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BOXARR: THE DIGITAL THREAD OF INTER-DEPENDENCY MANAGEMENT FOR HIGHLY COMPLEX SYSTEMS ENGINEERING

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ABSTRACT

This paper will discuss the systematic operations of utilizing the BOXARR platform as the 'Digital Thread' to overcome the inherent and hidden complexities in massive-scale inter-dependent systems; with particular emphasis on future applications in Military Ground Vehicles (MGVs). It will discuss how BOXARR can enable significantly improved capabilities in requirements-capture, optimized risk management, enhanced collaborative relationships between engineering and project/program management teams, operational analysis, trade studies, capability analysis, adaptability, resilience, and overall architecture design; all within a unified framework of BOXARR's customizable modeling, visualization and analysis applications.

The Challenges of Complex Systems Engineering

The increasing complexity of 'holistic' systems engineering is already widely manifest in consumer and commercial ground vehicles; with the proliferation of sensors, automation, inter-connectivity, embedded software, and inter-dependent systems and components. Likewise, the increasing demand for customization raises further challenges in effectively managing change.

The impacts of complexity resulting from such advances become significantly more profound in MGVs, where weapons and defensive systems are also involved. MGV designs increasingly have the potential to approach complexity levels that rival fighter aircraft and small warships. Such impacts have both obvious (inherent) and hidden influences, which can place missions, assets, and lives at risk.

This increase in MGV complexity is further exacerbated by:

- increasing 'mission complexity' - e.g.
  - joint-operations, multi-national forces, asymmetric warfare, etc.;
- dynamic and variable 'in theatre' operating environments;
- the increasing budgetary pressures for sustaining a lean warfighting force;
- the drive for holistic lifecycle engineering;
- massive and highly-distributed, global supply chains; and
- complex and support logistics and maintenance demands.

The value-potential of advancing MGVs technology is both evident and compelling. However, the resulting consequences of their inherent complexity and inter-dependency are less apparent or well understood. The granular impacts of systems design are extremely difficult to trace; small changes in one subsystem can have unforeseen and potentially critical effects on others, which may not appear to be directly related. Likewise, anticipating and accounting for the variable use-cases of complex systems is extremely challenging. The net effect of these challenges in MGV design and operation can often result in increasing development time, spiraling production and lifecycle maintenance costs, and the increased risks for asset viability and mission success.

Many of these potential risks arise from the extensive inter-dependencies required of modern systems engineering. However, there are few tools for effectively modeling, visualizing and analyzing the inter-dependences of holistic systems at the 'real-world' levels of scale and complexity now emerging in modern military vehicles.

The BOXARR Platform

BOXARR is a software platform and methodology purpose-designed to overcome this challenge and optimize complex systems engineering. BOXARR is an 'enterprise-class' solution, able to scale and propagate across the enterprise - in line with strategic planning or in response to user demand. The BOXARR platform can be deployed on Windows, OSX and Linux operating systems, and is comprised of the following functional key components (see Figure 1):

- BOXARR ScaleBridge
  - Server-side application comprising
    - ScaleBridge|Engine – standard-based webserver
    - ScaleBridge|DB – standards-based database server and schema
    - ScaleBridge|Portal – browser-based systems administration
    - CloudBridge – 'private cloud' application for external-party collaboration
    - Catalyst|API – managed API application for systems integration
- BOXARR nVision Client
  - Desktop user application (JAVA)
- BOXARR nSight Client
  - Browser-based user application

