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Supporting Force Structure Review through graph visualisation and capability view improvements

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Abstract: Program Viewer is a prototype Defence decision support tool for whole of portfolio capability management that focuses on schedule, cost, personnel and capability. The tool has already supported a number of decision-making activities in Defence including the current and previous Force Structure Reviews. Close interaction with stakeholders has enabled access to a rich source of Defence portfolio data for populating a Unified Profile for DoDAF and MODAF (UPDM) (Hause, 2010) compliant repository. So far, Program Viewer has facilitated understanding of project costs and slippage, scheduled milestones and milestone relationships between projects, and potential issues (Bulluss et al., 2014, Lo et al., 2015).

Our software tool has been augmented herein with temporal graph visualisation (Lo et al., 2011, Lo et al., 2009) to support exploratory analysis of the taxonomy of Defence capabilities and capital acquisition projects juxtaposed with cost information. Through employing the Java universal network/graph (JUNG) toolkit (O'Madadhain et al., 2005), the prototype supports graph visualisation through (a) spring, (b) Fruchterman-Rheingold (1991), (c) Kamada-Kawai (1989), (d) circle and (e) Inverted Self-Organising Map (Meyer, 1998) layouts. Temporal mode enables users to visualise the graph evolving over time, gaining an improved understanding of relative budget allocation to projects on a year-by-year basis. By scaling node areas proportionally to project costs (total or on a yearly basis), relative budget allocation to projects can be quickly gleaned from the graph. Customisable node shape and colour, and ability to zoom and filter out data by context promote greater understanding of data from different perspectives.

An adapted capability view (CV-3) based on the DoDAF viewpoints has also been implemented. As project numbers within the repository increased, the understanding of project dependencies and inter-relationships has correspondingly become more complex. The CV-3 provides an improved contextual understanding of projects mapped against capability, simplifying the visualisation for decision-makers.

Our prototype tool provides a unique capability that merges data that is typically held locally within Defence groups, processes the information and provides visualisations that improve management of the whole-of-life capability systems lifecycle. The First Principles Review (2015) recommendations for enhancing performance and accountability of Defence capability acquisition and sustainment, and enterprise-wide information management have highlighted the need for improved focus in the area that Program Viewer seeks to innovate in.

Keywords: *Program Viewer, graph visualisation, adapted capability view, Defence portfolio-level decision-making*

1. INTRODUCTION

As part of the 2015 White Paper development, Defence has engaged in a process known as a Force Structure Review (FSR) to develop costed force structure and capability options for a capable and sustainable future force (Dept. of Defence, 2014). To ensure Defence can realistically achieve the goals in its strategic plan, the FSR must be carefully considered, working within budget guidance levels and accounting for required enablers and Fundamental Inputs to Capabilities (FIC) including personnel and facilities (Crane, 2012). With an array of options and only limited resources across the joint services for future capability, it is appropriate that scrutiny is applied to the process to ensure value for money.

Not every proposal can be realised but ultimately the resultant force structure needs to deliver outcomes to satisfy all contingencies. Individual services have been asked to envisage their capability development requirements to meet Australia's projected strategic Defence needs (White, 2013). For example, Army's Strategic Plans Branch (2014) commenced the current FSR process by publishing a series of issues papers articulating anticipated limitations for its networks and combat systems, its special operations and joint amphibious capabilities, and the Land force as a whole. By understanding the status quo, considering gaps and implementing strategy-led capability development, Defence demonstrates accountability in its processes.

To support previous and the current FSR, DSTO has been developing a software tool called Program Viewer (described in Section 2) to facilitate planning for scheduling, costing and staffing. Through the tool, decision makers can access up-to-date information fused from multiple data sources, visualise data in an easy to comprehend form and manipulate values to explore impacts of potential decisions. Recent updates described herein focuses on improving the capability view (see Section 3) and introducing graph visualisation (refer to Section 4) to further enhance exploratory analysis of plans and option evaluation for capability acquisition. Being conceptual models, both provide different perspectives of project information. Diagrams used herein have been generated from unclassified sources mixed with fictitious data to facilitate discussion. Section 5 summarises this paper and highlights future ways for improving Program Viewer.

2. PROGRAM VIEWER

Program Viewer is a prototype Defence decision support tool for whole of portfolio capability management that focuses on schedule, cost, personnel and capability (Bulluss et al., 2014, O'Shea et al., 2012). Rather than designing a system based on ideal or perfect information, information is instead gathered from data sets currently used by Defence groups and fused to provide a situational picture, referred to as Defence capability situation awareness. As an analogy, this tool takes an Intelligence approach to decision support and situational awareness (Joint Chiefs of Staff, 2012) and while not perfect, the resulting picture represents the best available information at the time. Recently, the tool was improved by integration of slippage modelling to improve project planning for improved capability delivery to Defence (Lo et al., 2015).

