Research on project portfolio selection of maritime search and rescue system-of-systems construction based on dominance and multi-domain relationship

Wangchi Cheng¹, Shuhui Zhen¹ and Jin Wang*¹
¹Institute of Logistics Science and Technology, Beijing, 100166, China
*Corresponding author’s e-mail: wangjilst@163.com

Abstract. Project portfolio includes numerous projects and there are interactions and dependencies between projects. To overcome the shortcomings of traditional project portfolio evaluation methods, this paper proposes a project priority ranking method based on complex network theory and PageRank algorithm. This paper firstly analyses the dominance relationships among projects based on the establishment of evaluation criteria for projects; furthermore, deliverable-to-project multi-domain matrix (MDM) is established to measure the dependency relationship between projects based on design structure matrix (DSM). Considering the dominance and dependency of projects, this paper constructs a priority ranking model for projects based on the PageRank algorithm. Finally, taking the project portfolio selection for the construction of maritime search and rescue (SAR) system-of-systems (SoS) as an example, the ranking problem is discussed.

1. Introduction
With the implementation of the 21st century Maritime Silk Road and the “Ocean Power” strategy, new and higher requirements have been put forward for marine SAR. With the increasing frequency of maritime activities, coupled with vast seas and complex sea conditions, China’s maritime accidents will occur from time to time [1]. Therefore, maritime SAR tasks are becoming more and more arduous, and the difficulty of maritime SAR is becoming more and more difficult [2]. Moreover, China's maritime SAR SoS has not yet been fully implemented; especially the SAR capabilities in the open sea cannot meet the needs. It is still a long way to go to strengthen the construction of maritime SAR SoS.

To make sure the sustainable and iterative development of the SAR SoS, it is necessary to continuously increase relevant project inputs and determine a reasonable project portfolio selection in the planning stage of SoS construction. The project portfolio contains a large number of projects and the relationships between the projects are complex, and the failure of one project will have serious consequences for other projects. Therefore, how to evaluate the project portfolio to determine the prioritization of each project is critical for SoS construction decision makers in the context of numerous projects with high dependence and limited resources.

Project portfolio selection refers to the priority ranking of the project using qualitative and quantitative methods under the constraints of the evaluation criteria. The traditional project evaluation guidelines focus on cost and quality indicators, but evaluation criteria for project portfolio selection from the SoS perspective was ignored. What’s more, traditional project evaluation methods are simple, the mutual interaction between projects and its impact was neglected.[3]. Therefore, the project portfolio needs to address two key issues: 1) how to clarify the criteria for project evaluation in SoS...
construction projects and how to analyze the dominance and dependency between projects under different criteria? 2) how to establish a more comprehensive project evaluation method based on these dependencies? This paper proposes a project priority ranking method based on Design Structure Method (DSM) and complex networks. Using DSM to construct the dominant network and dependent network of the project portfolio, and then the PageRank algorithm is implemented to prioritize the projects in the construction of maritime SAR SoS.

2. Literature review

2.1. SAR SoS construction project portfolio
The construction of the maritime SAR SoS is a complex system engineering. It is just an organic whole consisting of emergency plans, organization, emergency resources, rescue technology, legal system and performance evaluation. Its fundamental goal is to continuously improve the command mechanism of maritime SAR, promote maritime SAR facilities and equipment, strengthen the quality of SAR personnel, establish a sound SAR regulations system, and enhance international and domestic SAR cooperation to boost the ability to deal with maritime crisis events [4].

2.2. Project evaluation criteria
This paper proposes multi-attribute evaluation criteria for project portfolio, which include not only the usual project evaluation criteria (such as SoS contribution rate, economic affordability and R&D time), but also the unique evaluation criteria (such as technology maturity, etc.) for SoS construction project.

(1) SoS contribution rate. Portfolio management is an important way to realize the strategy of enterprise. SoS contribution rate refers to the degree to which the achievements of projects boost the performance of the whole SAR SoS in aspects of call for rescue reporting, risk verification and assessment, command and control, information broadcasting, SAR monitoring, and post-disposal. It is a measure of the project’s contribution to accomplishing SAR tasks, achieving mission objectives and meeting stakeholder needs. Portfolio selection based on SoS contribution rate is an important mean to enhance business capability and sustainable development of an organization or enterprise.

