Computers & Industrial Engineering 120 (2018) 179–191

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

A governance platform for multi-project management in shipyards

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ARTICLE INFO

Keywords:
Shipbuilding
Multi-project management
Case-based reasoning
Decision-making support
Access control

ABSTRACT

Efficient multiple project management is very important to the project-based industries. Current multi-project studies in shipbuilding focus on designing mathematical models and heuristic algorithms to achieve optimal resource usage. However, due to the rigid requirements on complete information, these models are inapt to support decisions in the early stages (such as the project biding stage) that have been acknowledged more and more critical in the ever fierce market. On the other hand, although pieces of information management software have been developed for project management and production, there are works left to be manually executed, such as production prediction of a new project and control of the temporary system access delegated to business partners, hindering further improvements in work efficiency. To bridge these gaps, this paper innovatively proposes a governance platform architecture based on the theory of Governance of Projects. The framework views organization management as important as project management and adopts a new access control method which helps reduce the manual labor. Moreover, a case-based reasoning algorithm that supports planning prediction with limited information is designed. Finally, a prototype system is developed and tested in a shipyard in China. It proves to be both effective and efficient.

1. Introduction

Shipbuilding industry, characterized by the ETO (Engineering-to-Order) production mode, is typically a project-based industry (Zhang et al., 2012). To compete in the ever fierce market, shipbuilding companies are demanded to be competent to conduct several projects at the same time (Ahola & Davies, 2012). Generally, a shipbuilding project is very large and complex (Han et al., 2017). The number of activities can reach up to ten thousand and cross-working is common in shipyards. Since key resources (such as docks, quays and so forth) are finite and have a direct impact on the final project makespan, it is a primary issue to achieve continuous production with minimum project delay in the multi-project context. Meanwhile, considering risks brought by the high budget and the long period of a shipbuilding project, managers always tend to get a more precise prediction and estimation of a new project to bid.

Majority of current multi-project studies in shipbuilding focus on designing mathematical models and heuristic algorithms to solve the Resource Constrained Project Scheduling Problem (RCPSP) (Han, Yang, & Gong, 2010; Li, Hu, Lv, & Sun, 2013a, 2013b). Zhang et al. (2012) extends the RCPSP model with budget constraints and develops an optimization engine on top of Microsoft Project Server. However, rigid requirements on full information make these models inapt to support decisions in the early stages (such as the project biding stage). Boer (1998) develops a decision support system for shipyards to plan and schedule multi-projects. Although RCCP (Rough Cut Capacity Planning) function is provided in the order acceptance phase, the system still subjects to the input acquisition (a large number of process planning data) difficulties. Hans, Herroelen, Leus, and Wullink (2007) proposes a hierarchical project planning framework where flexible usage of planning methods is favored. Nonetheless, the research does not develop any practical tools.

Some researchers indicate that planning is a knowledge-intensive work and introduce case-based reasoning (CBR) method in process planning (Cho, Lee, & Chung, 1996; Qu, Jiang, & Tao, 2013; Seo, Sheen, & Kim, 2007) as well as in work structure decomposition (Li, Mao, & Zhang, 2017) for shipbuilding projects. It is noticeable that a whole plan of a potential project cannot be generated by these studies, let alone a balanced result based on the current production status (Loaggui, Lu, and Xu (1987) develops a network-planning aid system for multi-shipbuilding production. The system can support rapid project duration estimation of a new project on condition that the process

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https://doi.org/10.1016/j.cie.2018.04.026
Received 13 December 2017; Accepted 14 April 2018
Available online 23 April 2018
0360-8352/

sequence is known. In other words, decision makers have to acquire the process sequence of a new project by other tools (or manually). To conclude, there is a lack of an automatic tool to predict production for decision makers in the biding stage of a shipbuilding project.

On the other hand, more and more information management systems have been particularly developed for ship manufacturers to well manage their resource, project schedule, production cost and suppliers. Although such systems prove to be effective in their perspective domains, workers complain that sometimes they need to use several systems to complete one business workflow. It can be time-consuming and error-prone. Integration usage that follows the practical business process is on urge demand. Song, Woo, and Shin (2011) defines a standard shipbuilding production management system for shipyards to achieve high agility and flexibility. This system integrates main functional modules (planning & scheduling, material management, quality management and so forth) to work as a whole. However, no light is shed upon the system interfaces for partners to get appropriate information at the right time. This is obviously not good for shipyards to promote the cooperation with outer organizations. Besides, most project management information systems only adopt the role and the department as the access control criteria. It is much less convenient for the dynamic organization structure of a project, especially in the domain of shipbuilding where multi-tier suppliers and subcontractors are involved. The authority control can be very tedious in practice. To the best knowledge of the authors, no practical efforts have been put on dealing with this issue. This is partially because that when designing a project management system, organization management attracts less attention in contrast to scheduling management and other business management.

This paper attempts to design a novel governance platform for shipyards to better manage their multiple projects. The aim of the governance platform is threefold. Firstly, the system can integrate with most existing management software in shipyards and serve as a consistent computer-aided tool for business workflows. Secondly, the system can provide a stronger organization management that satisfies the increasing demand on seamless cross-enterprise cooperation. In this aspect, dynamic information access control for multi-organizations should be achieved with less manual work. Moreover, the platform can support decision makers with the planning prediction of a new project in the project biding stage, but merely requests a minimum set of data input. All these features will make this paper unique among peer studies.

The rest of this paper is arranged as follows. Section 2 examines closely to the multi-project management theory with a special attention on temporary organization management for multiple heterogeneous enterprises. Research on case-based reasoning applied in project planning is also analyzed. Section 3 designs organization and resource models necessary to realize the computer-aided Governance of Project (GoP). By this way, a unified representation of the organization, the resource, the process and the project is formed. Based on that, a conceptual framework is introduced, clarifying the structure as well as the operation processes. In Section 4, a planning and scheduling prediction algorithm for a wait-to-bid project is proposed .For implementation, Section 5 develops a prototype system of GoP platform and an application is given to show the benefit of GoP platform. Section 5 concludes this paper with limitations and future work.

2. Literature review

2.1. Multiple project management

In regard to multiple project management, a number of studies have been conducted in mechanism development and instruction innovation. Portfolio management and project governance (PG) are the two most prevalent multi-project management theory (Too & Weaver, 2014). The former is featured by clustering projects in terms of business strategy and market significance, highly depending on experts for its practical use. Even if the clustering process is computer-aided, a large proportion of manual work is still requested. The latter, defined by the Project Management Institute (PMI) as “an oversight function that is aligned with the organization’s governance model and that encompasses the project life cycle by providing a comprehensive consistent method of controlling project” (PMI, 2013), is a significant area of the corporate governance related to project activities. It is the management of project management with clear layers in the organization structure (Too & Weaver, 2014), ranging from the highest board directors to the project manager. To better understand PG and its technical core, some researchers established that there are two distinctive categories: external to any specific project (EXA) and internal to one individual project (INO) (Ahola, Ruuska, Artto, & Kujala, 2014). The idea of applying PG on offshore platform projects origins the research conducted by Ahola and Davies (2012). However, the research does not describe the framework or application manners.

In recent years, the notion of Governance of Project (GoP) has gained attention from both the academic society and the industrial enterprises. To some extent, GoP embraces the aforementioned two kinds of PG and deals with multi-projects in goals of multi-participators. It aims at the global strategic achievements rather than the local ones. Comparison between PG and GoP is presented in Table 1.

A conceptual GoP framework illuminated in Too and Weaver (2014) consists of the strategy system (the parent organization level), the executive system (the portfolio level), and the delivery system (the project level). The latter is again divided into the project management level and the workshop level (also the task level), respectively. All governance layers (the parent organization level, the portfolio level, the project level, and the task level) take responsibilities for the overall Project-based Organization (PBO). The strategy system is charged by the board of directors while the executive system is dominated by senior managers (Müller, Zhai, Wang, & Shao, 2016). The delivery system is proposed for fixed goals to deliver products in a concrete time. Serving as a critical link between the strategy and the executive system, the project sponsor is undertaken by either the project manager from the manufacturer or the project leader from the project owner. Its aim is to balance the benefits between the owner and the manufacturer. Another important role in GoP is Project Management Office (PMO) which connects the organizational governance with the governance of a specific project. The principal responsibility of PMO is to provide the executors (mainly senior managers in executive system) with accurate information about the current state and the near-future trends of all

Table 1
Comparison between PG and GoP (Ahola et al., 2014).

Category	Features	Key approaches	Object	
PG	EXA	(1). Unidirectional relationships (2). Flexibility in the choice of methods and processes	Define polices, institutions and the authority	Individual projects
	INO	(1). Bidirectional relationships (2). Flexibility in the choice of methods and processes	Establish a set of rules, procedures and shared practices	All participates firms in the project
GoP		(1). Heterogeneous types of projects, and inter-organizational relationships (2). Flexibility in organization structures	Execution across the interfaces of project, program, portfolio, as well as boundaries of organizations	Groups of projects and all stakeholders

conducting projects (Too & Weaver, 2014). Additionally, it provides consulting experience, project management knowledge as well as technical information to the individual project management team, thereby improving the overall project management capabilities (Aubry, Hobbs, & Thuillier, 2007). As regard to practical application, the GoP structure and its running emphasis may vary in line with the specific industry context (Ruuska, Ahola, Artto, Locatelli, & Mauro, 2011). Networked organization, the emphasized relationships and the self-regulation mechanism are potential key factors to the better performance of large multi-firm projects (Ruuska et al., 2011).