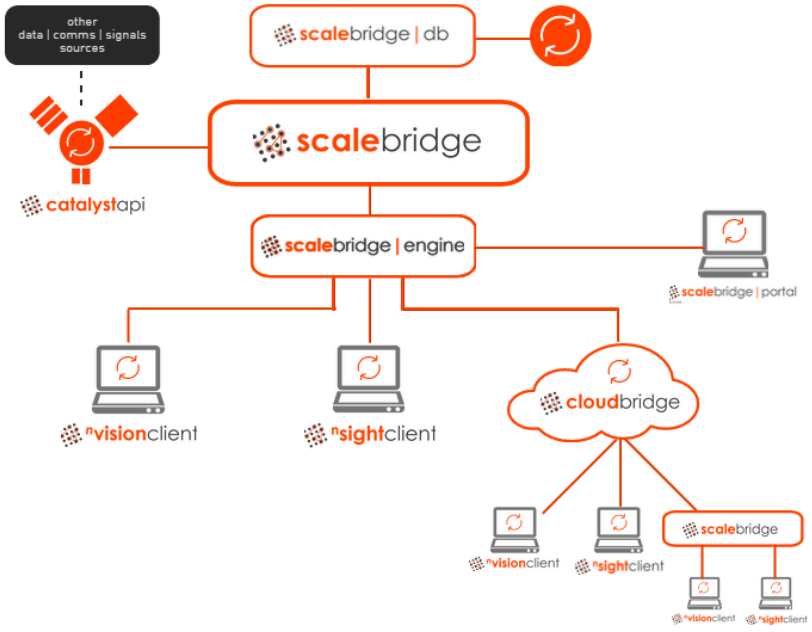


Figure 1: Relational schematic of the BOXARR software platform

BOXARR Collaborative Modeling Methodology

The BOXARR platform operates on four key principles:

- Intuitive Use:

building models using simple and universal 'common language' of 'boxes-and-arrows', such that systems, processes and programs, can be collaboratively modeled across a network, with maximum participation, and minimal training.

- Open Architecture:

allowing the effective sharing of system models, data and analyses with 3rd-party tools and applications; thus enhancing the holistic net value of all such systems.

- Data Rich:

with the ability to aggregate vast amounts of data from disparate sources, annotate all model objects (i.e. boxes, arrows, groups, etc.) with extensible parameters and functions; thus enabling both visual and computational solutions to evolving problems of complexity and optimization.

- Scalability:

to allow modeling, visualization and analysis of 'real-world' scale systems (i.e. system models potentially incorporating and computing millions of data-rich objects)

In turn, the BOXARR modeling paradigm is based upon the following fundamental design principles:

- 'Boxes' represent 'things' – e.g. parts, components, people, standards, etc.
- 'Arrows' represent 'inter-dependencies' – e.g. relationships, dependencies, cause & effect, process, etc.
- 'Groups' represent hierarchical sets of Boxes – e.g. systems, sub-systems, departments, work-centers, suppliers, programs, etc.
- 'Contexts' – enable Boxes to be 'grouped' in different ways i.e. according to their 'context' – e.g. by work breakdown structure, program, work-center, location, geography, phase, mission, etc. (Figure 2 and Figure 3)
- Boxes, Arrows, and Groups can be 'assigned with' or 'reference to' any amount of data
- User-defined functional computation can be run across the model

To collaboratively build models in BOXARR, multiple users can simply and concurrently:

- Create Boxes and associate the Boxes with data
- Join the Boxes with Arrows and associate the Arrows with Data
- Group the Boxes (in multiple contexts) and associate the Groups with data

