds to one or more dissemination paths, which are unique and compatible. The dissemination effect of each path is different, which results in different efficiency of the subject spreading information and learning to absorb information. The subject's willingness to exchange information includes the subject's willingness to disseminate information and to accept it. Suppose the willingness intensity of the member subject $k$ of the
category \( j \) subjects to disseminate their private information is \( \eta_{jk} \), the efficiency of disseminating information of the subject \( k \) is \( \rho_{jk} \), the willingness intensity of any other subject \( z \) in the system organization to receive information is \( \theta_z \) and the conversion rate of learning and absorbing information of the subject \( z \) is \( \omega_z \). The higher the willingness intensity \( \eta_{jk} \) of the subject \( k \) to disseminate information, the more favorable it is to disseminate information to the surrounding subject. And the higher the willingness intensity \( \theta_z \) of the subject \( z \) to receive information, the easier it is to transform and accumulate correct information. The roles of subject \( k \) and subject \( z \) can be randomly transformed, that is, each subject is both the information transmitter and the information receiver.

During the synergistic incentive cycle \( t \), the member \( k \) of the category \( j \) subjects disseminates information \( i_{jk}^{zt} \) to any other subject \( z \). Suppose that the threshold willingness intensity of the subject \( k \) to disseminate information is \( \eta_{jk} \) and the threshold willingness intensity of the subject \( z \) to receive information is \( \theta_z \), when \( \eta_{jk} > \eta_{jk}' \) and \( \theta_z > \theta_z' \), the subject \( k \) disseminates information \( i_{jk}^{zt} \) when \( \eta_{jk} < \eta_{jk}' \), whether the subject \( z \) is willing to accept information or not, the subject \( k \) is unwilling to disseminate information \( i_{jk}^{zt} \) in the \( uv \) dimension. In each synergistic incentive cycle, EPC subjects disseminate and receive information so mutually.

Suppose that the probability of the subject \( k \) hiding information stock is \( q_k \), when the subject \( k \) disseminating information to the subject \( z \) in the cycle \( t \), then the coefficient of the information stock of the \( uv \) dimension that the subject \( z \) received from the subject \( k \) by learning is \( \zeta_{uv}^{zt} \), as shown in Equation (6):

\[
\zeta_{uv}^{zt} = (1 - q_k^{zt}) \times \rho_k^{zt} \times \omega_z^{zt}
\]

When the subject \( k \) disseminates information \( i_{jk}^{zt} \) of the \( uv \) dimension to the subject \( z \), the information dimension is changed under the influence of dissemination willingness of the subject \( k \), as shown in Equation (7):

\[
i_{jk}^{zt} = \begin{pmatrix}
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
\vdots & \vdots & \ddots & \vdots \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt}
\end{pmatrix}
\]

Then the total amount of multi-dimensional information received by the subject \( z \) from the subject \( k \) in the cycle \( t \) is expressed in Equation (8):

\[
i_{uv}^{zt} = \zeta_{uv}^{zt} \times i_{uv}^{zt} = \begin{pmatrix}
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
\vdots & \vdots & \ddots & \vdots \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt} \\
i_{jk1}^{zt} & i_{jk2}^{zt} & \cdots & i_{jn}^{zt}
\end{pmatrix} \times \begin{pmatrix}
\zeta_{uv}^{zt} \\
\zeta_{uv}^{zt} \\
\vdots \\
\zeta_{uv}^{zt} \\
\zeta_{uv}^{zt}
\end{pmatrix}
\]

At this time, the effect of the subject \( k \) disseminating information to the subject \( z \) can be described by Equation (9):

\[
\frac{\hat{jkt}}{I_{uv}} = \begin{cases}
\frac{1}{I_{uv}}, & \eta_{jk} > \eta_{jk}' \text{ and } \theta_z > \theta_z' \\
0, & \eta_{jk} < \eta_{jk}'
\end{cases}
\]