2.2. Case-based reasoning in project planning

Case-based reasoning is a method adapting old experience to new problems (Kolodner, 1992). It is a rather effective way when there is not too much detail information about the new problem. The decision on whether to bid a new project is of great importance due to its profound effects on day-to-day enterprise operations. A short project period in prediction can easily incur project tardiness and cost overruns. On the contrary, a long makespan will impair the competitiveness in biding. It is difficult to use planning tools (like Gantt chart, critical chain etc.) to make accurate plan predictions when there is no detail design data. Jin, Han, Hyun, and Cha (2016) designs a CBR model to estimate construction project duration at the initial stage. The model consists of four processes. Namely, case retrieval, case reuse, case modification and case retain. To improve the satisfaction level of different managers, the model adopts standard coefficient for weights calculation of different parameters. Further, regressive interpolation method is applied to counteract the dismatch between the new project and the selected case in case modification stage. Wang, Jing, Wang, and Han (2013) selects material, structure, category and shape as the four features to distinguish a project in the planning case base and proposes a new plan generation strategy, combining CBR with model based approach. If no similar case is picked out from the case base, users can choose a generalized model instead. Li et al. (2017) proposes a hybrid method of CBR and artificial neural network to automatically generate the work breakdown structure of a new project. Fifteen attributes including contract category, cost estimation, project priority, product type and so forth are selected as model inputs. However, no details are given on the construction of case base or the calculation of similarity degree.

Based on deterministic production design information, CBR has been widely used on process planning. Lin et al. (2011) develops a multi-level case-based computer-aided process planning system. It utilizes tree structure to organize processes and allows users to interactively retrieve and revise the process case. Regarding the discrete manufacturing feature of shipbuilding, Cho et al. (1996) views block type and block structure as the similarity measurement in retrieving assembly process cases. Through careful analysis of block structure, Seo et al. (2007) takes main part type, connection number and combined connection relationship as the elements to calculate similarity of block assembly plan. Qu et al. (2013)) further extends the set of matching attributes with part count, liaison count and degree of freedom of the relation. Additionally, this research designs a genetic algorithm to evaluate the similar process plan alternatives, which is conducive for the decision-maker to select the least labor consumption assembly process plan.

Yang and Hu (2012) applies knowledge management theory to help shipbuilding companies realize a fine-grained and automatic management of planning. The outcome is a knowledge-based planning control system that supports autogeneration of the shipbuilding master plan. For retrieval in the knowledge base, the ship type and main dimensions are necessary input.

A major drawback of CBR method is that the similarity result cannot reflect activity sequence differences in different projects. To this point, a method of multi-knowledge-sources network planning assisted generation is proposed in Long (2014). At first, CBR is used to retrieve similar project plans and then knowledge rules of entity spatial relations, production functions and construction methods are used to check the activity logic sequence. The method has been applied in generating plans for the large-scale hydraulic and hydropower projects.

3. Architecture of GoP platform

3.1. Key information models necessary to realize computer-aided GoP

Based on the analysis above, three aspects are considered to be essential for the achievement of the computer-aided GoP: the governance structure, the governance process and the governance mechanisms, respectively. The governance structure deals with the complexity brought by the multi-organizations in shipbuilding projects. As regard to the governance process, special attention is called on how to realize and guarantee continue production across several projects. Governance mechanisms cover policies, working guidance etc. in order to resolve conflicts raised in the first two aspects. To work as the computer assistance, the mechanisms need to be represented in certain digital forms, such as workflow instances, knowledge files and algorithms. Through combination of several concrete mechanisms, the function of decision-making support can be achieved.

3.1.1. Models of organization and resource

Networked organization and relationship management are important to GoP performance (Ruuska et al., 2011). This paper proposes a multi-level multi-role PBO model (shown in the left side in Fig. 1) with the assignment of authority, accountability, risk and responsibility (AARR) into consideration. One organization in the PBO metric can access any resources in the realm of its AARRs.

Definition 1. A multi-level multi-role PBO is a networked organization in which the relationship of different roles and levels jointly affect the AARR partition for business activities. The PBO is defined by:

$$PBO: :=\langle \mathscr{L},\mathscr{R},\mathscr{O},\mathscr{S}^{\mathscr{R}},\mathscr{S}^{\mathscr{O}},\mathscr{F}(\mathscr{S}^{\mathscr{R}}\otimes\ \mathscr{S}^{\mathscr{O}})\rangle$$

where $\mathscr{L}$ is the general governance layer which ranges from the highest parent organization to the lowest task executor. $\mathscr{R}$ is the role and $\mathscr{O}::=\langle Company,Department,Interest\rangle$ is the independent organization inserted in the PBO. $\mathscr{S}^{\mathscr{R}}=\mathscr{R}\times\mathscr{R}$ is role relationship space. $\mathscr{S}^{\mathscr{O}}=\mathscr{O}\times\mathscr{O}$ is organizational relationship space. $\mathscr{F}\sim\mathscr{S}^{\mathscr{R}}\otimes\ \mathscr{S}^{\mathscr{O}}\rightarrow AARR_{\langle R,O\rangle}$ is the mapping function between the organization units and AARR. Here $\times$ and $\otimes$ represent the multi-attribute calculation of union and intersection, respectively.

Definition 2. $\mathscr{S}^{\mathscr{O}}_{a\rightarrow b}$ is the organizational relation between two organization units $\mathscr{O}_a$ and $\mathscr{O}_b$.

$$\mathscr{S}^{\mathscr{O}}_{a\rightarrow b}=\mathscr{O}_a\times\mathscr{O}_b=Cr^{p}_{a\rightarrow b}\vee Dr^{c}_{a\rightarrow b}\vee\mathscr{L}^{\mathscr{O}}_{a\rightarrow b},\mathscr{O}_a\in C_a,\mathscr{O}_b\in C_b,\mathscr{O}_a\neq\mathscr{O}_b$$

in which $Cr^{p}_{a\rightarrow b}$ indicates the company relationship between company C_a and company C_b under project p and $Cr^{p}_{a\rightarrow b}=\varnothing,\ if\ C_a=C_b$, additionally, $Cr^{p}_{a\rightarrow b}\neq Cr^{p}_{b\rightarrow a}$ which means that the company relationship has a direction; $Dr^{c}_{a\rightarrow b}$ represents the department relationship of $\mathscr{O}_a$ and $\mathscr{O}_b$. inside of the company c and $Dr^{c}_{a\rightarrow b}=\varnothing,\ if\ C_a\neq C_b$; $\mathscr{L}^{\mathscr{O}}_{a\rightarrow b}$ stands for the matrix relationship of $\mathscr{O}_a$ and $\mathscr{O}_b$ in the PBO, and if $\mathscr{O}_a$ and $\mathscr{O}_b$ are in the same level and play the same role, then only one of the two relation types that may occur: cooperative or none. Otherwise, $\mathscr{L}^{\mathscr{O}}_{a\rightarrow b}=\varnothing$.

Definition 3. AARRs are imposed on the organization for performing concrete business activities in a certain time.

$$\mathrm{AARR}_{\langle\mathscr{R},\mathscr{O}\rangle}=\begin{cases}Au,\mathscr{Q}(Au),\mathscr{P}(Au)\\Ac,\mathscr{Q}(Ac),\mathscr{P}(Ac)\\Rg,\mathscr{Q}(Rg),\mathscr{P}(Rg)\\Rs,\mathscr{Q}(Rs),\mathscr{P}(Rs)\end{cases}$$

where $\mathscr{Q}(X)$ is the mapping function $X\rightarrow resource$, $\mathscr{P}(X)$ is the

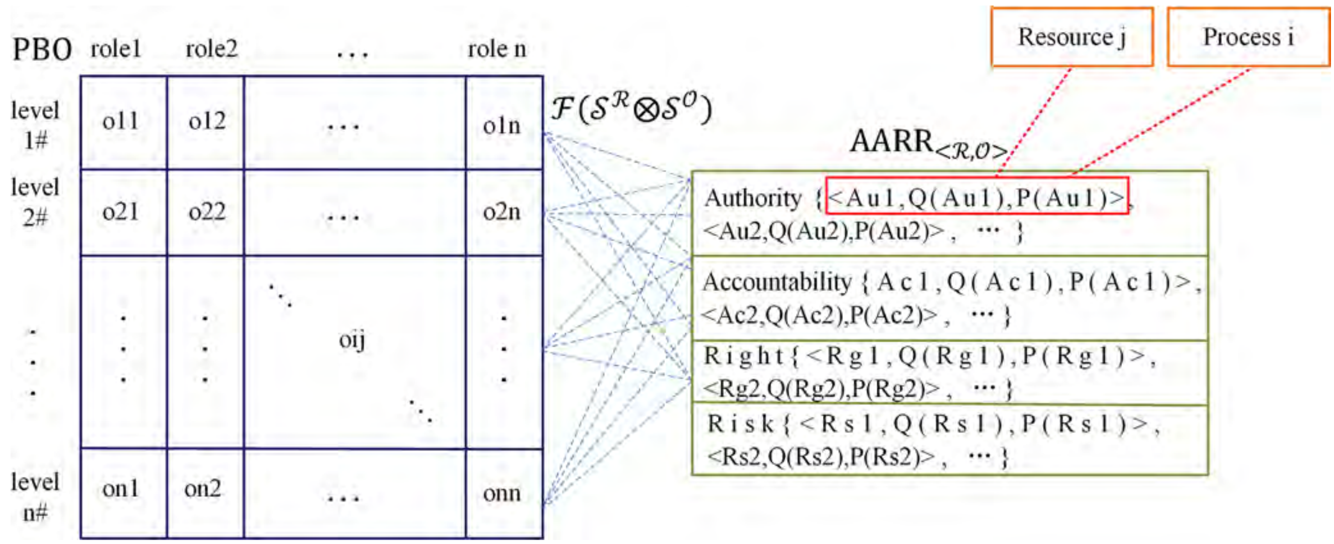

Fig. 1. Organization model of GoP for ETO companies.

mapping function $X \rightarrow process$ respectively. This is shown in the right side of Fig. 1.