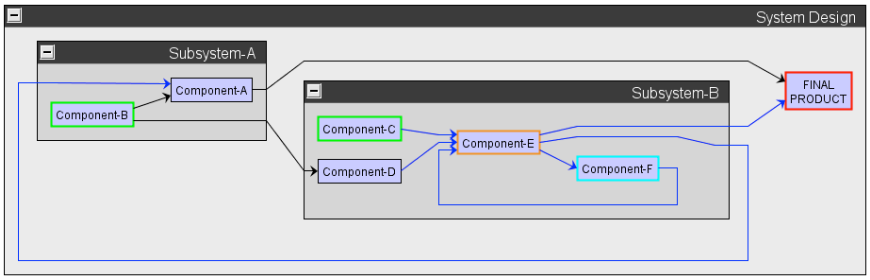


Figure 2: Example components A~F grouped by "Work Breakdown Structure" context

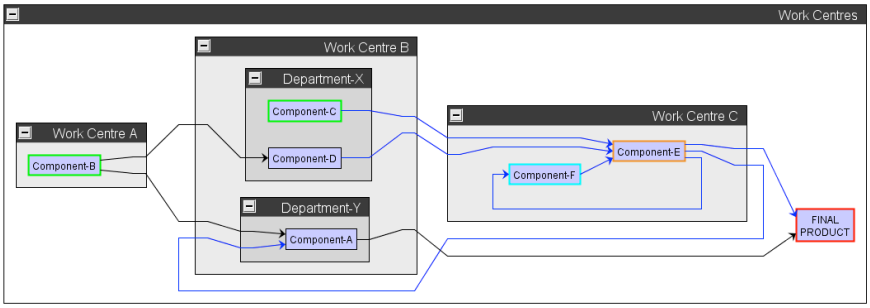


Figure 3: Example components A~F now grouped by "Work Centre" context

Given that complex systems are designed by multiple persons with respective specialist skill-sets, the BOXARR platform support fully collaborative modeling, with multiple users collaborating on the same model in real time. Users can raise 'Requests' to fulfill dependencies outside of their specialist domain or work-area (Figure 4). These Requests can be posted and appear in the respective specialist Group area of the model and can be simply 'satisfied' by the relevant specialist user by linking the Request with an Arrow from an existing Box (or creating a new Box, Figure 5).

The BOXARR platform then enables user-defined formulaic computational analysis of the model, corresponding to the model structure along with relevant data, KPIs or other metrics (e.g., Figure 6). Such analyses further aid the user to identify and mitigate hidden risks and inter-dependencies, or compute time/cost efficiencies, or readiness levels (etc.).