(2) Economic affordability. The economic affordability of a project means that within the scope of relevant national regulations, the performance indexes of the project results are compatible with the payment capacity and the requirements of the organization or enterprise. When the life cycle cost of project (including R&D cost, operation and maintenance cost) matches the resources available to it, its economic affordability is the best. It is not that the lower the cost of life cycle, the better the economic affordability. It is obviously unacceptable if the life cycle cost exceeds the affordability of the anticipated resources. Similarly, if the resources are sufficient and the life cycle cost is excessively compressed, the performance indexes of the project can not achieve the optimum, and it is also not economically affordable, at least its economic affordability is not the best. Reasonable economic affordability means, projects must achieve the goal of enhancing the business capability of the organization or enterprise, while reducing the cost of the whole life cycle of the project.

(3) R&D time. R&D time determines how enterprise responds to stakeholder needs and technological development, and how quickly enterprise can benefit from project outcomes.

(4) Technical readiness. Technical readiness refers to the state of development of technology relative to a specific system or project, which reflects the degree to which technology meets the expected goals. The process of technology readiness is basically the process of approaching the fidelity of the three attributes of technology configuration, technology integration in the system, technology demonstration or verification environment until the final product is reached.

2.3. Design Structure Matrix (DSM) method
The Design Structure Matrix (DSM) method proposed by Steward [5][6] is a powerful network modeling tool to represent the elements involved in the interface and their interactions. Diagonal entries represent system elements and off-diagonal entries (i,j) represent directional relationships from...
element j to element i. DSMs have been used to model a variety of system architectures, especially those of processes and organizations. A Domain Mapping Matrix (DMM) is a rectangular matrix mapping elements from one system domain (e.g., processes) onto another (e.g., projects). An MDM is an aggregation of two or more DSMs and DMMs that can be utilized to reveal, derive, and compare relationships within and across domains. Sosa [7] and Yang et al. [8] used a product DSM and an organization-product DMM to derive an org DSM. We use a similar approach in this paper.

3. Modelling project domination and multi-domain relationship

3.1. Project domination graph based on Evaluation Criteria

As mentioned above, the difference in SOS contribution rate, economic affordability, R&D time and technical maturity among different projects in the engineering office reflects the superiority and inferior relationship between nodes. We construct the project domination graph [9], which is a directed weighted graph with the project as the node and the criterion relationship between projects as the edge. The direction of edge reflects the direction of dominance between projects and the weight reflects the intensity of dominance between projects. Figure 1 shows the five exemplary projects with their corresponding criteria levels. For the SOS contribution rate of the project, the node attribute value in the projects network is the revenue rate of the project. If P1 project’s contribution rate is greater than P2 project, which indicates that P1 is better than P2 under the criterion and P1 is dominant to P2, there is a directed edge from P1 to P2. Similarly, for the evaluation criteria such as economic affordability, R&D time and technical maturity, the project dominance chart under a single criterion can be constructed (Figure 1(b) and (c)) and the superimposed Figure 1(a)-(c) can be obtained under multiple criteria.

Figure 1. Five exemplary projects with criteria levels, single-criterion values, and criterion-specific domination links

The construction process of projects domination graph: 1) Determine the evaluation criteria \( C = \{c_1, \ldots, c_k, \ldots, c_M\} \) for project portfolio decisions. 2) Evaluate the scores of different projects under the constraints of each criterion. Under the criteria \( C_k \), the scores of project \( P_i \) and \( P_j \) are \( x_k(i) \) and \( x_k(j) \). 3) Calculate preference \( P(x_k(i), x_k(j)) \) with equation (1). Under the criterion \( C_k \), if \( x_k(j) \) is better than \( x_k(i) \), \( P(x_k(i), x_k(j)) = 1 \), which means there is a directed edge from \( P_j \) to \( P_i \) in the projects domination graph; otherwise, \( P(x_k(i), x_k(j)) = 0 \).