To achieve a coordinated production and supply pace in a shipbuilding project, a unified resource representation among the project organization is necessary. Business integration methods through ontology have been developed in recent year (Chen & Chen, 2014; Lv, Ni, Zhou, & Chen, 2016). To this point, the first step for resource control is to organize resources provided by different companies. The resource mapping is proposed as:

$$\mathscr{M}: Re_o \rightarrow Re'_{o'}$$

among which Re_o represents the resource ontology of non-leading companies (here indicating the partner companies) and $Re'_{o'}$ represents the merged resource ontology with the leading company (the shipbuilding company). $Re'_{o'}$ will be used as a basis for project planning and scheduling.

To restrict the governance scope, this paper defines two major categories and six upper classes of $Re'_{o'}$ (shown in Fig. 2). In the physical resource category, there are manufacture resource, material resource, intelligent resource, and data acquire resource. The manufacture resource consist of semi-finished products, equipment and facilities, and working sites (such as workshops, factories, and gantry cranes etc). The material resource include the general raw materials that can be procured in large batches, for instance steel panels, flanges, welding consumables and so on. Particularly, the material resource contains the purchased equipment to be assembled on the final product (e.g. mud gas separator), functional systems (e.g. hydraulic oil system) and outfitting sets. The intelligent resource refers to experts, technicians, highly-trained managers and experienced workers. The data acquire resource are those tools for monitoring, facilitating and tracing work.

In the virtual resource category, there are knowledge resource and software API resource. Knowledge resource can be accumulated and transferred as the project proceeds (Chen & Chen, 2014). Moreover, it will accelerate business processes. Project cases, product design knowledge and project plan templates are in this class. This resource class has been recognized as a critical factor for enterprises' competence in the market. Software API resource allows computer intelligent units (e.g. agents) to call the services. It is worthy to note that access control lists of each software are managed through this resource class.

Definition 4. A concrete resource Re after integration can be described as:

$$Re ::= \langle reid, hr_{Re'_{o'}}, recat, recap, restate, timetable_{re} \rangle$$

where $reid$ is the identifier of a concrete resource after merging. $hr_{Re'_{o'}}$ is the resource hierarchical location in $Re'_{o'}$, $hr_{Re'_{o'}} = (depth, width)$. $recat$ is the resource class listed above. $recap$ is the resource capability, if the resource is a working site, then the capability represents the parameters and conditions of the site. $restate$ is the resource state, if the resource is usable, then the $restate$ equals 1 else $restate$ is 0. $timetable_{re}$ is the resource usage records without project borders. The unique resource ontology tree provides a basis for assigning rights and authorities to specific organizations.

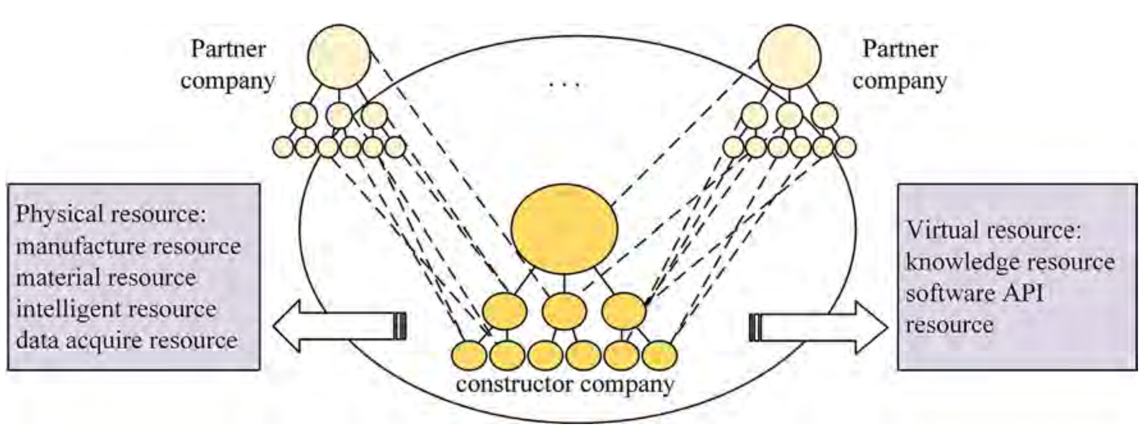

Fig. 2. Resource model of GoP for ETO companies.

3.1.2. Models of process and project

To address the complicated processes of multiple projects in shipbuilding enterprises, this paper defines the task and the activity as the control unit of the governance processes.

Definition 5. A task is the planned work inside a specific project. Serving as the basic control unit in GoP, a task is represented by

$$Task: := \langle tsid, objectivetsk, inputstsk, outputstsk, [pretsk, sectsk], [plnt, acut] \rangle$$

where *tsid* is the identifier of a particular task, including the task serial number, task name and task description; *objectivetsk* is the predetermined outcomes by doing the task in the anticipated way; *inputstsk* is the indispensable resources and information enacting a task, including goals and demands on quality and pre-arranged organizations. *outputstsk* is the outcomes of a task, such as byproducts, quality checklists and material consumption tables. *pretsk* is a container of predecessor tasks in plan. *sectsk* is a container of successor tasks in plan. *plnt* is the vector of planned time information, comprising of the earliest/latest begin time, the earliest/latest end time, and time buffer for resilience. *acut* is the vector of actual execution time information, comprising of actual begin time, suspending period, and actual end time.

Definition 6. an activity is an optimal collection of tasks from several projects. The collection criteria could be the best or the rational use of resources. An activity is by no means limited to the manufacturing activity.

$$Activity: := \langle acid, input_{act}, outputact, precon, astate, criteria \rangle$$

where *acid* is the auto-generated identifier of a concrete activity; $input_{act}$ and *outputact* are the sum of inputs and outputs of tasks in an activity, respectively. *precon* is a set of events enacting the activity. *astate* is the activity status and *criteria* is a set of collection rules.

Project-centric is one of the common characteristics of ETO companies. Business processes, the inventory level and diversity, as well as the infrastructure and equipment arrangements are determined by the nature of a project. For example, a project for building an inland passenger ship requires the company to revise a peer design and to procure a large amount of accommodation outfitting pieces. While if the project is to manufacture a chemical carrier, the production company has to arrange special workflows for consistent quality checks. Furthermore, since some procured goods require excessively strict conserved environment, special storage sites and processing workshops, as well as crafts and equipment, are needed. In this regard, projects aiming at different kinds of products exert a great influence on the daily operation of ETO enterprises. Thus, this paper comes up with a project information model as blow.

Definition 7. A project is described by its contract, product, and the production resource features.

$$p: := \langle pjid, contractp, productp, refeaturep, pstate \rangle$$

among which *pjid* is the identification number of a project; *contractp* is the information describing the owner, the project period and the management mode; *productp* is the information set of product models, such as structure-oriented product models, geometry-oriented product models, feature-oriented product models, and knowledge-oriented product models (Zhang & Zhang, 1995); *refeaturep* is a set of distinctive resource features to produce the wanted product. *pstate* is the project state.

Based on the project information model, projects are likely to be clustered by one or some of the features. On one hand, clusters will help the machine learn tacit rules from the plan and resource arrangement. When there is a potential project to bid, the machine can rapidly simulate the production plan. On another hand, an enterprise can identify the most profitable or skilled product types and then assign the priority to each kind of business. The common clustering way is similarity calculation through BOM (Bill of Materials) (Jiao, Zhang, Pokharel, & He, 2007) or product structure (Cho et al., 1996; Qu et al., 2013; Seo et al., 2007). Consider that the constructor enterprise has m project clusters with j projects. It can be represented as

$$Epcluster: := [Cluster_1(p_{11},...,p_{1t}),...,Cluster_m(p_{m1},...,p_{mt})]$$

where $Cluster_i$ denotes the ith project cluster and p_{it} indicates the tth project in $Cluster_i$. Let np_i represent the size of $Cluster_i$, then $\sum_1^m np_i$ equals j. For each $Cluster_i$, additional information is stored as:

$$Cluster_i: \langle clsid, Strategy, Goal, \preceq S_p, \preceq G_p \rangle$$

among which *clsid* is the identifier of a project cluster; $\preceq$ is a strictly partially ordered relation, showing the breakdown structure (*Strategy*,*Goal*). This model is conducive to recommending portfolios.

3.1.3. Model of GoP mechanisms

GoP mechanisms in this research are defined as:

$$GoPMec: := \langle negotiationMec | resolutionMec | evaluationMec | rewardMec \rangle$$

among which *negotiationMec* is a set of problem solving mechanisms designed for the multi-agents (organizations or workers) decision making process. It defines the way how agents cooperate with each other. *resolutionMec* is a container of methods and solutions to the problem encountered during the multi-project execution. Examples are gathering *task* s from different projects to form an *activity*, rescheduling with abnormal works and so forth. Rules (including CBR similarity calculation rules, business workflow rules, inference rules etc.) are stored in *resolutionMec*. *evaluationMec* saves methods to evaluate suppliers' performance, partners' contribution as well as the projects' performance. *rewardMec* serves as a stimulus buffer for organizations to improve work performance. Mechanisms in *rewardMec* can be used to simulate a virtual working condition, such as increasing the price in one bid round, adding extra man hours and so on.