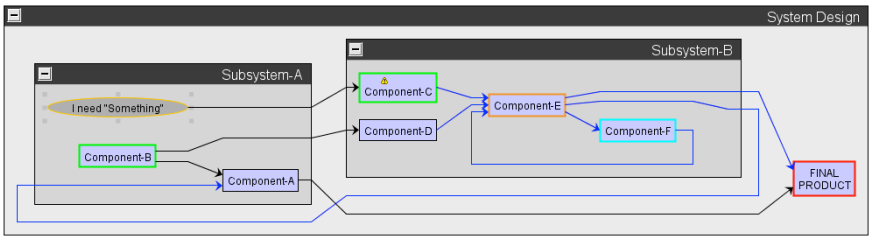


Figure 4: Example design Request

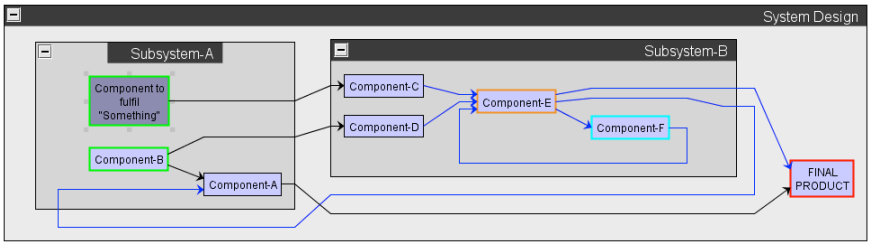


Figure 5: Example design Request fulfilled by a new component

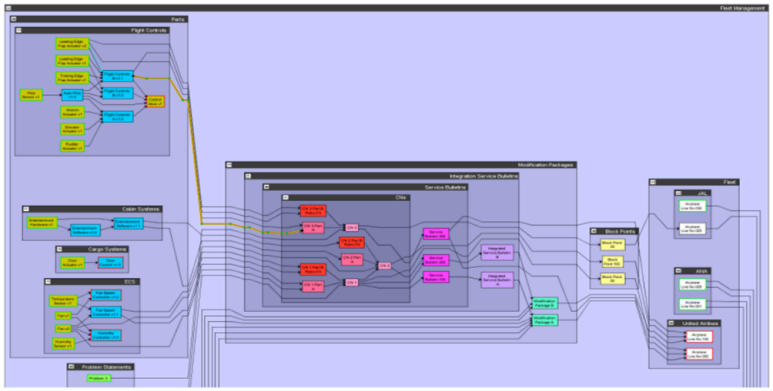


Figure 6: Example heat-mapping readiness levels through computational analysis

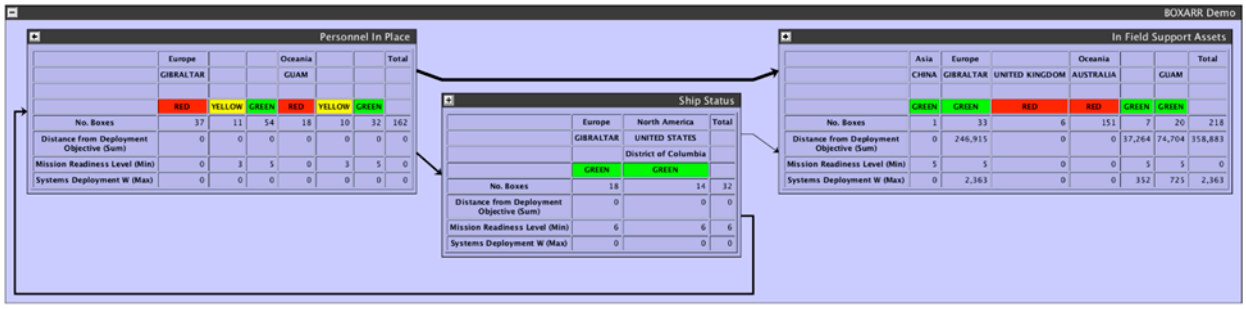


Figure 7: Example Groups heat-mapping KPIs through computational analysis

In the massive-scale designs associated with complex systems such as MPVs, models can be easy navigated and filtered to visualize the desired area(s) of concern, critical paths or inter-dependencies. Groups can also present computated data of the objects (Boxes, Arrows, Groups) within the Group, as user-defined pivot tables (see Figure 7).

To further aid complex system design, and facilitate effective program management, the BOXARR platform enables users to run an integrated scheduler across the model and its associated data. This feature then enables the user to visualize the system model in additional applied contexts, such as (see Figure 8):

- Data tables
- Inter-dependency matrix
- GANTT program
- Multi-axis Pareto optimization

Accounting for the geographical factors and determinants, provides stakeholders with further insight into the complexities and inter-dependencies of systems, programs and missions. The BOXARR platform enables models to be overlaid onto mapping systems (such as Google/OSM) to visualize, navigate and analyze areas of concern. Maps can be filtered to desired system elements and associated inter-dependencies, and then represented as summaries, tables and pivot charts.

BOXARR's collaborative architecture can be utilized to enable external consultants, industry partners, and global allies to collaborate on system models within role-based security.

By exploiting these principles, BOXARR can support highly complex system designs with the efficient and effective capture, documentation, visualization, analysis and optimization of the complex inter-dependencies between requirements, systems, designs, processes, supply chains and production methodologies, on a massive 'real-world' scale.

Applying BOXARR to MPV Systems Design and Engineering

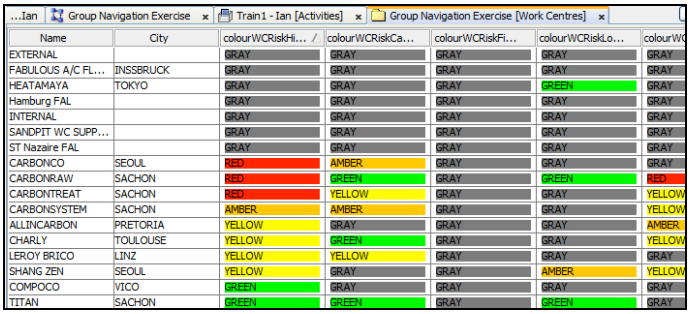
Designing and engineering the complex systems involved to produce a MPV is a significant challenge; requiring the input, expertise and experience of disparate personnel across the military enterprise, as well as external industry contractors, partners and allies. Likewise, as we have seen emerging challenges of complexity and inter-dependency compound the challenge and the exposure to unforeseen risk:

- Assessment and adoption of emerging technologies
- Proactive and reactive customization
- Inter-operability with new and legacy system components
- Embedded software code
- Internet of Things
- Financial complexity
- Highly distributed supply-chains
- Production capacity
- Environmental and legislative compliance
- Cyber security
- Safety
- etc.

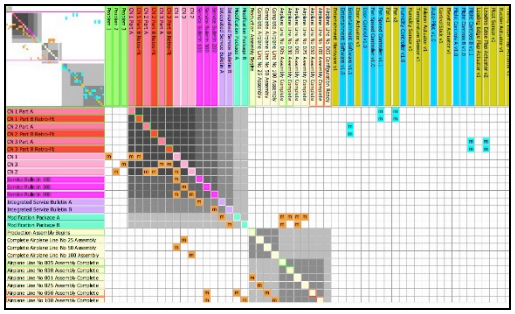
BOXARR's powerful modeling and analysis platform enables teams to collaborate on designing and building systems on a massive-scale (incorporating millions of data-rich objects), efficiently and effectively.