\[
P(x_k(i), x_k(j)) = \begin{cases} 
1 & x_k(j) > x_k(i) \\
0 & x_k(j) \leq x_k(i) 
\end{cases}
\]  

(1)

Further, we obtain the project domination graph shown in Figure 2(a), which reflects the direction and number of dominance between projects. In this paper, we assume that the relative importance of different criteria is not differentiated. Figure 2(a) can be represented by the DSM matrix shown in Figure 2(b). In DSM matrix, the “column” indicates that the project has a dominant relationship with other projects (i.e. superior to other projects) and the “row” indicates that the project is subject to other projects (i.e. inferior to other projects).
Further, we calculate the local relative domination relationship DSM (RDR_DSM) based on the characteristics of the domination graph. It can be measured as the proportion of the relationship that i dominated by j relative to the total relationships with all of their adjacent projects:

\[ RDR_{-DSM}(i, j) = \frac{DR_{-DSM}(i, j)}{\sum_{q=1}^{N}(DR_{-DSM}(i, q) + DR_{-DSM}(q, i))} \quad i \neq j \] (2)

Where \( n \) is the number of projects (i.e. the number of nodes in the network), \( DR_{-DSM}(i, j) \) represents the value in the dominance relationship DSM.

3.2 Deliverable-to-project MDM

The Multi-Domain Matrix (MDM) model can be utilized to reveal the relationship between different domains (Yang et al., 2014). MDM is an extension of DSM modelling in which two or more DSM models in different domains are represented simultaneously. In this paper, we use the deliverable-to-project MDM model to capture dependency relations between projects related to deliverable’s features. As shown in Figure 3(a), the MDM includes deliverable DSM, project DSM and DMM. A DSM \((i,j)\) is a square matrix in which a cell on the diagonal can represent element (e.g., activity, component or organization unit). A number in an off-diagonal cell \((i,j)\) shows a dependency strength between elements.

![Diagram of MDM model](image)

**Figure 3.** Deriving overlapping relationship between projects based on MDM

The dependency strength \( P_{-DSM}(I, J) \) among projects (see Figure 3 (a)) which results from deliverable relationships can be calculated with Equation (3)[8].

\[ P_{-DSM}(I, J) = \sum_{i=1}^{n}(DMM(I,i) \times \sum_{j=1}^{n}(D_{-DSM}(i, j) \times DMM^T(j, J))) \] (3)
Where $D_{DSM}$ (I, J) is the value of dependency strength between deliverable $i$ and $j$ in the deliverable DSM, where each row and column is a deliverable. $DMM(i,j)$ is the mapping value between deliverable and project where its value indicates the deliverable’s contribution in different construction projects. $P_{DSM}$ (I, J) represents the comprehensive intensity which is influenced by the capability of interface from the deliverable interface.

3.3. Identifying relative importance of SAR SoS construction projects

In order to comprehensively reflect the impact of the domination relationship and deliverable-to-project dependency relationship on project priority ranking, this paper uses the PageRank algorithm to build the project prioritization model in the project portfolio.

$$M = (1 - \alpha) \times P_{DSM}(I, J) + \alpha \times RDR_{DSM}(i, j)$$

Where $\alpha$ is known as damping factor. Because the PageRank model focuses on the influence of the dependency relationship matrix, $\alpha$ is usually set at 0.15.

Calculate the eigenvector $R'$ for the largest eigenvalue of $M$ (i.e., principal eigenvector) by equation (5):

$$R' = M \times R$$

4. An illustrative Example

To validate the proposed concepts and models, we applied them to a maritime SAR SoS construction project portfolio as an example. The project portfolio consists of 3 major categories and 8 subcategories projects. A is a SAR equipment project, the main purpose of which is to provide a means for the enterprise to perform missions; B is an organization construction project, which represents the current operation mode of the enterprise and the future planning direction; C is a data and information system development project to support the normal operation of SoS. A1 and B1 are major leading projects for A and B respectively. A2, A3 and B2, B3 are supporting projects. As mentioned above, when evaluating the project portfolio, the three dominance criteria are: SoS contribution rate, economic affordability and R&D time. One dependency criterion is technical readiness. Detail as follows: A1 represents Key SAR equipment R&D,A2 Additional equipment R&D,A3 Individual equipment R&D,B1 Organizational structure and function determination, B2 SAR resources layout and application research, B3 SAR procedure and rule establishment,C1 SAR data centre construction, And C2 SAR command monitoring and decision-making optimization system construction.