3.2. Conceptual framework of GoP platform

While the information models provide a basis to achieve computer-aided GoP, it is still insufficient for the companies to take advantage of them directly. To offer as much computer assistance as possible, a dynamic planning and control framework was developed to mediate complexities and uncertainties between the strategic and the operational project management (Sang, Peña-Mora, & Park, 2006). It consists of four embedded functional layers (from inner to outer): the strategic core utilizes system dynamics to catch changes; the tactic layer of Multi-agent System (MAS) provides the dynamic adjustment capability; the operational layer supports business analysis in the help of network-based tools and simulation methods, and the interface layer employs visual techniques to enhance human-machine interaction. Even though the structure is not suitable to the wanted GoP platform (particularly to the function of flexible information access control), it enlightens the present study to a certain point. At the first place, this study does not intend to develop more new yet functional redundant systems from scratch, rather it attempts to make full use of existing ones. Service Oriented Architecture (SOA), a software design mode in which services are provided and used through a communication protocol over the network, seems very competent (Linthicum, 2016). In this sense, the existing management software and computer-aided tools can be regarded as virtual resources and called through interfaces or standard files. Thus, as shown in Fig. 3, the proposed conceptual framework of GoP platform is comprised of four layers: the strategic layer, the governance processing layer, the operation tool layer and the interface tool layer, respectively.

3.2.1. The strategic layer

The strategic layer leverages workflow modeling tools and

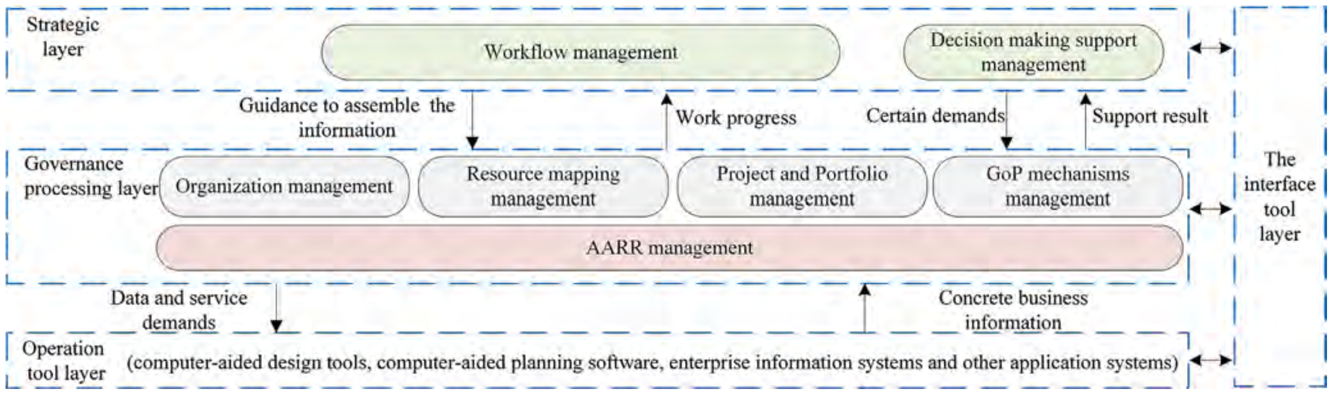

Fig. 3. Conceptual framework of GoP platform.

encompasses decision-making support components. In the light of Sang et al. (2006), the application of system dynamics allows users to analyze business from a dynamic viewpoint. Thus, arrangements and adjustments of organizations in cooperation processes can be captured and modeled. Further, the captured information will be delivered to the governance processing layer where the extended information, represented using GoP information models (proposed in Section 3.1), would be assembled or altered accordingly. For instance, workflow definitions will be converted into a series of rules and then stored in *GoPMec* in the governance processing layer. According to these rules, time information of *task* in plan and relationships in *PBO* will be assembled to support AARR setting. As a result, workers from the outer organization can access the corresponding inner system information within certain time limits. Another critical function of this layer is to support managers to make decisions. Through the decision making support component, managers define clear needs, select GoP mechanisms, and get the integrated support information provided by the governance processing layer. When there is a complex decision-making support need, it is allowed to make the composition of several GoP mechanisms.

3.2.2. The governance processing layer

The governance processing layer carries the information models designed above. Three primary purposes of this layer are stated as follows. Firstly, it mediates complexity and dynamics from the upper strategic layer and provides data analysis as well as data mining services to the upper level. Secondly, it collects, converts and integrates data from different software in the lower level regardless of the organizational borders. Last but not least, it helps automatically assign the information permission of software in the operation tool layer to the dynamic organization. Specifically, inference on *PBO* and plan prediction of a project is conducted in this layer.

3.2.3. The operation tool layer

The operation tool layer consists of computer-aided design tools, computer-aided planning software, and other enterprise information systems. In this paper, these digital systems are regarded as well-packed services with unified interfaces and standard service description files. The functions and workflows inside an individual system will not be changed, but the information access control rules (as one kind of software API resource) is delivered to the governance processing layer

3.2.4. The interface tool layer

The interface tool layer is a vertical layer spanning the above ones. It is responsible for facilitating and enhancing communication between the different layers by means of graphical tools and visual techniques. Additionally, through this layer, scattered working data will flow in GoP platform and business information will flow out and be displayed to instruct the detail work operations. Sensors, robots and interrogators are classified in this layer.

3.3. Governance process on GoP platform

Another critical issue is to design the system workflow to practically realize the GoP platform. In the authors' view, guidance should be presented stepwise for the users. However, due to the length of this paper, only key processes in the whole governance workflow are considered and shown in Fig. 4. Detail procedures are illustrated as follows.

3.3.1. Process 1: decision-making support for biding a project from planning prediction perspective

At the first place, basic project information (including the duration, the estimated start time and the product category) and product parameters are required. If there are no project clusters (portfolio) at hand, managers need to input (or select) a project cluster algorithm in order to generate project clusters. Otherwise, the user needs to initialize a similarity calculation algorithm and set the parameters' value. If there is not a proper algorithm, the user is required to create a new one in the GoP platform. CBR process is conducted to find similar cases for the potential project. The project plan can be obtained and be refined in the scheduling simulation. Consequently, managers can get a detail production plan prediction which is beneficial to make decisions on the bid. Since this process is a vital point of this research, a three-step planning prediction algorithm is further explained in Section 4.

3.3.2. Process 2: Resource merging and AARR assignment

After signing the contract, the resource merging and AARR assignment process begins. Firstly, the project team inside the shipbuilding company is organized and then the resource ontology and the *PBO* are settled. If a supplier/subcontractor is signed in, his resource ontology will be merged with the present one (the ontology mapping and merging methods proposed in Lv et al. (2016) are used in this research), and the *PBO* will be updated too. Following that, *PBO* relationship inference is conducted and the AARR information will be updated in accordance. The latter also needs workflow definitions as initial conditions. An example of the inference process is given in Section 4.2.

3.3.3. Process 3: multi-projects scheduling

Going through the first two processes, the new project is located in a portfolio with organization and resource arrangement settled. Moreover, the project plan is adapted to the practical production status. In this process, changes and disturbances during the project execution is further considered. The multi-projects scheduling algorithms (Han et al., 2010; Li et al., 2013a, 2013b) are stored in the form of *resolutionMec* in the proposed GoP platform. As the GoP platform provides a loose coupling architecture, users can select anyone of these algorithms and adapt it to their certain scheduling problem.

