Role of Interdependencies in Strategic Portfolio Optimization

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ABSTRACT

One of the key inputs for capital portfolio optimization is the objective function characterizing the desired end state. While defining an objective function for more tactical problems is usually straightforward, the objective function at the strategic level presents a particular challenge. At this level, many inputs are by necessity qualitative, tied to national policies and political preferences, strategic outcomes, as well to capability requirements. Furthermore, there are often dependencies between different projects that are currently considered at best only implicitly. This often disadvantages smaller enabling projects that do not provide as much political value. Until recently, data collection and populating the objective function needed to be done manually, relying on the subject matter expertise of military analysts who review project and policy documents and leverage personal knowledge of political announcements. It is very desirable to have a more comprehensive and less subjective methodology. There is a wide range of information available for defence projects, both online and off, that could be leveraged for a more comprehensive analysis. Unfortunately, much of this information is in the form of unstructured texts which complicates any analysis. With the maturing of natural language processing, we believe that it could be possible to develop an approach to automate the processing of documents that contain information about capital projects. In order to assess the viability of this approach, we propose using Twitter data combined with the current government policy documents to identify information about the projects (Who announced it? Where? Is it identified in the defence policy?). This could be used to better quantify the political preferences of individual projects in order to increase the transparency of the portfolio optimization process. This, by extension, would increase the repeatability and effectiveness of decision-making in the capital investment program for the Department of National Defence (DND).

1.0 INTRODUCTION

The business of the Department of National Defence, like that of any large corporation, consists of many diverse portfolios. From large capability procurements, to the procurement of support systems, personnel, and to institutional support there are diverse investment decisions that need to be made. Generally, the demand surpasses the supply and the investment portfolios need to be carefully constructed. Furthermore, prioritizing a large number of different projects across defence portfolio presents an even more significant challenge. While many western nations have gravitated toward a Capability-Based Planning (CBP) approach to inform their investment planning process [1][2][3], it remains a challenge to create strong links between CBP and the creation of a long-term investment plan [4]. There have been attempts to introduce sophisticated optimization models designed to help decision makers choose from among various combinations of individual capabilities that might be delivered.

Since 2010, these sophisticated methods have been largely abandoned in favour of simpler but more labour intensive methods (such as the ranked list approach). On the surface, the ranked-list approach appears to be very practical. However, this approach can become too focused on short-term affordability and often exhibits too much of a project-by-project focus rather than a broader strategic focus. [5] One of the key limitations of a ranked-list approach is its inability to properly quantify project interdependencies; this includes i) mutually exclusive projects, ii) projects that depend upon each other and must be executed together, and iii) projects that increase the value of other projects' deliverables. Rempel and Young [5][6] developed a visual analytics methodology for the optimization of a capital investment portfolio using a multi-knapsack optimization algorithm. It was combined with an interactive, visual interface intended to facilitate the input of subject matter expertise to improve and refine the capital investment portfolio. Their model allows the capture some interdependencies, in particular those for mutually exclusive projects. It does not, however, consider the impact of interdependencies on the value of projects. At the present, an upgraded version of the portfolio optimizer is being developed via collaboration between Defence Research and Development Canada (DRDC) and the National Research Council (NRC).

One of the reasons why project interdependencies are often overlooked is because project managers are generally hesitant to introduce a new source of risk over which they have no control. Coupled with the general difficulty of incorporating interdependences into the structure of a portfolio, it is no surprise that the interdependencies are largely ignored.

This paper looks at some of the challenges in defining the value or objective function for defence portfolios. The paper is organized as follows. In the next section the challenges of defining value for diverse projects, as well as describing constraints and restraints are outlined. Then, the interdependency model is proposed, and a methodology for parsing project documents and other information sources is suggested. Finally, the future research directions are discussed.

2.0 PORTFOLIO OPTIMIZATION: DEFINING OBJECTIVE/VALUE FUNCTION

Usually, in order to optimize a portfolio, each of the considered projects or initiatives is assigned a value. Considering the budget, interdependencies, and other constraints, the objective is then to maximize the value of the portfolio of projects or initiatives. A typical example of a value function for a portfolio is the expected profit. This objective does not work very well in defence. Furthermore, assigning a single value in the defence context becomes a rather difficult problem [7]. In this context, how does one compare values of diverse capabilities and enablers? How does one compare, for example, realized value of a fighter aircraft versus a ship, or a computer network?