When the pre-stage information loss rate of the subject \( z \) is \( \sigma_z \), and after obtaining information disseminated by the subject \( k \) in the cycle \( t \), the dimension structure of the information stock of the subject \( z \) is changed into the Equation (10):

\[
I_{z}^{t} = I_{z-1}^{t} \times (1 - \sigma_z) + I_{uv}^{zt} \zeta_{uv}^{zt}
\]

Based on the information integration, we can design the synergistic incentive mechanism scheme of EPC subjects. The overall information level of the EPC organization system \( I_{org} \) can be expressed by Equation (11):

\[
I_{org} = \begin{pmatrix}
I_{org1} & I_{org2} & \cdots & I_{orgn} \\
I_{org1} & I_{org2} & \cdots & I_{orgn} \\
\vdots & \vdots & \ddots & \vdots \\
I_{org1} & I_{org2} & \cdots & I_{orgn} \\
I_{org1} & I_{org2} & \cdots & I_{orgn}
\end{pmatrix}
\]

Suppose there are \( N \) subjects with independent decision-making ability in EPC synergistic incentive system. In each synergistic incentive cycle, the information exchange of subjects can promote the update of the information dimension \( \zeta_{uv}^{zt} \) of all subjects, and further promote the overall information level of EPC organization system to a new height. The information \( i_{uv}^{zt} \) on any dimension of the EPC organization system can be expressed by Equation (12):

\[
i_{uv}^{zt} = \begin{cases}
1, & \sum_k = 1^N_k \ z > 0 \text{ and } \sum_k = 1^N_k \ z < 0 \\
0, & \sum_k = 1^N_k \ z = 0 \\
-1, & \sum_k = 1^N_k \ z < 0
\end{cases}
\]

The overall information level of the EPC organization system is the major factor that affects the implementation effect of incentive scheme in each synergistic incentive cycle. Only when the consistency and mutual assistance of the subject’s opinions meets the synergy degree requirement in the design of incentive mechanism, the synergistic incentive mechanism can be carried out in practice and achieve the ideal effect. The integration of the consistency and mutual assistance of the subject’s opinions is called the incentive synergy degree \( H_{uv} \), which is represented by the correct rate of matching the comprehensive information dimension of EPC subjects with the information needed for synergistic incentive, as shown in Equation (13):

\[
H_{uv} = \frac{1}{m} \sum_{u=1}^{S} \sum_{v=1}^{S} \sum_{j=1}^{S} \left| \frac{I_{org}^{j}/I_{uv}}{I_{uv}} \right|
\]
The theoretical research and practical analysis of organizational behavior also prove that the implementation effect of the internal incentive scheme is positively related to the consistency degree of subject’s opinions. Taking $\pi_{uv}$ as the correlation coefficient between decision-making behavior and incentive synergy degree of subjects, the calculation formula of synergy degree $H^T$ of the EPC organization system in life cycle is obtained, as shown in Equation (14):

$$H^T = \pi_{uv}H_{uv}$$

(14)

By designing the questionnaire and using the expert scoring method, the $\pi_{uv}$ value can be determined.

### 3. RELATED HYPOTHESIS AND PARAMETER DESIGN

In view of the above mathematical model, the relevant assumptions and calculation parameters are first designed, and then the mathematical relationship between synergy and incentive is analyzed by computational experiment method and the influence mechanism and evolution law of information on the performance of synergistic incentive of EPC subjects are studied.

#### 3.1. Situational design of information models

According to information master types by the subject, the subject can be divided into three types. These three types of subjects are randomly distributed in the spatial environment of the whole synergistic incentive information platform. There are three ways to exchange and update information among the subjects: first, communicating in the implementation of engineering projects; second, learning from the surrounding high-level subjects; and third, obtaining from the organizational information platform.