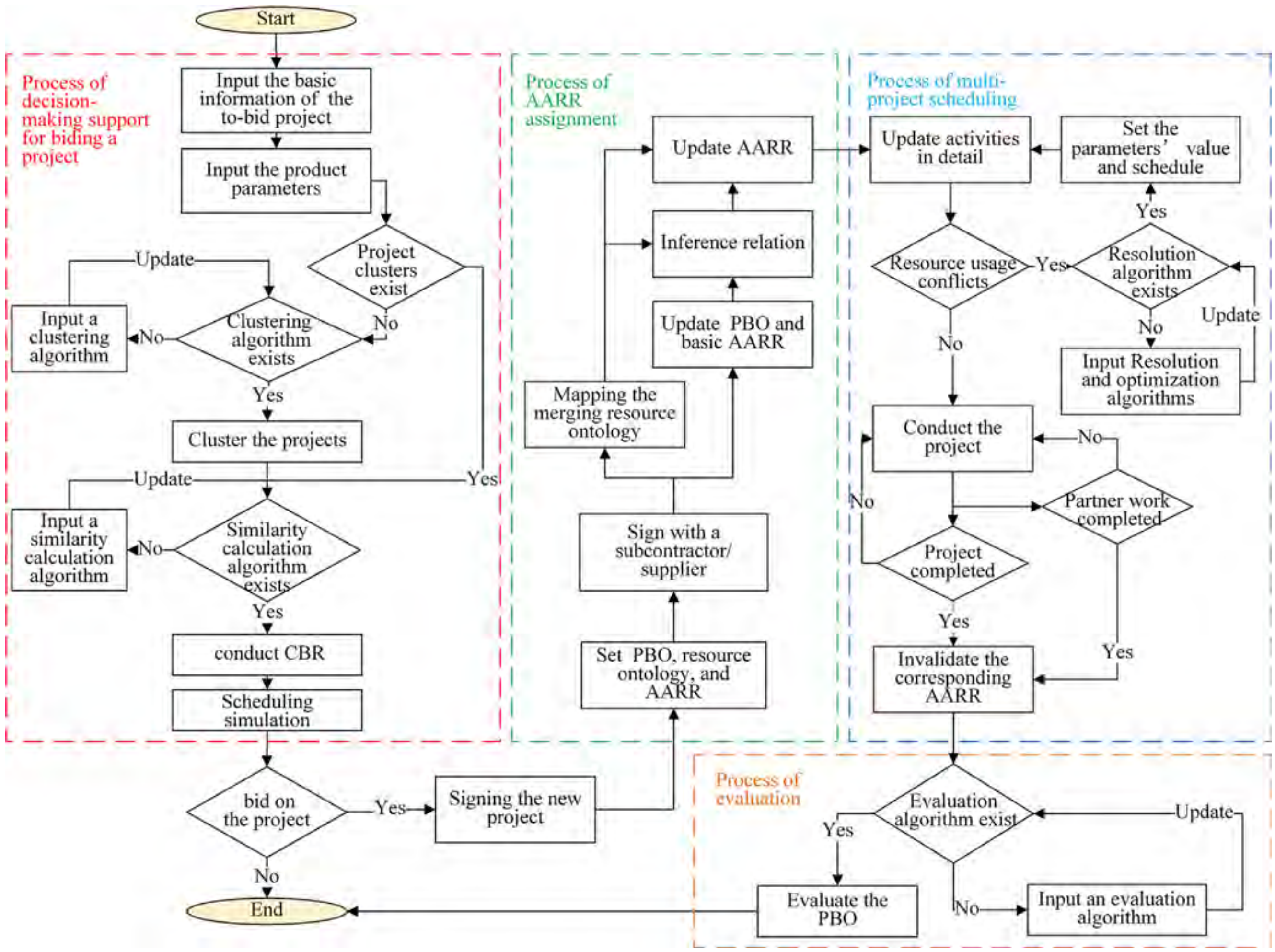

Fig. 4. Four key governance processes of the GoP platform.

3.3.4. *Process 4: partner and project work evaluation*

If the project (or a partner's work) is completed, the corresponding AARR are invalidated in the GoP platform. Then, the evaluation of project performance (or the partner' performance) begins. If there is an evaluation algorithm for the certain purpose, the user just need to set the parameters' value and trigger the system to get results. Otherwise, the user must create a new evaluation algorithm.

4. A CBR-based planning prediction algorithm

Based on the information models proposed in Section 3.1, a three-step planning prediction algorithm for a wait-to-bid project is designed in this section. The three steps are:

- Retrieve a similar project from the project base
- Acquire the plan of the similar project and reason the new project plan
- Rearrange the new project plan with resource constraints considered

Table 2 lists the variables in the proposed algorithm and Table 3 shows the pseudocode.

In the first step, similarity measurement has a great influence on the result of case retrieval. In general, the similarity degree between case A and case B is calculated by

$$sim_{AB} = \sum_{i=1}^{n} w_i \times sim(f_i^A, f_i^B) \tag{1}$$

Table 2
Variable definition.

Variable	Definition and description
dr_{ij}	Similar degree between p_{ij} and p_{new}
$degree_i\langle p_{ij}, dr_{ij}\rangle$	Vector for calculation results of $Cluster_i$
$tsp\langle p_{ij}, dr_{ij}\rangle$	Vector for the highest dr_{ij} record in each $degree_i$
tv	Similarity threshold value
$crr\langle p_{ij}, [\ reid, timetable_{re}\ ]\rangle$	Resource records of uncompleted projects
$tpp\langle p_{ij}, dr_{ij}, [\ task\ ]\rangle$	Final template project plan
$reOccCon\langle reid, p_{ij}, [timetable_{re}\ ]\rangle$	Predicted resource occupation conflicts
$stim\_pl\ \langle[\ task\ ], [reid, timetable_{re}\ ]\rangle$	Stimulated project plan

w_i is the weight of the ith feature and usually set by experts. $f_i^X = (x_1, x_2, \ldots, x_j, \ldots, x_m)$ is the ith feature of case X (A or B) and x_j is the j th attribute value in this feature. $sim(f_i^A, f_i^B)$ is the feature similarity and n is the total number of features. To calculate $sim(f_i^A, f_i^B)$, methods vary in accordance with the data type of a feature. In the context of this research, contract type, product geometry parameters, resource occupation features and so forth in Definition 7 can be selected as the similarity measure. Thus, two data types might be involved, including the number type and the enumeration type. Based on the previous research (Qu et al., 2013; Zhang, Wang, & Wang, 2016), this paper proposes a feature similarity calculation method as blow.

Table 3
algorithm pseudocode.

```
INPUT: p_new, tv;
OUTPUT: tpp, reOccCon, stim_pl
//find the most similar project in each cluster, acquire resource plans
FOR i = 1: m
  FOR each p_ij in Cluster_i
    calculate the dr_ij;
    IF dr_ij > tv
      degree_i.add (p_ij, dr_ij);
    IF pstate_ij is "not completed"
      crr.add(p_ij, queried resource plan and usage records);
  END
  degree_i.sortFromHighToLow();
  tsp.add(degree_i.getFirstOne());
END
//find the template plan and make modification
tsp.sortFromHighToLow();
tpp.add(tsp. getFirstOne(), queried plan in the form of task);
reason plnt of each task in tpp;
attach the reasoned plnt to inputstsk of each task
//simulate the production
extract timetable_re of each resource from crr
reOccCon.add(resource occupation conflicts);
invoke a RCPSP solving algorithm
stim_pl.add(the result);
RETURN tpp, reOccCon, stim_pl
```

$$sim(f_i^A, f_i^B) = \begin{cases} 1-\frac{1}{m}\times\sqrt{\sum_{j=1}^{m}\frac{(x_j^A-x_j^B)^2}{(x_j^{max}-x_j^{min})^2}} & f_i \text{ is number type} \\ \frac{Num(f_i^A\cap f_i^B)}{Num(f_i^A\cup f_i^B)} & f_i \text{ is enumeration type} \end{cases} \quad (2)$$

It can be seen that for the number type, the calculation relies on the distance, indicating how differences the values are, but for the other type it depends on the count of same elements in two cases. So, if f_i^X has both types in its attributes, the similarity calculation is suggested by

$$sim(f_i^A, f_i^B) = 1-\frac{1}{m}\times\left(\sqrt{\sum_{j=1}^{m-k}\frac{(x_j^A-x_j^B)^2}{(x_j^{max}-x_j^{min})^2}} + \sum_{j=1}^{k}\left(1-\frac{Num(x_j^A\cap x_j^B)}{Num(x_j^A\cup x_j^B)}\right)\right) \quad (3)$$

among which k is the number of attributes of the enumeration type and $k \leqslant m$.

On top of the retrieved case, the project plan can be obtained from the database and regarded as a template. It is necessary to make modifications to adapt to the new project p_{new}. Because of a lack of detail information in the biding stage, this paper presumes that task sequences remain the same and only the time attribute of each task needs modification. More specifically, for each task in the template, the duration is multiplied with a proportion $period^{new}/period^{case}$. If the modified duration is not an integer, the value needs round down (up) if the task is allocated in the front (second) half of the template plan. Then use the estimated release date of p_{new} and $period^{new}$ to refresh the plan. Table 3 a planning prediction algorithm for a potential project. Since step 2 provides a predicted project plan, the resource usage for p_{new} can be also predicted so that resource conflicts can be examined. In this research, two kinds of conflicts are considered: one is the overlapping occupation of the key spatial resources (e.g. dock and slipway) (Boer, 1998) and the other is overuse of renewable resources (e.g. man hours) than the regular capacity (include the subtract capacity and work overtime in the template in this context). At this stage, we presume that only tasks on the critical path of accepted projects will not be changed. Thus, a $task_j^{new}$ of p_{new} that provokes the first kind of conflicts might be rearranged before or after the resource downtime. A mathematical model to resolve the conflict is established as:

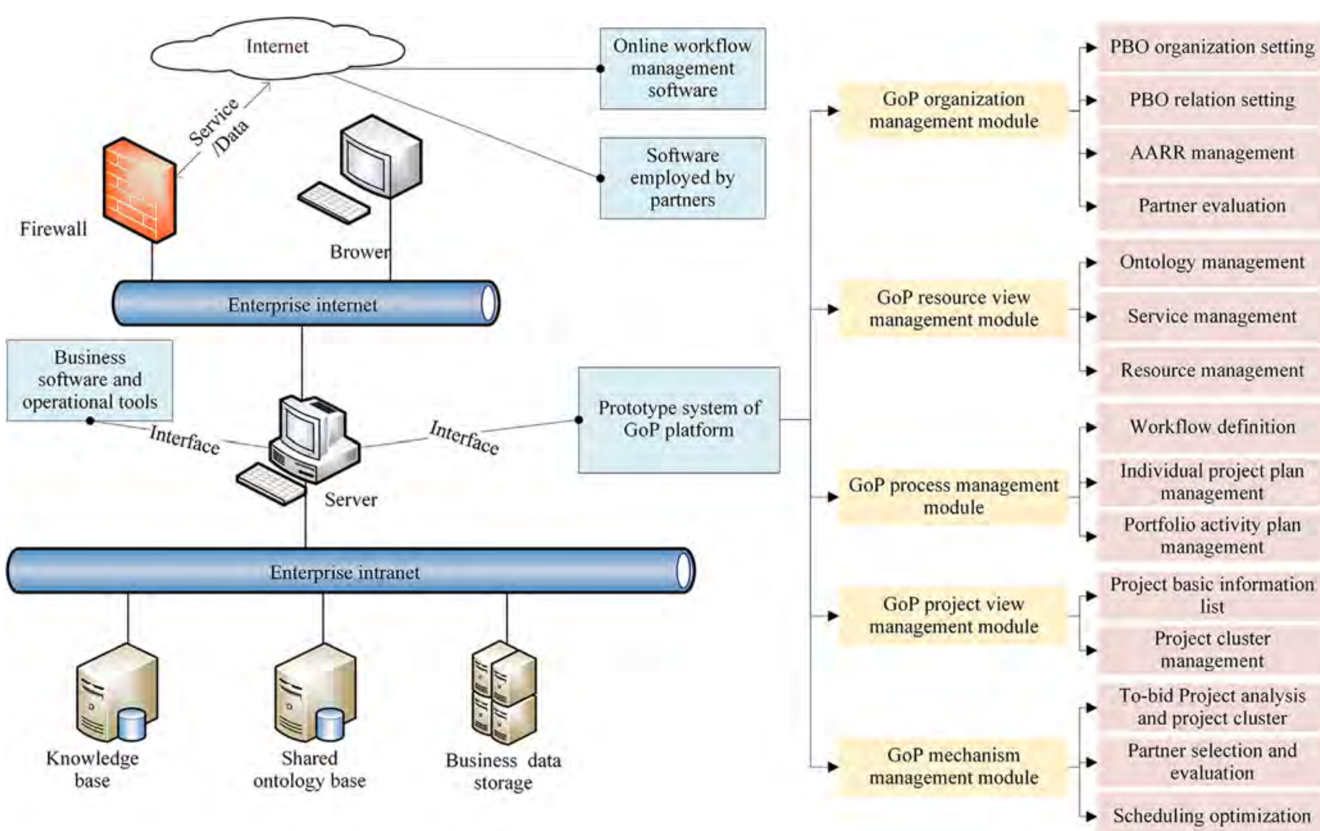

Fig. 5. Hardware structure and function structural tree.

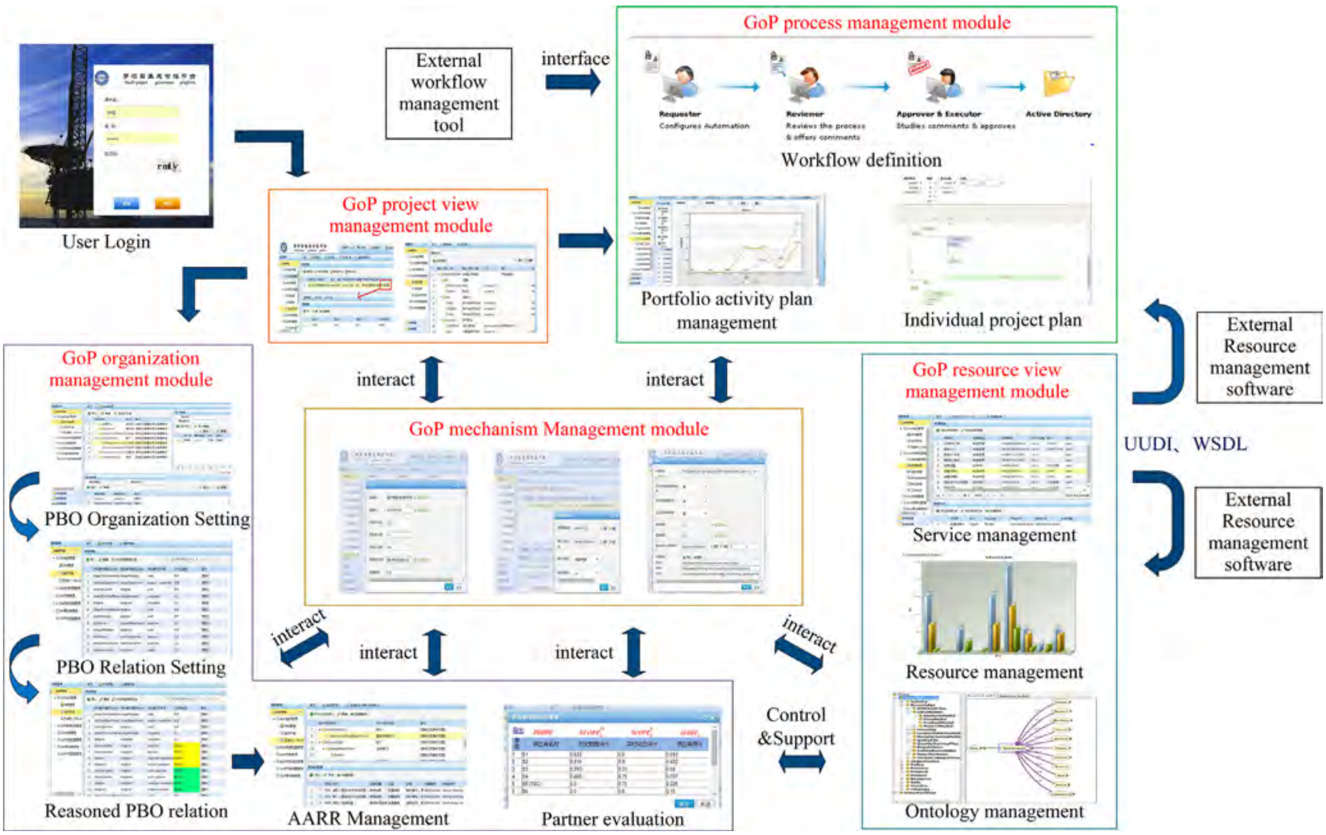

Fig. 6. Interface and interaction process of the prototype system.

Table 4
Project information.

Project	Shape L× B× D (m^3)	Function working depth (m)	Period (year)	State
EC00515	70.0 × 68.0 × 9.5; Triangle	121.9	2.75	Completed
HJ00134	101.0 × 110.0 × 30.0; Rectangle	175.0	3	In progress
EC00516	80.9 × 87.6 × 11.0; Triangle	130.0	2.5	In progress
PP_20180401	70.36 × 76.0 × 9.45; Triangle	122.6	2.5	Wait to bid
Project	Process technique			
EC00515	High-strength steel; Non-destructive Testing(NDT); graving dock construction			
HJ00134	Ultrahigh-strength steel Non-destructive Testing(NDT); slideway construction			
EC00516	High-strength steel; Non-destructive Testing(NDT); graving dock construction			
PP_20180401	Ultrahigh-strength steel Non-destructive Testing(NDT); graving dock construction			

$$minimize \sum_{j=1}^{N} |C_j - d_j|$$

$$\text{s.b.} \sum_{j=1}^{N} q_{jk}^{s} \times x_{jt} \leqslant Q_{kt}^{s} \quad (4)$$

$$|C_j - d_j| = 0, j \in \{J_{critical} - J_{critical}^{new}\} \quad (5)$$

$$\sum_{t=r_j}^{T} x_{jt} = 1 \quad (6)$$

$$x_{jt} = \begin{cases} 1, & if\ task_j\ is\ scheduled\ during\ time\ period\ of\ t \\ 0, & otherwise \end{cases} \quad (7)$$

The target function is to minimize the change of present multi-project plans. C_j is the task completion date and d_j is the due date. N is the total number of all uncompleted tasks. q_{jk}^{s} represents the resource capacity $task_j$ needs. Constraint (4) ensures that spatial resources are not required more than the capacity. Constraint (5) guarantees that tasks on the critical path of accepted projects is not rescheduled. Constraint (6) and (7) enforce that a task is done in the time horizon. Based on this result, RCPSP solving algorithms (Han et al., 2010; Li et al., 2013a, 2013b) can be applied to resolve the second kind of conflicts. A detail discussion of RCPSP is not the focus of this paper, and interested readers are referred to these references. As a result, a refined plan prediction based on the practical production status is obtained.5 Implementation and validation

4.1. Prototype system of GoP platform

Using open source Spring framework, Java Agent Development Framework (JADE) 4.3.3 and Oracle 11 g, a prototype system that adopts browser/server mode has been developed and deployed in a marine engineering corporation in China mainland. Fig. 5 describes the hardware architecture and the function structural tree. Workflow management software is integrated from the internet through services, and the operational tools are integrated by interfaces. There are five major functional modules: GoP organization management module, GoP resource view management module, GoP process management module, GoP project view management module and GoP mechanism management module, respectively. Interfaces and interaction processes of the prototype system are shown in Fig. 6.