Theoretically, each of the projects should be aligned with capability requirements as identified through the strategic planning process (which, at this time, in Canada is the CBP process). This alignment, however, can be non-trivial to establish. There are usually a number of ad hoc projects addressing immediate requirements that can skew the process. In addition, CBP generally focuses on the main force employment capabilities, while the enablers and infrastructure tend to be somewhat neglected. In addition to considering the capability requirements identified by CBP, the current defence portfolio optimization process utilizes a type of a political value to prioritize projects [8]. This value has several aspects, all of which are assessed by subject matter experts. Each project is assessed with respect to its alignment with the defence policy of the day and it is also assessed against stated (or implicit) government priorities. The process of assigning political priorities is fairly labour intensive. For example, among other aspects, it considers by whom and where an announcement of a particular project was made. A project announced by the Prime Minister in national media, for instance, would be ranked higher than a project announced by the Minister of National Defence at a local military establishment. This approach can be quite subjective, and relies on the monitoring of news media. Furthermore, it is likely to underestimate the value of support capabilities that do not have a media appeal. For example, building a new base warehouse, or acquiring an improved computer system are unlikely to make national headlines.

There is another aspect of trying to establish relationships among projects. While some of the dependencies are captured in the project documentation, identifying them can be very labour intensive. In addition, some of the dependencies may be missed, particularly if they are more in the operational domain rather than in the technical domain. Some dependencies might be due to the techniques, tactics, and procedures, and in some cases may be context dependent. A proper, detailed, analysis of the interdependencies is currently missing from the portfolio management process. This is not just a Canadian problem; it is a common issue across many allied forces. There are two drivers behind this. One is the difficulty of establishing interdependencies across multiple domains and levels. Identifying the non-technical dependencies would require analyzing large numbers of doctrinal documents by SMEs who could interpret capability dependencies and translate them to the relationship between projects. To complicate things further, in some cases the projects may not be truly dependent on each other in the sense that one capability would not function without the other, but they may enhance each other value. A simple example would be a shoulder-launched missile and a thermal sight; the missile will work without the sight, but the sight will significantly enhance the missile’s operational value in low light conditions. Both projects are more valuable together.

In summary, there are many considerations that enter into the definition of an objective function, as well as the constraints and restraints, for a portfolio optimization models. At the present time these are largely considered manually, employing a limited number of SMEs. As such, it is highly desirable to develop methodologies that would assist in providing a more comprehensive analysis of the relationships between projects and the assignment of their relative values.

3.0 INTERDEPENDENCIES MODEL

Australian Defence Science and Technology Group (DSTG) developed a methodology to assess and quantify interdependencies among defence capabilities [9] [10]. This framework, suitable for high-level analysis, is called SCMILE (for Sensing, Command & Control, Physical Mobility, Information Mobility, Logistics & Enablers, Engagement) [9]. In addition to providing specificity with regards to the type of dependency between capabilities, it also allows a criticality value to be assigned to the dependencies. This framework has been employed by the Australian Defence Forces to develop technical and tactical links between various assets [9]. For instance, an aerial collection platform might support an intelligence fusion cell, and in turn it may depend on aerial refuelling. Hence, the aerial refuelling capability supports both the aerial collector, and the fusion cell. Figure 1 shows an example of the Joint Strike Fighter (JSF). The JSF platform requires basing and maintenance (L), it is dependent on Aerial Warning and Control System (AWACS), but it also provide situational awareness to AWACS (S), and it is dependent on the missiles for engagement (E), while missiles require the platform to be launched from.

The SCMILE framework implementation has several limitations. The main one is that currently, all the implementations are very labour intensive and rely on manual entry of dependency information by the SMEs [10]. It has been tested at the operational level, with some considerations of policy imposed limitations; due to the required level of detail it becomes rather cumbersome if used across multiple levels. While the framework could be expanded to consider these additional layers (as is done in the reference [9]), this added complexity of considering multiple levels would render manual assessment very difficult, if not completely unfeasible. Figure 2 shows a simple example of two layers (operational level added to the example in Figure 1). The ground operations and air lift depend on air dominance (complete suppression of the enemy air force) for protection, and the targeting to ensure air dominance depends on the intelligence collection to determine targets. Additional complications can be generated by introducing dependencies across scales. For instance, basing and maintenance of the aerial platforms may require ground forces for force protection; maintenance may rely on the air lift for the delivery of parts. There may be also co-dependences of all components on factors at the same or different levels.

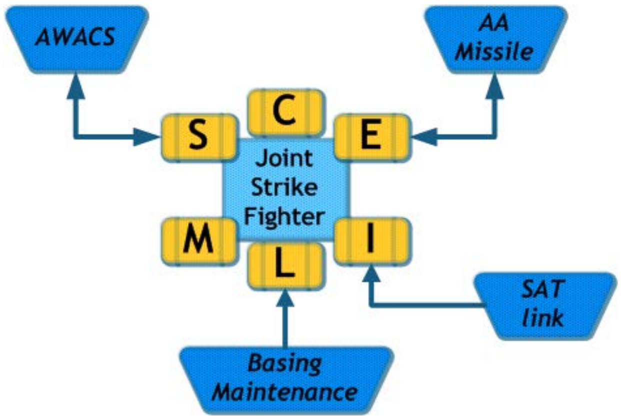

Figure 1: JSF interdependencies at tactical level.