According to the description of the information dimension stock of the system subject, each subject has the information vector that dominates his own policy making when making strategy selection and forms the policy-making information dimension space, as shown in Equation (11). This information dimension space can be divided into three areas: area A for recessive private information, area B for professional knowledge information and area C for information of engineering experience. According to the information that the subject is good at using in strategy selection, the EPC subject is divided into three categories: category I subject is good at using information on area A, category II subject is good at using information on area B and category III subject is good at using information on area C. The recessive private information such as fair cognitive psychology is available to every subject, and the subject often relies on this perceptual cognition in strategy choice. In the process of synergistic incentive among subjects, we have to think seriously about the existence of this recessive private information.

According to the concepts of information redundancy width and information redundancy length, this experiment defines the grade of information redundancy width and information redundancy length as follows: if the subject is good at using one area information and the other two areas, the subject has the high grade of information redundancy width; if the subject is good at using one area information and the other area, the subject has the middle grade of information redundancy width; if the subject is only good at using one area information and does not have the information of the other two areas, the subject has the low grade of information redundancy width. If the subject is proficient in applying per-dimension information of each area, the subject has the high grade of information redundancy length; if the subject can master information for more than 60% dimensions of each area, the subject has the middle grade of information redundancy length; if the subject only grasps a few dimension information of each area, the subject has the low grade of information redundancy length.

3.2. Basic parameters setting of information model

Based on the information exchange activities of EPC subjects in the actual engineering background of EPC, this information model analyzes the internal relationship and its evolution between the organizational synergy degree and incentive utility, and finds the key factors and effective ways to design synergistic incentive mechanism. The calculation experiment process includes creating Information-Share project, selecting to create the subject file, defining the structure file KSContext and its sub-environment file SubContext, forming initialization computing environment and defining environment parameter and the xml file of subject behavior pattern, etc. The benchmark parameter settings of the calculate experiment model are shown in Table 2.

### 4. ANALYSIS OF EXPERIMENTAL RESULTS

#### 4.1. The influence of information redundancy length on synergistic incentive effect

Figure 4 shows the influence of information redundancy length on synergistic incentive effect. Figure 4a shows that with the increase of incentive cycle, the longer the information redundancy length, the more unified the opinions among subjects, the more good the synergy degree and the higher the efficiency of synergistic incentive. Figure 4b shows that under benchmark parameters of the model and running environment of the system, with the increase of synergy cycle, the longer the information redundancy length, the faster the incentive utility growth and the higher the efficiency of synergistic incentive. The above results are due to the fact that the more information dimensions that the subject grasp, the better the matching with the information dimensions needed for synergistic incentive, the wider the perspective when participating in decision-making, the less susceptible the subjective emotions and the higher the synergy degree. Generally speaking, the EPC organization system should not only train professionals in the information field that the subject is good at, but also introduce or train interdisciplinary and knowledge innovation talents, in order to increase the information redundancy length and improve the synergistic ability of subjects.
Table 2. Basic parameters of the information model.

| Variable name                      | Valuation | Variable name                      | Valuation | Variable name                      | Valuation |
|------------------------------------|-----------|------------------------------------|-----------|------------------------------------|-----------|
| Subject category                   | 3         | Subject quantity $N$               | 360       | Informational dimensions $m$       | 360       |
| Subject quantity of category 1     | $N/3$     | Subject quantity of category II    | $m/3$     | Subject quantity of category III   | $N/3$     |
| Information dimensions on area A   | $m/3$     | Information dimensions on area B   | $m/3$     | Information dimensions on area C   | $m/3$     |
| Average level of decision-making   | 0.6       | Level of ancillary information 1   | 0.3       | Level of ancillary information 2   | 0.3       |
| The threshold willingness intensity to disseminate information $\eta_{jk}$ | 0.55      | The threshold willingness intensity to receive information $\eta_{z}'$ | 0.5       | Probability that the subject hides information $q_z$ | (0.15,0.3) |
| Information dissemination efficiency $\rho_{jk}$ | 0.65      | Information loss rate $\sigma_z$   | 0.35      | Learning efficiency of the subject $\omega_z$ | (0.1,0.2) |
| Correlation coefficient of the decision $\pi_{uv}$ | (0.8,0.95) | Synergistic incentive cycle $T$ | 300       | Synergy/incentive utility criteria | 1         |

Figure 4. The influence of information redundancy length on synergistic incentive effect.