Close interaction with stakeholders has enabled access to a rich source of Defence portfolio data covering schedule, cost, personnel and capability (Bulluss et al., 2014, O'Shea et al., 2012) for populating a Unified Profile for DoDAF[1] and MODAF[2] (UPDM) (Hause, 2010) compliant repository. Designed around an organisational information-centric paradigm, Program Viewer improves decision by accessing stovepipe repositories and enabling information visualisation through various charts (such as Gantt, line, pie and layered). Coincidentally our approach of leveraging actual Defence stakeholder data resembles the future enterprise-wide information management agenda envisaged in the recent First Principles Review (FPR) (2015), where corporate applications access enterprise (master) data. The review considers the current Defence environment as being a fragmented application landscape with corporate data locked behind locally stored spreadsheets and user software.

So far, Program Viewer has facilitated Defence portfolio analysis through visualising project costs and slippage, scheduled milestones and milestone relationships between projects, potential issues and capability frameworks. Without Program Viewer, seeking to understand even a fraction of the necessary data involves subject matter experts (SMEs) from multiple Defence services and groups explaining from pre-generated charts and analysis of tables of data. Through augmentation of data, our tool enables, for example, graph visualisation to support real-time exploratory analysis of relationships between Defence capabilities and projects, and project costs over time.

[1] US Department of Defense Architectural Framework
[2] UK Ministry of Defence Architectural Framework

3. IMPLEMENTING ARCHITECTURAL VIEWS

Central to Program Viewer is a UPDM and DODAF based repository that enables generation of many DoDAF architectural views (Dept. of Defense, 2014) including:

- ***PV-2: Project Timelines*** that convey key project milestones and interdependencies
- ***CV-3: Capability Phasing*** representing planned timing of Defence capability

Gantt charts were used extensively in the tool to convey temporal aspects of Defence projects and capabilities. However, as project numbers increased, these views were increasingly overloaded with information and became difficult to understand. To address this, we (1) enabled information filtering to improve readability and (2) created a variant of the CV-3 that grouped projects by capability. An adaptive CV-3 view applied to unclassified sets related to (2) is shown in Figure 1. Projects in the chart are colour coded to milestone phases and are now grouped more meaningfully by capability.

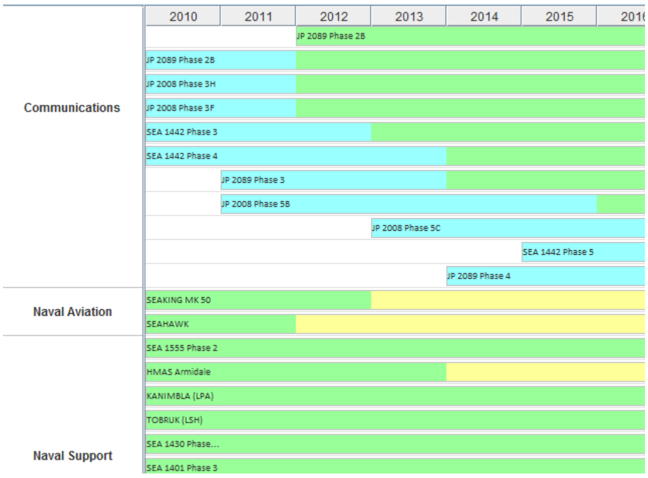

Figure 1: Adaptive CV-3 representing capability and project phases.

Program Viewer's support for multiple capability frameworks enables users to switch between alternatives to understand how a project fits within different capability goals and priorities. In FSR 2015, this view was especially useful for visualising schedule and milestone dependencies of projects within a capability. A stacked graph then facilitated examination of the project grouping's budgetary cost spreads to ensure a gradual proposed spend that met budgetary constraints.

4. USING GRAPH VISUALISATION TO SUPPORT EXPLORATORY ANALYSIS

In mathematics, a graph $G = (V, E)$ comprises of a set of vertices V whose elements are connected by a set of edges E (Cormen et al., 1990). Graphs are important data structures for representing many forms of information including, for example, computer, telecommunication and social networks, entity-relationships, data flow charts and resource allocation maps. A visual representation has an advantage of rapidly conveying pertinent information about a dataset to a user. In previous applications of graph visualisation, researchers scaled node sizes (area) to quantify amounts (Boyack et al., 2005), illustrated group membership through colours (Batagelj, 2009) and used edge thickness to convey relationship strength (Batagelj and Mrvar, 2003). Directional edges have represented paths of information flow (Au et al., 2009, Cormen et al., 1990) while geolocation enabled nodes to be overlayed onto maps (Scheurer and Curtis, 2008).