Importantly, BOXARR enables the stakeholders to unite all the 'contributing' and 'influencing' aspects of the system within a unified inter-dependent model – e.g. strategies, concepts, research, technology areas, milestones, things, parts, assets, processes, standards, compliance, work-centers, locations, people, skills, supply-chain, programs, phases, etc.

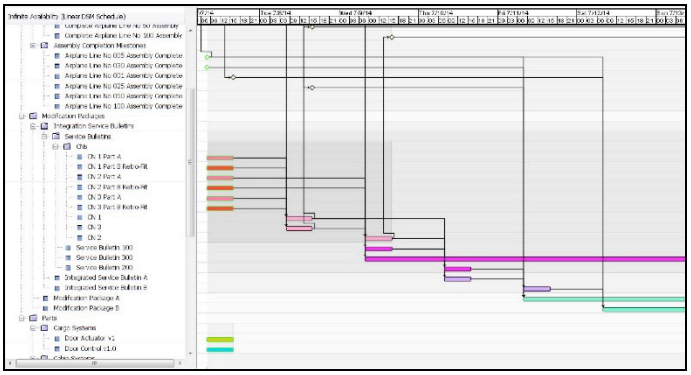
- Collaboratively design and model holistic systems quickly and intuitively
- Role-based user security maintains focus and integrity of sensitive data and IPR
- Create multiple system component types (Boxes) – e.g.
- Things, parts, assets, processes, standards, work-centers, locations, people, etc.
- Create flows, relationships and dependences between system components (Arrows)
- Group system components into multiple hierarchies – e.g.
- Things, parts, assets, processes, standards, work-centers, locations, people, etc.
- Assign and reference system objects (Boxes, Arrows, Groups) with data and documentation



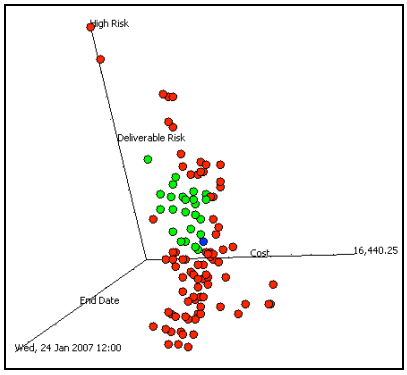
A) model visualized as a data table



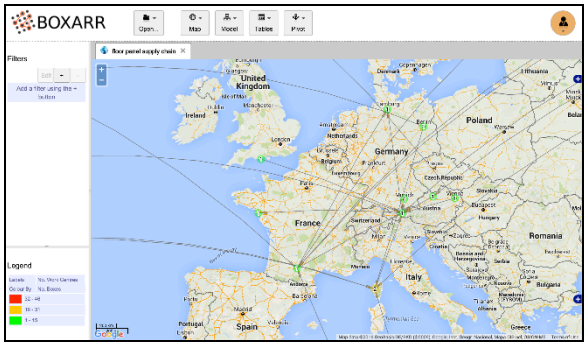
B) Model visualized as a dependency matrix



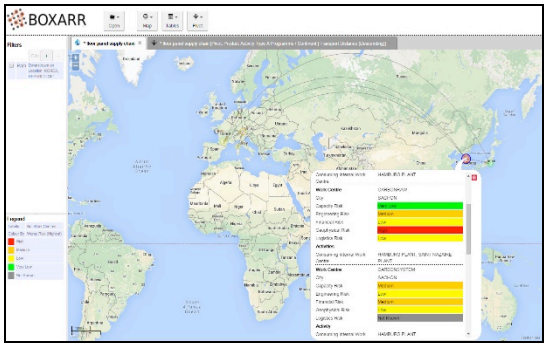
C) Model visualized as a GANTT / Program



D) Model visualized as trade-off of objectives



E) Model visualized as geospatial relationships



F) Incorporating data filtering, reporting and analysis

Figure 8: Various model visualizations in BOXARR

- Raise requests to other team members to fulfill dependencies and deliverables
- Filter and visualize complex systems in multiple user-defined and role-based contexts
- Identify the inherent and hidden inter-dependencies within the system design
- Analyze and optimize the system design using user-defined functions
- Simulate and analyze the impact of change in the system design
- Run integrated scheduler to generate a holistic works program (GANTT)
- Exportable to Microsoft Project
- Quickly switch between system design visualizations – e.g.
- Model, contexts, tables, pivots, matrix, Pareto, GANTT, etc.