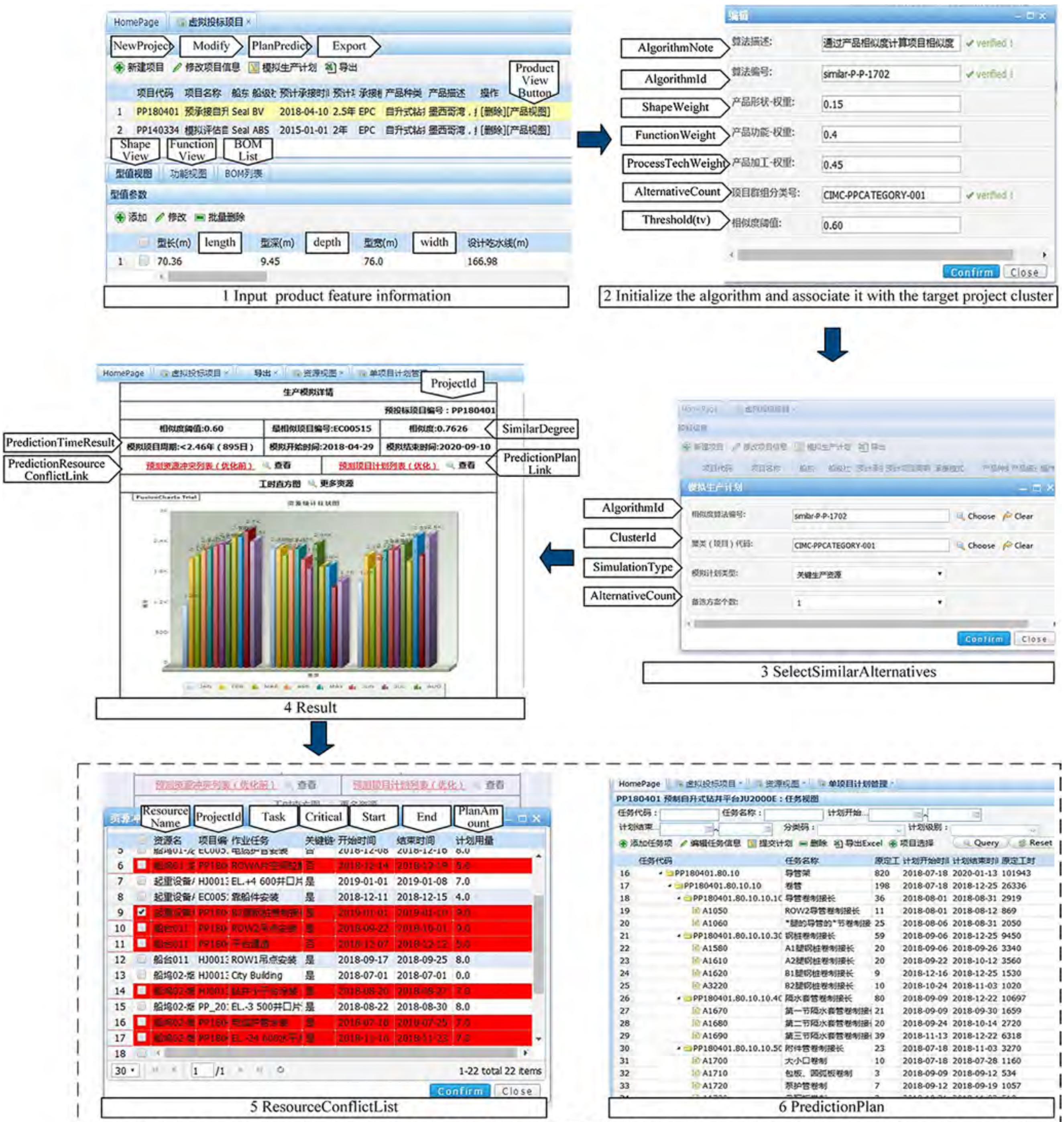

Fig. 7. Screenshots of process 1 planning prediction of a potential project.

Table 5
The similarity values.

Project Cases	EC00515	HJ00134	EC00516
Similarity value	0.7626	0.2819	0.7026

4.2. Application and results

The marine engineering corporation intended to bid a jack-up platform project (*pjid*: PP180401). There was only one project portfolio (*clsid*: CIMC-PPCATEGORY-001) with three jack-up platform projects. The project information is listed in Table 4. To analyze how the new project will affect the work arrangement and the resource use, the manager turned to the GoP platform. In this case, shape, function and process technique were chosen as the similarity measure and the weight was set to 0.15, 0.4, 0.45 respectively, as the expert recommended. This initialized algorithm was labeled by “similar-P-P-1702”. The number of alternative cases was set to 1, indicating that only the most similar case would be chosen. The project scheduling simulation type was set to “the balance use of key resources”. Fig. 7 shows screenshots of the planning prediction process in the system.

Using the Eqs. (1)–(3), similarity values between the new project and the cases are calculated, the results are listed in Table 5. It shows that the biggest similarity degree is 0.7626 and one of the others is less than the threshold value (0.60). Thus the most similar project (*pjid*: EC00515) is selected. To illustrate the similarity calculation method,

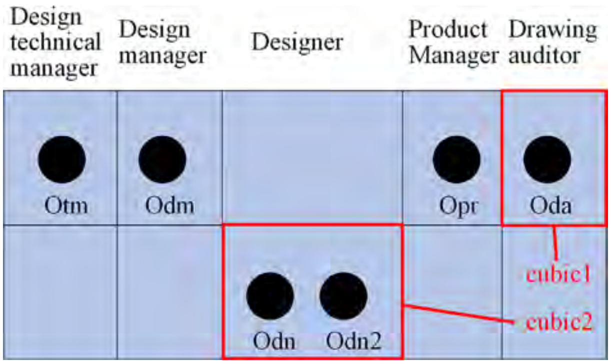

Fig. 8. An example of organization model.

Table 6
Attributes and relationships of the *PBO* segment.

Attribute	Value					
C	C_a	C_a	C_a	C_b	C_b	C_c
$\mathscr{R}$	$\mathscr{R}_{tm}$	$\mathscr{R}_{dm}$	$\mathscr{R}_{dn}$	$\mathscr{R}_{dn}$	$\mathscr{R}_{pr}$	$\mathscr{R}_{da}$
D	D_{a1}	D_{a2}	D_{a2}	D_{b1}	D_{b1}	D_{c1}
Cr^p	$Cr^p_{a\to b}$: *supervise*, $Cr^p_{b\to a}$: *supply*, $Cr^p_{c\to a}$: *supervise*, $Cr^p_{c\to b}$: *approve*					
Dr^c	$Dr^{C_a}_{a1\to a2}$: *support*					
$\mathscr{L}^{\mathscr{O}}$	$\mathscr{L}^{\mathscr{O}}_{dn1\to dn2}$: *cooperate*					
$\mathscr{S}^{\mathscr{R}}$	$\mathscr{R}_{tm}\times\mathscr{R}_{dn}$: *audit*, $\mathscr{R}_{dm}\times\mathscr{R}_{dn}$: *audit*, $\mathscr{R}_{tm}\times\mathscr{R}_{dm}$: *assist*, $\mathscr{R}_{pr}\times\mathscr{R}_{dn}$: *audit*, $\mathscr{R}_{da}\times\mathscr{R}_{dn}$: *audit*					

Note: D_{a1} and D_{b1} are Technical Department, D_{a2} is Design Department and D_{c1} is Drawing-Auditing Department

the calculation between EC00515 and PP_20180401 is presented. The feature similarity values of $sim(shape^A, shape^B)$, $sim(function^A, fucntion^B)$ and $sim(processTech^A, processTech^B)$ and the case similarity value (sim_{AB}) are obtained by:

$$sim(shape^A, shape^B) = 1-\frac{1}{4}\times\left(\sqrt{\frac{(70.36-70.0)^2}{(101.0-70.0)^2}+\frac{(76.0-68.0)^2}{(110.0-68.0)^2}+\frac{(9.45-9.5)^2}{(30.0-9.5)^2}} + \left(1-\frac{Num(\text{Triangle}\cap\text{Triangle})}{Num(\text{Triangle}\cup\text{Triangle})}\right)\right) = 1-\frac{1}{4}\times(0.1908+0) = 0.9523$$

$$sim(function^A, fucntion^B) = 1-\sqrt{\frac{(122.6-121.9)^2}{(175.0-121.9)^2}} = 0.9868$$

$$sim(processTech^A, processTech^B) = \frac{Num(\text{Non-destructive Testing(NDT);graving dock construction})}{Num(\text{high strength steel;ultrahigh strength steel;Non destructive Testing(NDT);graving dock construction})} = 0.5$$

$$sim_{AB} = 0.15\times sim(shape^A, shape^B) + 0.4\times sim(function^A, fucntion^B) + 0.45\times sim(processTech^A, processTech^B) = 0.7626$$

The bottom left of Fig. 7 shows the resource conflicts that occur before the predicted plan is optimized. For the simulation type of "the balance use of key resources", the corresponding RCPSP algorithm is the one proposed in Li et al. (2013a). The refined plan is shown in the bottom right of Fig. 7 and its man-hour bar chart during the new project period is given in the middle left of Fig. 7.

Once the project is signed, there begins the process of ontology integration, organization setting and information access allocation. The users set the *PBO* structure and its basic relationships. For simplicity and typicality, take the machinery design process as an example and the fragment of *PBO* is depicted in Fig. 8. Five roles and three companies involved are Design Technical Manager ($\mathscr{R}_{tm}$), Design Manager ($\mathscr{R}_{dm}$), Designer ($\mathscr{R}_{dn}$), Product Manager ($\mathscr{R}_{pr}$), and Drawing Auditor ($\mathscr{R}_{da}$), a ship owner company (C_c), a machinery vendor company C_b, and the shipyard (C_a). Organizational information based on the proposed organization model is listed in Table 6.