In order to align the framework with the Canadian Armed Force (CAF) doctrine, the SCMILE concept should be replaced by the Command, Sense, Shield, Sustain, Act framework [11]. Directional links can be used to map the dependencies corresponding to these groups of activities. The nature of the dependencies can be captured by adding metadata to the links. That is, the dependencies can be technical, tactical, or operational; they can be also quantified as critical or optional. Cross-level dependencies could be possibly denoted by using numerical coding for the ends of the links. An example depicting aerial dominance in the CSSSA framework is in Figure 3. Red arrows show technical dependencies, green lines are tactical dependencies, purple lines are operational dependencies. The blue 2-3 line represents a cross-level dependency with the tactical element ("Basing and Maintenance of aircraft") dependent on the operational element "Ground Operations" for security.

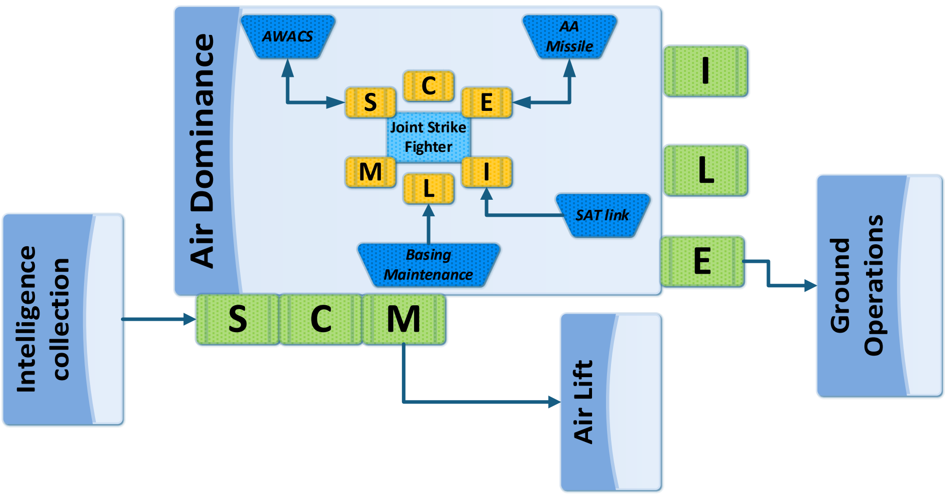

Figure 2: JSF example across tactical and operational level.

Once the framework is expanded, it could potentially be used to improve the value function of projects based on the number of dependent/enabling projects. In this manner, the enabling projects lacking media lustre would have appropriately increased value function. However, to achieve this, an automated approach of identifying interdependencies needs to be developed. A possible solution is proposed in the next section.

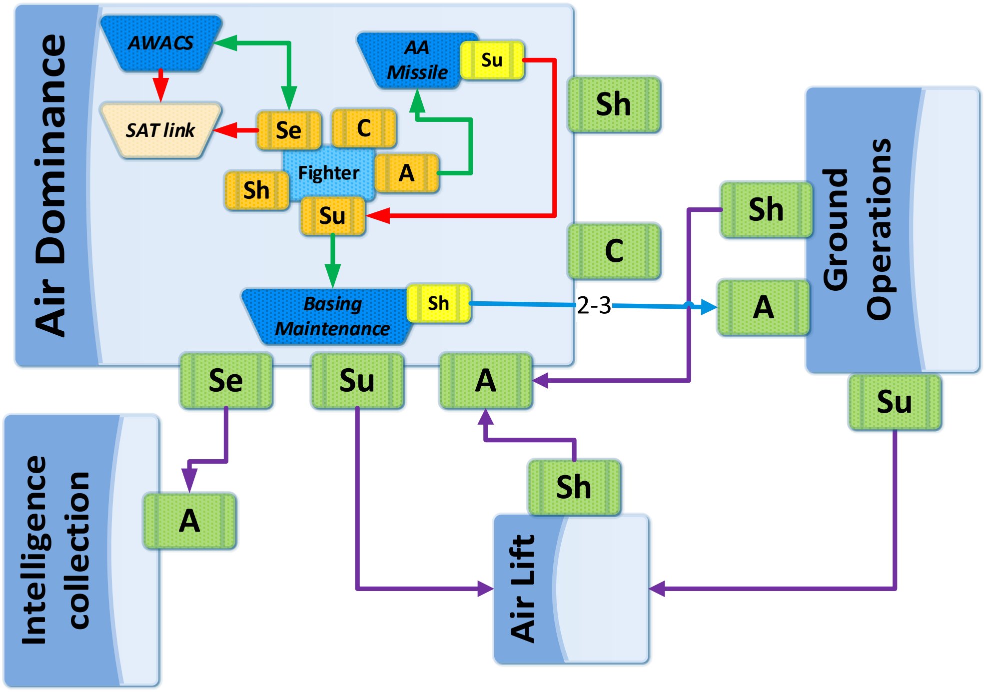

Figure 3: CSSSA example across tactical and operational level.