Applying BOXARR to MPV Production Process and Roll-out Programs

Efficient and profitable manufacturing and production relies upon a complex web of inter-dependencies. Manufacturers also face an increasingly complex operating environment: emerging markets & opportunities; increasing technical capability; embedded software; increasing reliance on inter-operability between components; unprecedented financial complexity (often with lean margins); global environmental and legislative pressures, etc.

The "systems design" model for the MPV can then be incorporated into a Production Process. Thereby applying the capabilities and methodologies of the platform, BOXARR provides MPV manufacturers, OEMs and the military customer with powerful suite of applications to manage complexity and optimize their production processes:

- Effectively and efficiently design and model holistic production processes
- Analyze holistic production processes in multiple filtered and contextual visualizations
- Identify key relationships between parts, work-centers, and people
- Identify critical paths, inherent and hidden inter-dependencies
- Identify sub-optimal production areas for re-purposing and streamlining
- Simulate and analyze the impact of systems and process change
- Simulate and analyze requirements for effective ramp-up in production levels
- Simulate and analyze the impacts of decommissioning and consolidation
- Make better informed decisions, faster, based upon granular impact
- Effectively plan for, and execute change strategies
- Marry production process with supply-chain for increased optimization
- Achieve and sustain a lean production model

Applying BOXARR to MPV Missions

Effectively planning & executing MPV missions potentially involves multiple phases, multiple operating bases, disparate and distributed supply-chains, and multiple parties or joint-operations.

Poorly planned and executed mission-tasks can result in significant pre-mission stoppages, delays, over-runs and re-schedules, with extremely costly outcomes. Likewise hidden inter-dependences can have unforeseen impacts across and beyond the mission scenarios; resulting in compounding risk to outcomes, assets and safety.

Some planning and execution applications (project/program/mission management) can have inherent flaws, such as allowing "successor tasks" to lead to "predecessor tasks", or limitations in respect to coping with the holistic influences, inter-dependencies and impacts involved. This leaves the 'human' to try and make such associations - which is effectively impossible; particularly in a dynamic program of work or mission, where unforeseen change is unpredictable but inevitable [3][4].

BOXARR's unique paradigm provides MPV mission analysts and commanders with a powerful suite of tools to collaboratively plan and execute missions, efficiently, and effectively.

- Holistic 'system' models can incorporate millions of data-rich objects
- Simply navigate through complex massive-scale models using intuitive tools and filters
- Effectively visualize complex massive-scale models in multiple user-defined contexts - e.g.
- Holistic (collapse models to designed depths)
- Visualize by work breakdown structure
- Visualize by work center / department / team
- Visualize by location / geography
- Visualize by process / program / phase / etc.
- Select any object in the model and click to:
- Filter to visualize critical path (upstream and/or downstream)
- Filter to visualize user-defined inter-dependencies and relationships
- Click to run user-defined functional analyses across the entire model or groupings
- Click to heat-map model objects based upon KPI metrics or other data parameters
- Simulate and analyze the impact of change in system design or data metric

Importantly, as we have seen above, the mission-analysts' mission model can incorporate and account-for inter-dependencies all the way back through the maintenance, production, supply-chain, design and development, and requirements of the MPV program. This may or may not have a tangible effect on the mission-plan at hand, however it enables analysts and stakeholders to effectively build upon a knowledgebase of relational impacts against particular mission scenarios and metrics, which overall contribute to more effective mission-planning. This becomes particularly relevant in terms of significant scale warfare, where complexities and inter-dependencies are on a massive-scale and consistently influenced by a dynamic operational theatre environment.

Applying BOXARR to MPV Holistic Lifecycle

As we have discussed, a fundamental element of complexity is the 'web' of inherent and hidden inter-dependencies within large systems, and therein the complex relational impacts which can propagate across the system as a result of change at any point in the system. The net effect is the increasing potential for unforeseen compounding risks, which can produce unexpected symptoms and lead to critical problems.