Based on ***Definition 2***, $\mathscr{S}^{\mathscr{O}}$ can be reasoned. For instance, $\mathscr{S}^{\mathscr{O}}_{da\to dn1}$ is obtained by:

$$\mathscr{S}^{\mathscr{O}}_{da\to dn1} = Cr^p_{c\to a}\vee Dr^{cc}_{da\to dn1}\vee\mathscr{L}^{\mathscr{O}}_{da\to dn1} = supervise\vee\varnothing\vee\varnothing = supervise$$

In the same way, $\mathscr{S}^{\mathscr{O}}_{da\to dn2} = approve$ can be acquired. Further, $\mathscr{S}^{\mathscr{R}}\otimes\mathscr{S}^{\mathscr{O}}$ are: $\mathscr{S}^{\mathscr{R}}_{da\to dn1}\otimes\mathscr{S}^{\mathscr{O}}_{da\to dn1}$: $audit\wedge supervise$, $\mathscr{S}^{\mathscr{R}}_{da\to dn2}\otimes\mathscr{S}^{\mathscr{O}}_{da\to dn2}$: $audit\wedge approve$ A workflow in this case is the collaborative design of the spud leg with a raw water lift submersible pump inside (spanning 35 days in the predicted plan). An API resource in C_a is a self-developed engineering management system (abbreviated to SEMS). In C_b, it is a drawing management system (abbreviated to DMS). The authority are "read only", "read", "write", "modify", "delete", "apply", "respond" and the combinations. *audit* is associated with the authority of "read", "write" and "respond" to the certain API resource (for example, the review page in SEMS or DMS). *supervise* is associated with the authority of "read only" to the API resource (for example, the engineering schedule page in SEMS or DMS). *approve* is associated with the authority of "read" and "respond" to the API resource (for example, the review page in SEMS or DMS). Thus a person in the role of $\mathscr{R}_{da}$ has the "read", "write" and "respond" access to the review page in SEMS and "read only" access to the engineering schedule page in SEMS during the 35 days. Additionally, he has the "read", and "respond" authority to DMS within the period.

The bottom-left corner of Fig. 6 shows $\mathscr{S}^{\mathscr{O}}$, $\mathscr{S}^{\mathscr{R}}\otimes\mathscr{S}^{\mathscr{O}}$, $AARR_{\langle\mathscr{R},\mathscr{O}\rangle}$ in the GoP platform and inference parts of $\mathscr{S}^{\mathscr{O}}$ and $\mathscr{S}^{\mathscr{R}}\otimes\mathscr{S}^{\mathscr{O}}$ are colored by yellow and green respectively. One advantage is that these relationships are quite general and relatively constant for the enterprise cooperation in a shipbuilding project. In other words, the information structure need little revisions for new organizations.

Once the partner completes its work or the project is finished, the corresponding AARR set will be automatically invalidated. A user can conduct the performance evaluation through selecting and initializing the evaluation algorithm stored in GoP mechanism module. At present,

Table 7
Time consumption and the number of used software comparison.

Condition	Work		
	System access setting	New project prediction	Machinery supplier performance evaluation
Without GoP platform	Average 13 min, 1 system (engineering management system)	Average 95 min, 4 systems (P6, enterprise standard file management system, work balance simulation system and Microsoft Excel)	Average 90 min, 3 systems (ERP, MES and Microsoft Excel)
With GoP platform	Average 7 min	Average 14 min	Average 12 min

Note: the recorded time includes necessary time to change software and input data. The "system access setting" only records the authority assignment work for users in the design process.

Table 8
Correctness of access assignment.

	Access assignment				Total	
	Right	Wrong	Missing	Additional	With GoP	Without GoP
Count	185	1	18	20	208	206
Rate (%)	90.78	0.49	8.74	9.71	100.97	100

an adapted Analytic Hierarchy Process method, designed in one of our serial studies, is deployed to evaluate a machinery supplier's performance. Due to the scope of this paper, details are not presented but the running result is shown in the bottom middle of Fig. 6.

4.3. Evaluation

We did the same work under two conditions (with and without the help of the GoP platform) in the marine engineering corporation and then recorded the time consumption. Comparison in work efficiency is shown in Table 7. It can be seen that there is an obvious decrease in working time. Reasons for time reduction in "new project prediction" and "machinery supplier performance evaluation" reside in the integrated data, the redesigned workflow and the new established algorithms. In contrast, time decreases in "system access setting" are caused by delegation of repetitive work to the computer. Consider that current *PBO* involves n_c enterprises, n_r roles and n_l organization units in each layer. Obviously, $0 \leqslant n_l \leqslant n_c$. The number of software pages at present is N and each page contains n_e functional permissions. A new member organization unit $\mathscr{O}$ registers M pages in the software API resource. Each page has n_m functional permissions. We use x_j to represent the share status of each functional permission, $x_j = 1$ represents "share", otherwise $x_j = 0$. Then using previous methods, the worker need to operate $\sum_1^N \sum_1^{n_e} x_j$ times to share the present functional permissions to $\mathscr{O}$ and $n_r \times \sum_1^M \sum_1^{n_m} x_j$ times to entitle the present *PBO* to access $\mathscr{O}$'s registered API resource. Let s_1, s_2 denote the manual operation count of the previous method and this research, respectively. Then $s_1 = \sum_1^N \sum_1^{n_e} x_j + n_r \times \sum_1^M \sum_1^{n_m} x_j$ and $s_2 = 2 \times \sum_1^{n_c} x_c + n_l + n_r$. At best, $s_1 = 1 + n_r$ and $s_2 = 2 + n_r$. But as the cooperation among enterprises goes deeper, information share demands will significantly increase, so s_1 will grow rather faster than s_2.

To evaluate the effectiveness, we further compared the access assignment results under these two conditions. Again, for simplicity but typicality, the example of the machinery design process is used. Table A.1 lists the result and Table 8 gives the statistics. The right rate amounts to 90.78% and only one access (0.49%) is incorrectly assigned. However, about 9% access was not attached to the *PBO* and around 10% system permissions were additionally offered. By asking three experts in the company, 9 out of these 20 additional permissions were distinguished as useful results. The right additional permissions to some extent help to reduce the fault that are caused by workers' limited experience. The rest additional permissions concentrate on C_b roles' authority to the review page in SEMS, with 3 functions wrongly opened to each role and 6 functions in total, reaching 54.55% in this category.

5. Conclusions

Effective multiple project management is a vital issue to shipbuilding companies. The information management systems built so far are inapt in this context because of limitations in the underlying theory and some missing functions. Governance of Projects (GoP) is an advanced multi-project management theory that controls either multiple organizations or multiple projects. Thus, this paper tried to develop a GoP platform for shipbuilding companies to manage multi-projects with as little as possible manual work. Particularly, three concrete goals, namely a framework to utilize existing information management software as a whole, automatic information access assignment and the production prediction of a potential project were achieved by the proposed platform. The proposed methods and the developed prototype system add both academic and application value to this study.

However, this research also has limitations. Firstly, it is limited to shipbuilding companies in China which are subjected to inconsistent computer aids for multi-project management. Applications in other industries are certainly required to test the effectiveness and efficiency of this work. Besides, more attention is required on the middleware selection to integrate the four conceptual layers. For efficiency and accuracy improvements, the proposed CBR-based algorithm needs further revision, especially when there is a large number of projects in the case base. In this regard, how to make full use of the project cluster to reduce the search space is a direction. The present project cluster method is merely based on the product, so more cluster criterion could be designed and tested for improvements. Another weakness is that *PBO* reasoning in the GoP platform now can only deal with clear and simple organization relationships. Judging from the evaluation section, it can be seen that the total false rate reaches 14% in one design process. So, special design of more complex inference rules and development of a more strong inference engine is worthy of research efforts. Considerations should also be taken into the way to employ more GoP mechanisms in the GoP platform.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Acknowledgement

This research was funded by Ministry of Industry and Information Technology of the People's Republic of China [grant numbers 2012545] and National Natural Science Foundation of China [grant numbers 51679059].The authors would like to acknowledge the support of Wang Ning from Yantai CIMC RAFFLES Offshore Limited for technical feedback.

Appendix A.

See Table A.1

Table A1
Number of system access assigned to different roles under two conditions.

		C_a								C_c		C_b			
		$\mathscr{R}_{dm}$		$\mathscr{R}_{dpm}$		$\mathscr{R}_{tm}$		$\mathscr{R}_{dn}$		$\mathscr{R}_{da}$		$\mathscr{R}_{pr}$		$\mathscr{R}_{dn}$	
		M	G	M	G	M	G	M	G	M	G	M	G	M	G
SEMS	Technical file page	6	6	6	6	6	6	4	4	1	1	4	3	1	3
	Drawing view page	3	3	3	3	5	5	6	6	2	4	2	3	2	4
	Engineering schedule page	4	4	4	4	3	3	4	4	1	1	3	3	3	3
	Review page	5	5	5	5	5	5	4	4	4	4	**0**	**3**	**0**	**3**
DMS	Technical file page	3	4	4	4	4	1	2	2	2	2	7	7	7	7
	Drawing view page	3	4	3	4	3	1	2	2	1	4	7	7	7	7
	Engineering schedule page	2	1	2	1	2	1	1	1	2	2	5	5	6	6
	Review page	3	1	3	1	3	1	1	1	1	2	4	4	4	4
	Certificate view page	2	1	2	1	2	1	2	2	2	2	3	3	3	3
Total		31	29	32	29	33	24	26	26	16	22	35	38	33	40

NOTE: M represents the condition without the GoP platform, and G represents the condition with the GoP platform

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