Figure 2 shows Program Viewer's user interface for graph visualisation of capability-project taxonomy. A key benefit of the software tool is in facilitating real-time interaction with large datasets for analysis at the macro level, or in detail as required by the user. For this reason, while graph screenshots herein convey properties and relationships at one perspective and may not clearly show all details, a user interacting with the tool can zoom-in to focus on specific nodes (Batagelj, 2009) or apply filters to obscure irrelevant data.

4.1. Graph Layouts

Graph visualisation or layout focuses on techniques that produce drawings of graphs (Six and Tollis, 2006). Effective layouts facilitate exploratory analysis of data to understand groupings, identify disconnects and establish information flows. The Java universal network/graph (JUNG) toolkit was chosen for graph drawing in Program Viewer because of built-in support for layouts (O'Madadhain et al., 2005), including:

Circle Layout: Nodes are randomly and equally spaced on a circular ring

Spring Layout: A simple force-directed spring-embedder

FR Layout: Fruchterman-Rheingold (1991) force-directed spring-embedder

KK Layout: Kamada-Kawai (1989) minimises total compression or tension on all springs

ISOM Layout: Inverted self-organising map based on competitive learning (Meyer, 1998)

While traditional force-directed algorithms generally produce aesthetically pleasing drawings, some suggest that these layouts perform poorly on large graphs (Kobourov, 2013). Multiple layouts have been included to enable analysts to choose the most suitable representation based on the data. Figures 2 and 3 compare graphs generated from a common dataset to highlight differences between alternative layouts.

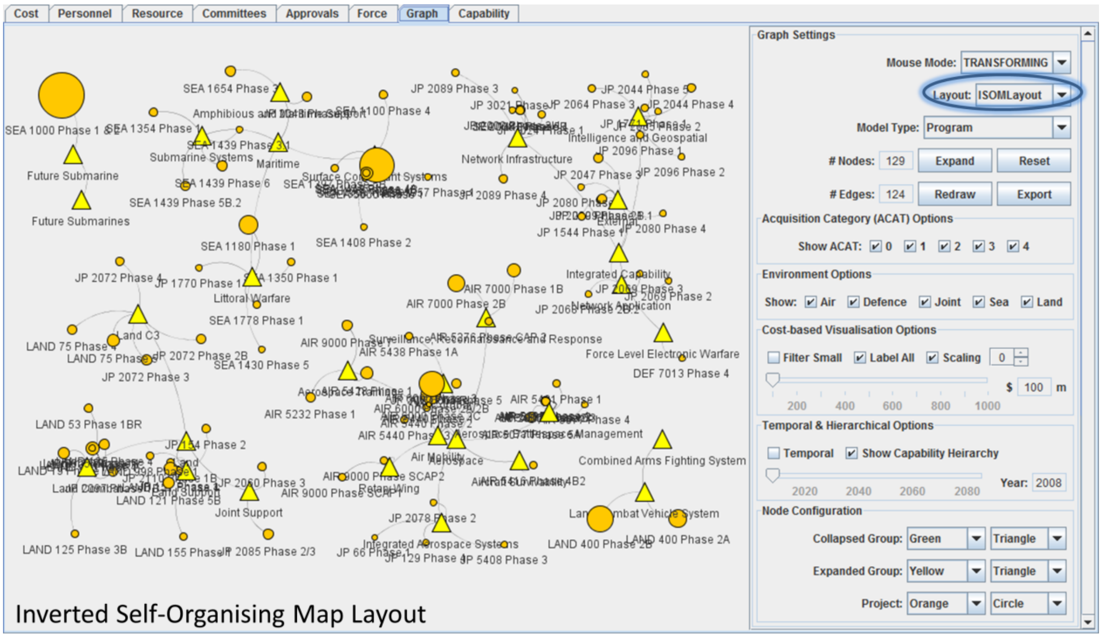

Figure 2: Graph of Defence capability-project taxonomy using an inverted self-organising map layout.