4.0 NATURAL LANGUAGE PROCESSING AND IDENTIFYING INTERDEPENDENCIES

In the last few years there have been tremendous progress in the domain of natural language processing (NLP) [12][13]. NLP is a branch of artificial intelligence that helps computers understand, interpret and manipulate human language. In general terms, NLP tasks break down language into shorter, elemental pieces, tries to understand the relationships between the pieces and explores how the pieces work together to create meaning. Basic NLP tasks include tokenization and parsing, lemmatization/stemming, part-of-speech tagging, language detection and identification of semantic relationships.

One of the challenges of automated analysis of the relationships between defence projects is that the sources are often in unstructured form. If all the relevant data were in the form of relational databases, the analysis of dependencies would be much simpler. While some key information is often included in databases, it is rarely comprehensive, and other valuable data sources are often in unstructured text form. This is especially true if one attempts to assess relationships between projects across multiple scales. Examples of unstructured data sources can include media announcements, social media posts, doctrinal writings, statements of requirements and calls for proposal, analysis documents, and even project documentation.

Employing NLP, one could feasibly extract the text-based project information about expected dependencies, or potential benefits to other projects from the technical to operational level. This work might require developing a dictionary between taxonomies used by different service organizations. Furthermore, at the strategic and political level expected industrial benefits to Canada could be possibly identified from public statements and bid submissions. Monitoring social media such as Twitter® to track media announcements and other political statements about defence procurement could perhaps provide additional supplementary information.

The obtained linkages between different projects can then be mapped to directional graphs where project would be represented by nodes, and the dependencies by edges. The edge metadata could be used to distinguish among different types and levels of interdependencies. Two projects could be independent, in which case there would be no edge between them, or they could be one or several edges, which can be one directional or bi-directional.

Consider this hypothetical example; the SMEs that analyse projects and assign values for the portfolio optimization process have several new projects to review, listed in Table 1. Project F is an infrastructure project while the rest are naval capital equipment acquisition projects. Some of the naval projects are very high profile (such as B and D) and will be assigned high values without the need for a prolonged analysis. Project F will result in improved facilities at two existing naval bases and will lead to new facilities in two other locations. The economic impact on the communities at the new locations will be very significant and will result in a large volume of social media activity outside of the Defence community. In this scenario, the evaluation of the dependencies between Project F and the entire list of Defence projects would be significantly improved by the proposed analysis methodology. In addition to the economic benefits, the proposed analysis method would probably show that Project F brings value to Project C as that project will be dependent upon well maintained ships for supply and maintenance. The strength of this dependency relationship might be rather difficult for a SME to gauge, the proposed graph analysis approach should be more effective. This will enable better definition of a value function (that will then need to be translated into objective function for the optimization).

Table 1: Hypothetical list of new projects for Defence (for example purposes only).

Project	Description
A. Destroyer Mid-Life Upgrade Project	Mid-life refit of fleet with upgrades to weapons and sensors
B. New Coastal Patrol Ship Project	New fleet for coastal patrol and defence
C. Coastal Surveillance System Project	Installation of new sensor systems for both above and below water surveillance.
D. Auxiliary Replenishment Tanker Replacement Project	New fleet of replenishment vessels
E. Destroyer Radar Upgrade Project	Upgrade current radars during the mid-life refit for compatability with new weapon systems
F. Fleet Maintenance Facility Expansion Project	New or improved fleet maintenace facilities in four locations
G. Naval Surface-to-Surface Missile System Project	New surface-to-surface missile systems for destroyer mid-life refit

5.0 CONCLUSION

Incorporating project interdependencies into the portfolio structure has potential to improve the capital expense optimization. Including the dependencies in the consideration of project value would better reflect that some key enabling projects, while not having great political or media value in themselves, are critical for more visible projects.

It is proposed to use the NLP methodologies to scan project documentation, as well as other information sources, to identify project dependencies. Graph analysis combined with the SCMILE-like methodology adapted to the Canadian doctrine and defence environment could then perhaps be used to represent (and quantify) the interdependencies. This would in turn strengthen the value/objective function used in the portfolio optimization.

6.0 REFERENCES

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