The ability for stakeholders to combine the entire system lifecycle within a 'holistic' BOXARR model enables the impacts of change at any point in the system to be simulated, visualized, computed, analyzed and optimized, prior to implementation of such change. This approach can significantly reduce the evident and unforeseen risks associated across the entire lifecycle program of an MPV; which in turn optimizes the entire MPV lifecycle, saves time and money, optimizes the success potential for both works programs and missions, and minimizes the risks to assets, personnel and the general public.

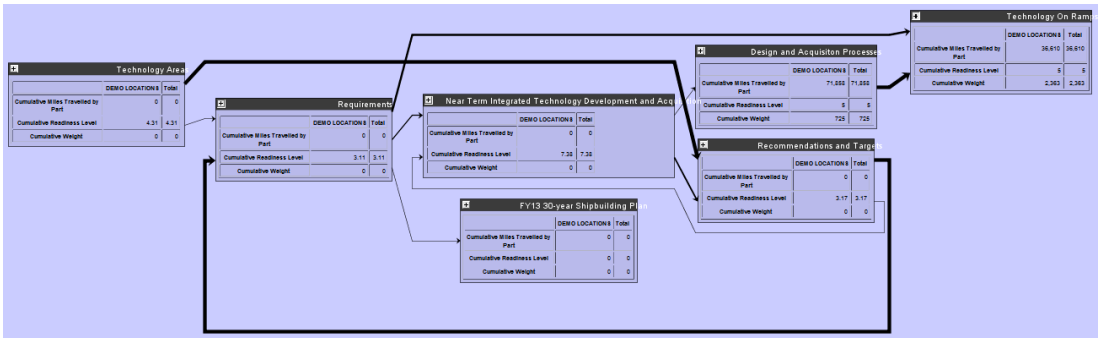


Figure 9: Example BOXARR lifecycle model derived from US Navy 30-year Ship Development Program (collapsed)

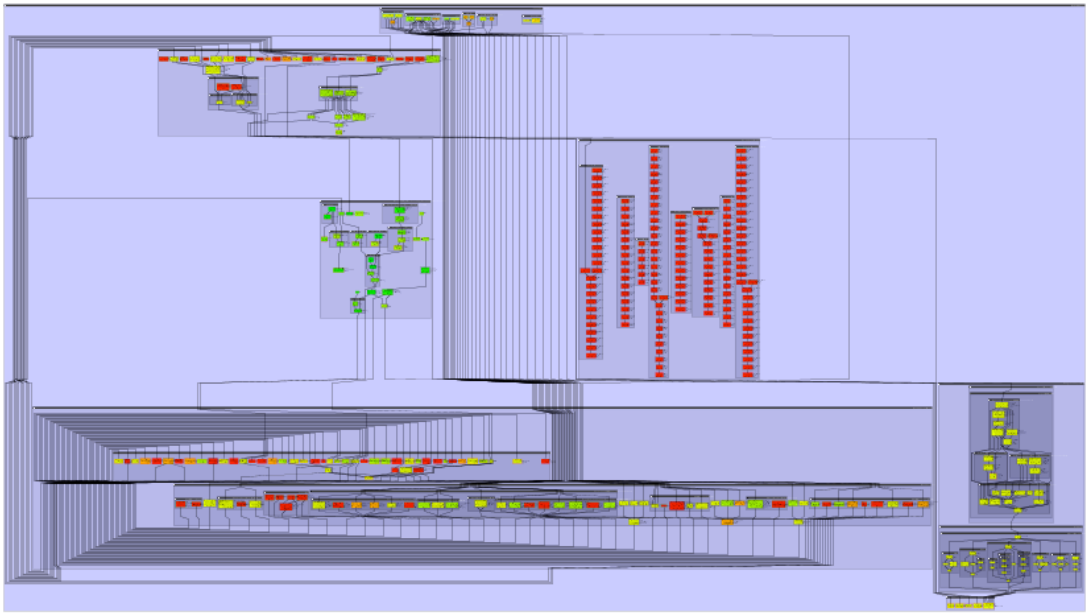


Figure 10: Example BOXARR lifecycle model derived from US Navy 30-year Ship Development Program (un-collapsed)

Applying BOXARR as a Pan-Organizational Knowledgebase

BOXARR enables the enterprise to efficiently aggregate and reference information from effectively any source, by leveraging the existing data systems utilized across the organization. In turn, new "Smart" data and signals technologies can be readily incorporated.