4.2. The influence of information redundancy width on synergistic incentive effect

Figure 5 shows the influence of information redundancy width on synergistic incentive effect. Figure 5a shows that under benchmark parameters of the model and running environment of the system, with the increase of incentive cycle, the wider the information redundancy width of EPC subjects, the faster the unity speed of opinions and the higher the synergy efficiency. Figure 5b shows that with the increase of synergistic cycle, the wider the information redundancy width of EPC subjects, the faster the rising speed of the incentive utility curve and the higher the incentive efficiency. Therefore, the EPC organization members should not only be familiar with the professional knowledge in the professional field, but also strengthen the learning of cross-disciplinary knowledge in order to increase the information redundancy width of EPC subjects.

4.3. The influence of organization structure of subjects on synergistic incentive effect

By adjusting the ratio of subjects who are good at different types of information in the model parameters, this article analyzes the influence of EPC subject’s structure on synergistic incentive effect. The number ratio of the 3 category subjects is set respectively as 2/3, 1/6, 1/6; 1/2, 1/4, 1/4; and 1/3, 1/3, 1/3. The influence of the subject’s structure of three different proportions on the synergistic incentive utility is shown in Figure 6.

Figure 6a shows the influence evolution of adjusting the number proportion of EPC subjects on the synergistic utility under different incentive cycle. In the early stage of incentive, the more uneven the distribution of the three types of subjects in the synergistic incentive organization system, the faster the increased speed of synergy degree; but with the increase of the incentive cycle, the more uniform the distribution of the three types of subjects, the
earlier the maximum synergy can be achieved. Figure 6b shows that with the increase of the synergistic cycle, the more uneven the proportion of subject’s number, the easier it is to produce the incentive effect quickly; the more uniform the proportion of the subject, the more stable the curve trend in the early stage, but the faster the maximum incentive utility can be obtained in the later stage. It can be seen that under the negotiation mechanism, which the minority is subordinate to the majority, if the number of a certain category of subjects is dominant, it is easy to reach an agreement in the short term, and the efficiency of synergistic incentive in the early stage is higher than circumstances when there are equal numbers of all kinds of subjects.

4.4. The influence of information structure of subjects on synergistic incentive effect

If the other initial parameters remain unchanged, only the number proportion of information dimensions in the regions A, B and C is adjusted respectively to 2/3, 1/6, 1/6; 1/2, 1/4, 1/4; and 1/3, 1/3, 1/3. The influence evolution of adjusting different types of information dimension on the synergistic incentive utility is shown in Figure 7.

As shown in Figure 7a, when the number of information dimensions is focused on a certain area (such as information on area A), the EPC subjects can achieve a higher synergy degree in a short incentive cycle; but with the increase of
Analysis of the information sharing mechanism of the synergistic incentive among EPC subjects of energy efficiency

the incentive cycle, the organization members with uniform distribution of information dimension can reach the highest synergy degree quickly. Figure 7b shows that the worse the distribution uniformity of information dimensions, the easier it is to obtain higher incentive utility in a short synergistic period, while the better the distribution uniformity of information dimensions, the worse the incentive utility in the initial synergistic stage, but the faster the increased speed of incentive utility in the later stage. It can be seen that when the information dimensions needed for synergistic incentive is concentrated in a certain area, it is easy to achieve better synergistic incentive effect in the short term. However, in the long run, the uniform distribution of all kinds of information is conducive to the assimilation of the information level among all kinds of subjects, narrow the knowledge gap between the subjects and shorten the period of reaching the highest synergistic incentive utility.