4.2. Colour, Shape and Size in Visualisation

Shape, colour and size for nodes and edges provide important visual cues for interpreting graph information (Batagelj, 2009). Assigning associated nodes with a common colour enables, for example, users to rapidly discern groupings within the dataset. Currently, users can specify the shape and colour of group (category) and project nodes as shown in Figure 4(b). Colourisation of nodes based on category may be feasible future work. In visualisations of large-scale publication datasets, Boyack et al (2005) effectively conveyed numbers of journals in each cluster through node size (area). Without scaling, all DCP projects appear identical in Figure 4(a) but when nodes areas are scaled proportionally to total project costs in Figure 4(c), analysts can immediately identify projects with a larger budget allocation.

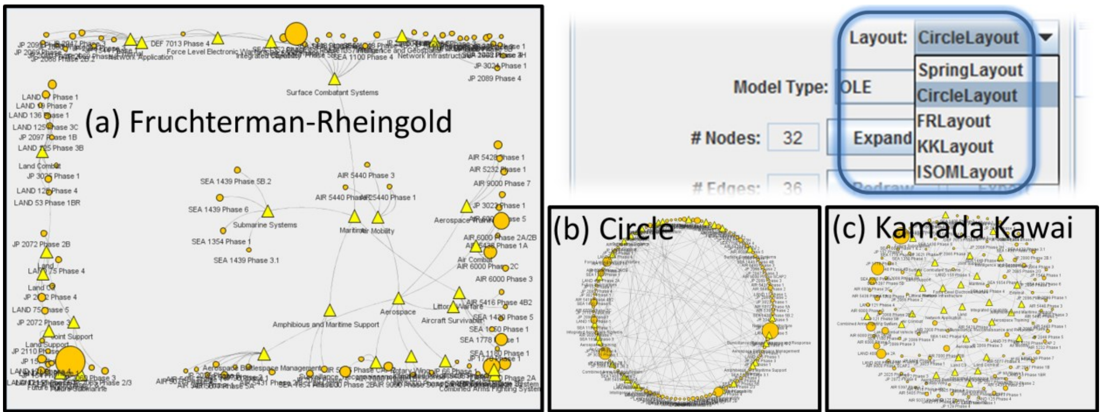

Figure 3: (a) Circle vs (b) Kamada-Kawai vs (c) Fruchterman-Rheingold layouts of DCP[3] project data.

4.3. Temporal Visualisation

Often overlooked in graph analysis is the perspective offered through the temporal dimension, with the typical approach aggregating information over time to produce a single static view (Batagelj, 2009). However, displaying graph evolution over time can sometimes yield a deeper understanding of an observed

[3] Defence Capability Plan

system (Lo et al., 2011, Lo et al., 2009). In addition to static graphs, temporal-based visualisation is featured in Program Viewer (see Figure 5) to enable exploratory analysis over time, highlighting relative budget allocations to projects on a year-by-year basis. Rather than scaling node areas proportional to total project costs, yearly project allocation is used instead.