Models then become effective organic knowledge bases within which virtually any specialist knowledge and experience can be easily recorded and retained, in practical and inter-dependent context. Such information can then be readily shared and accessed across the organization at the time/place where most benefit can be derived:

- Empowering local personnel to solve problems locally
- Reducing unplanned downtime through conditions-based preventative maintenance
- Minimizing requirement for costly ad-hoc activities/maintenance
- Minimizing dependency on 'external expert' resources
- Reducing operating overhead across multiple enterprise contexts
- Ensuring best practice, procedural guidance and safety governance are consistently maintained. Importantly, recording and sustaining the ongoing development of 'systems' such as MPV programs within BOXARR models means stakeholders are able to retain intelligence and experience in a commonly accessible and collaborative format. This becomes an invaluable resource in future MPV development (as well as to other defense programs); as program developers can quickly and effectively reference and 'learn' from previous experience and avoid repeating errors in design or process which resulted in unforeseen negative consequences.

Proven Real World Value

BOXARR is a proven technology with real-world value; relied on by some of the world's largest organizations in both the defense and commercial domains; solving problems of complexity and inter-dependency. For example:

- Modeling and managing the highly distributed global supply-chain of the leading European commercial aircraft OEM; reducing their time required to overcome unplanned supply-chain disruptions from several weeks down to a few hours (e.g. shortages, natural disasters, political disruptions, etc.).
- Modeling and optimizing the highly complex queuing networks in aircraft production for the leading North American commercial aircraft OEM; facilitating their effective ramp-up in production demands by saving many hundreds of man hours per month.
- Collaboratively capturing the U.S. Navy's ship design process from over 100 Naval Architects to provide a standard for future ship design, and vital systems inter-dependency information for ongoing collaborative hull and weapons systems engineering (see Figure 9 and Figure 10) [1][2].
- Streamlining processes and works-programs for ship builders and subsystems designers at other major global defense industry contractors.

Conclusions

Military Ground Vehicle (MGV) systems are becoming increasingly complex and likewise reliant on the growing inter-dependency of component systems. By inference from the commercial sector, and with ongoing advances in technology, there is high probability that this trend will continue to accelerate. This poses significant challenges to both the military and its industrial partners in optimizing the value of MGV lifecycles, including identification and mitigation of on-going inherent and hidden risks, amongst others.

The above applications combine to greatly empower the military and its industrial partners to make better, faster, impacts-based decisions across the MGV lifecycle – enhancing systems engineering practice to visualize and navigate highly complex systems and identify and mitigate compounding risks of inter-dependency; optimizing quality/time/cost efficiency in production, operations and maintenance, identifying and mitigating inherent and hidden compound risks, and improving the safety of assets, personnel and the general public.

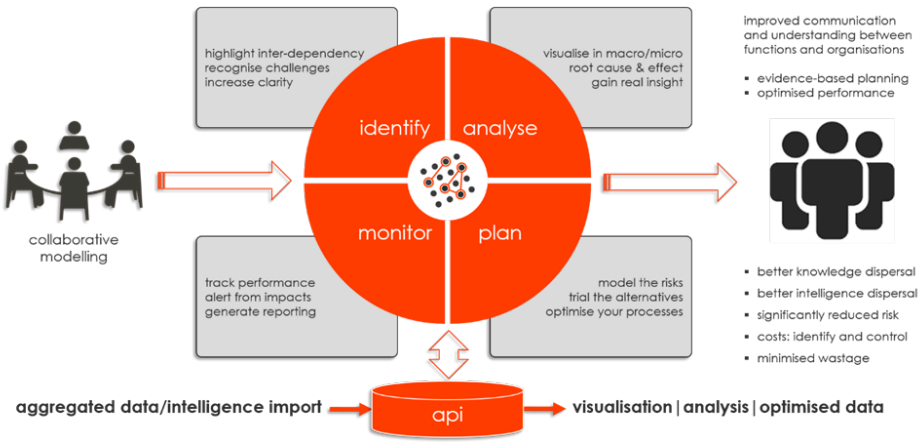


Figure 11: BOXARR from data to understanding

Through the complete process described in this paper (Figure 11), from collaborative modeling to data understanding, (BOXARR provides the 'Digital Thread' by which the entire MPV lifecycle can be modeled, visualized, computated, analyzed and optimized.

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