4.5. The influence of communication path of subjects on synergistic incentive effect

Figure 8a shows that the wider the information communication path, the higher the incentive utility under the same synergy cycle. Figure 8b shows that the wider the information communication path among subjects, the higher the synergy degree can be obtained in a shorter incentive cycle. It is easy to know that the higher the synergistic effect, the better the incentive utility. Obviously, establishing a good information exchange platform and increasing the information communication path can optimize the information exchange environment and the willingness of the members to exchange information, and speed up the unity of opinions among subjects. It is an indispensable link in the design of synergistic incentive mechanism.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the information integration platform of EPC subjects, this paper designs the synergistic incentive model, simulates the synergistic incentive process among subjects by using the calculation experiment method and analyzes the influence of related factors on the synergistic incentive effect. The results show that increasing the information redundancy length and the information redundancy width can improve the synergy degree and incentive validity. Changing the proportion of subjects in different information areas and adjusting the uniformity of different types of information dimensions can affect the effectiveness of synergistic incentive, increase the path of information communication, improve the efficiency of information dissemination and promote rapid agreement of opinions among subjects.

However, under the background of the global fight against COVID-19 epidemic, the information exchange modes of people-intensive contact form such as group meetings, live exchanges, banquet and so on are restricted and the information communication path becomes narrower, which affects the information exchange efficiency and reduces the synergistic incentive validity among EPC subjects. To overcome the influence of COVID-19 epidemic situation on synergistic incentive among EPC subjects, this paper proposes the following strategies based on the experimental results of the above synergistic incentive model:

(1) Innovate the information exchange models adapted to the COVID-19 epidemic situation

Social media is becoming major sources of customer information and prime channels of communication [26]; increasingly firms are looking to use social media to connect with different stakeholders [27]. The Internet platform represented by social media has opened up a new perspective of information exchange.
Figure 8. The influence of communication path of subjects on synergistic incentive effect.

and cooperation [28, 29] and also created an interaction dimension among subjects [30], which can make up for the information exchange deficiencies brought about by the epidemic situation of COVID-19 to a certain extent. But the potential information asymmetry of social media can appear as information noise such as negative word-of-mouth [31] and the lack of sharing mechanism of recessive information [32], which can easily induce the moral hazard of EPC subjects. Overall, the function of the Internet platform needs to be supplemented and optimized: in the course of information exchange such as teleconferencing and network interaction, audio and video recording materials can be produced for verification; the multi-subject synchronous face-to-face communication based on multi-dimensional visualization information platform of Building Information Modeling is used to filter information noise and realize non-destructive transmission of information; and the key links of EPC implementation process can also be simulated by VC (Virtual construction) technology to replace field management.

(2) Establish the multi-subject information communication mechanism

For the purpose of eliminating the trust crisis and moral hazard among EPC subjects due to information asymmetry, the following measures can be taken: establishing information communication channels for EPC subjects and encouraging the subject to actively provide raw data and quality management information; inducing the subject to work together in the form of group cooperation to promote the establishment of information feedback system among ESCO?owner and other subjects. At the same time, the information communication should be in compliance with the laws and regulations, be true and effective, and be individual responsibility for the division of labor, and make clear provisions on the contents, forms and management responsibilities of the information communication.

(3) Construct the credit evaluation system of EPC subjects

With regard to the trust crisis and breach contract among subjects due to information asymmetry during the implementation of the EPC project, it is necessary to establish the credit evaluation mechanism of EPC subjects to form a good credit environment, which can be used to supervise and standardize the fidelity of information communication. Further, it is easy to establish the information-sharing mechanism with the attribute of ‘win-win, trustful and timely’ in the EPC organization system, so as to improve the decision-making efficiency of subjects, promote EPC subjects to transform from the decision-making mode of maximizing its own interests to the decision-making mode of maximizing the overall benefit of the project and drive EPC subjects to form the alliance of income-sharing and win-win cooperation. In addition, the paper has some limitations. First, due to the need of epidemic prevention and control, face-to-face communication of the population is limited, which leads to the relative inconvenience of collecting on-site communication data resources. Second, this study only considers the information exchange between EPC subjects, not the information influence transmitted by the external environment. Third, the computational model only considers the situation of one party’s subject transmitting information and the other party’s learning and has not yet considered the two-way information transmission of both sides and even multiple parties, which needs to be further discussed.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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