First, build a dominance relationship among these SAR SoS construction projects (see Figure 4). Dominance relationship DSM reflects the dominance relationship between projects under the multi-criteria constraints. For example, A1 is the core equipment for critical capabilities, it is superior to B1 at the SoS contribution rate, but B1 is a planning project, its economic affordability and R&D time are superior to A1. That is $DSM(4, 1) = 1$, and $DSM(1, 4) = 2$.

![Figure 4. The initial dominance and dependency relationship DSM of the project](image)

Using the PageRank algorithm, the priority ranking vector of the project combination is obtained:
\[ R^* = (A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2)^T = (0.482, 0.401, 0.386, 0.623, 0.472, 0.441, 0.177, 0.022)^T \]

It can be seen that: 1) B1 has the highest priority (PageRank value is 0.623). B1 outperforms all other projects in terms of economic affordability and R&D time; at the same time, other projects rely on it. 2) A1’s priority is second (PageRank value is 0.482). 3) Category C projects get the lowest priority.

5. Conclusion

Project portfolio selection is an important strategic decision for the development of enterprise and SoS construction. How to evaluate the importance and priority of projects in a scientific, accurate, comprehensive and rational way is an important issue for enterprise. This paper proposes a priority ranking method for projects based on the PageRank algorithm, which can better reflect the impact of node and relationship attributes on project ranking in project portfolio. This method is a multi-attribute evaluation method. Considering the dominace relationship and multi-domain dependency of project nodes, it can prioritize without relying on the preference information of decision makers. Finally, taking the project portfolio of maritime SAR SoS construction as an example, the effectiveness of the model and algorithm is verified.

The main limitations of this research are: 1) the evaluation criteria of projects should be further constructed from the perspective of project dependence and the relationship between projects should be analyzed accordingly. 2) Further, we need to compare with other algorithms to illustrate the superiority of our method.

References
[1] Wu, H., Wang, J., Ananta, R. R., Kommareddy, V. R., Wang, R., & Mohapatra, P. (2018). Prediction based opportunistic routing for maritime search and rescue wireless sensor network. Journal of Parallel and Distributed Computing, 111, 56-64.
[2] Karimi, H. R., Zhang, H., & Ding, S. (2018). Advanced methods in control and signal processing for complex marine systems.
[3] Siljander, M., Venäläinen, E., Goerlandt, F., & Pellikka, P. (2015). GIS-based cost distance modelling to support strategic maritime search and rescue planning: A feasibility study. Applied Geography, 57, 54-70.
[4] National Maritime Search and Rescue Emergency Plan. (2006) http://www.gov.cn/zhuanti/2006-01/23/content_2615966.htm
[5] S. D. Eppinger. and T. R. Browning, Design structure matrix methods and applications. Cambridge, MA: MIT Press, 2012.
[6] Browning, T.R. (2016). Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities. IEEE Transactions on Engineering Management, 63(1), 27-52.
[7] Sosa, M.E. 2008. A structured approach to predicting and managing technical interactions in software development. Research in Engineering Design. 19(1): 47-70.
[8] Yang, Q., S. Kherbachi, Y. S.Hong, C. Shan. 2015. Identifying and managing coordination complexity in global product development project. International Journal of Project Management, 33(7):1464-1475.
[9] Scholz, M., Pfeiffer, J., & Rothlauf, F. (2017). Using PageRank for non-personalized default rankings in dynamic markets. European Journal of Operational Research, 260(1), 388-401.