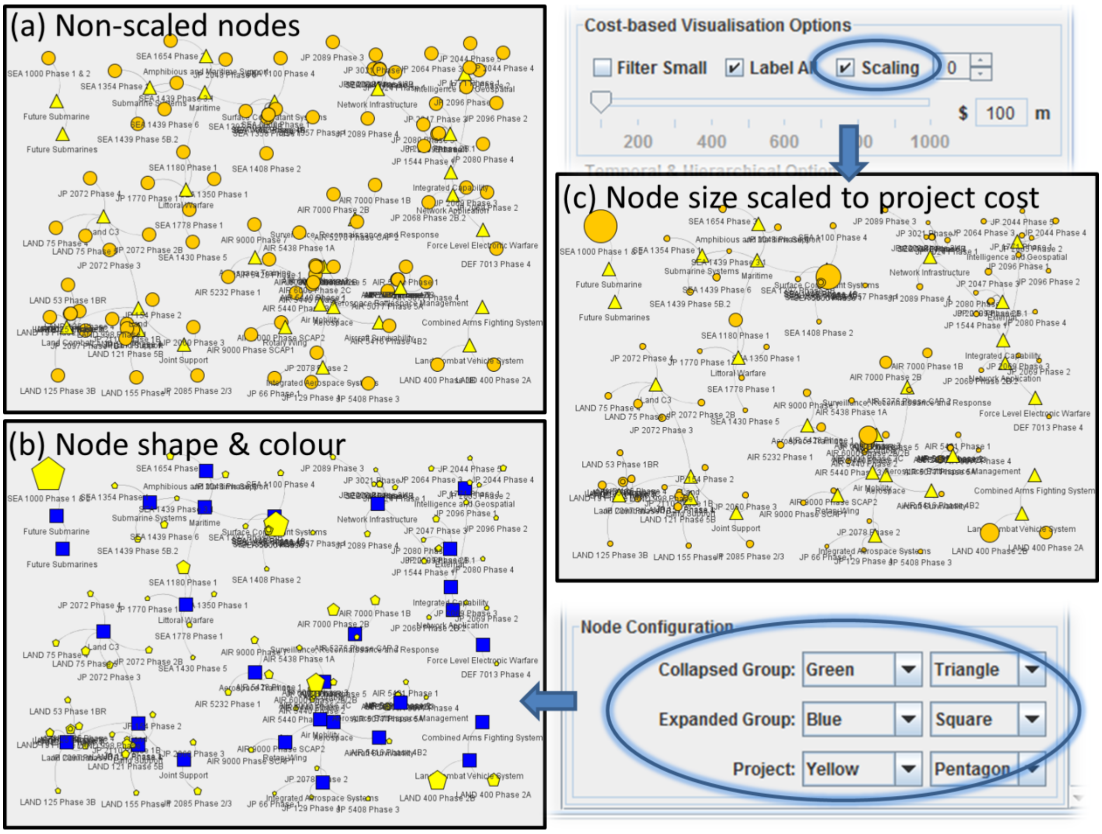

Figure 4: Adjusting colour, shape and sizes of nodes for more effective visualisation.

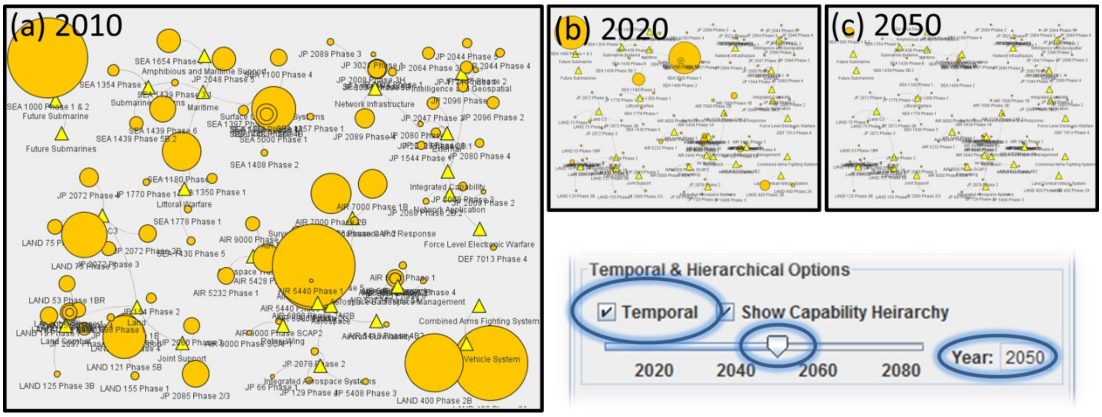

Figure 5: Visualising changes in budget allocation to DCP project over time.

4.4. Graph Navigation and Filtering

Program Viewer supports detailed analysis of the data through zoom control into segments of interest and filtering out nodes cluttering the diagram as shown in Figure 6. Currently, users can elect to (Lo et al., 2015):

- Obscure labels or remove nodes for projects under a user specified cost threshold (see Figure 6(a))
- Focus on projects of a chosen Environment (Air, Defence, Joint, Sea and Land) (see Figure 6(b))
- Select projects of a specified acquisition category (ACAT), related to complexity (see Figure 6(c))

Hovering the mouse over any node brings up a tooltip showing detailed information about the project or capability (group / category). Users can right-click a node to edit project information including project name, ACAT rating, and project milestone data including Year of Decision (YOD), Initial Operational Capability (IOC), Assets Under Construction (AUC) and Planned Withdrawal Date (PWD) (Dept. of Defence, 2012).

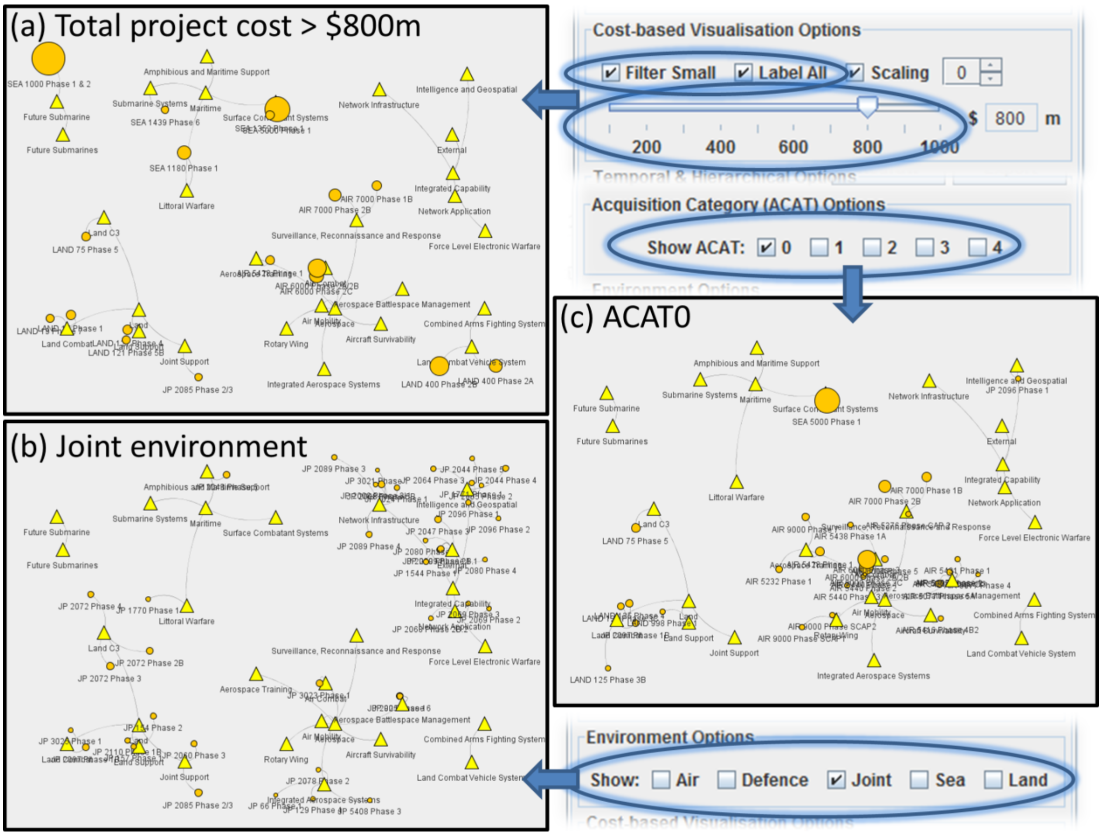

Figure 6: Filters reduce information overload by enabling analysis on a subset of data.

5. SUMMARY AND FUTURE WORK

One of the recommendations in the recent FPR proposes for Defence to move from multiple, overlapping processes, applications and systems to an enterprise-wide information management agenda where groups make use of and populate common data sources for better decision making. At DSTO, we have been developing a prototype decision support tool called Program Viewer for whole of portfolio capability management that has supported the recent and previous FSRs. As envisaged in the FPR, we have understood the importance of enterprise data and have engaged with a number of Defence groups to integrate what are normally disparate data sources into a single UPDM compliant repository.

Previous versions of Program Viewer focused on presenting information simply and meaningfully as Gantt, line, pie and layered charts. This paper describes recent improvements through (1) an improved Gantt chart view that groups projects by capability and (2) graph visualisation for better illustration of Defence capability-project taxonomy. The result of the upgrade is an improved capability that facilitates exploratory analysis, providing alternative perspectives of the data and the ability to adjust the view's zoom level. For the graph view, we have enabled multiple graph layouts, user defined node shape and colour schemes, and resizing of nodes to reflect project costs for improved visualisation. Built-in data filters in the graph view potentially reduce information overload by excluding irrelevant data based on user parameters. Selecting temporal mode allows the operator to visualise the graph of project information on a year-by-year basis to show relative annual budget allocation to projects.

Our team is continually improving Program Viewer with possible future upgrades to include:

- Integrating more data repositories
- Web-enabling the application to allow browser-based use of the tool
- Colour-coding graph nodes to reflect association to capabilities
- Laying graph nodes over maps when geospatial information is available
- Considering suitable graph metrics for project data

The enterprise-wide management of capability and the merging of the Defence Materiel Organisation (DMO) with the Capability Development Group (CDG) into the Capability Acquisition and Sustainment Group (CASG) as proposed in the FPR has resulted in considerable interest in our tool. Program Viewer's ability to provide a clearer picture of the whole of capability lifecycle aligns well with the future CASG entity responsible for the end-to-end capability acquisition and sustainment process.

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