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# The Challenges of Digitisation and Data Analysis in the Maritime Domain

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**ABSTRACT**
The volume of collected and synthesised data available to governmental leaders assessing the maritime domain has increased rapidly over recent years. Analogue data has given way to digital data, which provides an opportunity for better storage, analysis and transfer. Data infusion and management has become the key constraint in respect of data collection. Using data to make decisions requires the appropriate tools and processes to assess and transfer data to near real-time user domains. In the maritime environment, there is a constantly growing demand for intelligence, surveillance and reconnaissance (ISR) data for both national security and commercial purposes, including data sharing among partner nations. However, an increase in available data does not automatically equate to an increase in decision-ready information. Rather, the increase in data can overwhelm sensors, databases and analysts. The concept and use of "big data" exacerbate the already overwhelming flow of data in terms of the volume, variety, and velocity of the data being received. This paper will explore the digitisation of the maritime domain, and the prospect of performing data analysis in a world of rapidly growing data.

**Abbreviations:** BAMS: Broad area maritime surveillance; DAMA-DMBOK: *Data Management Association Guide to the Data Management Body of Knowledge*; ECDIS: Electronic chart display and information system; EDM: Enterprise data management; ELT: Extract, load, transform; ETL: Extract, transform, load; ISR: Intelligence, surveillance and reconnaissance; MDA: Maritime domain awareness; PWC: PriceWaterhouseCoopers; ROI: Return on investment; SDLC: Systems development life cycle; TCPED: Tasking, collection, processing, exploitation and dissemination; WGS: Wideband global satellite

## 1. Introduction

Digitisation in the maritime environment is a challenge that is being faced around the world. Digitisation is the process of collecting (or converting) information into a digital format.[1] In a digital environment, information is organised into discrete units of data (called bits) that can be separately addressed and stored.[2] Analogue and digital are two different types of data that can be collected. Analogue data is represented by continuously

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variable physical quantities.[3] Digital data, on the other hand, is data in the form of binary digits. Many organisations have efforts underway to digitise all analogue data, and collect new data only digitally. A film camera vs a digital camera offers an example of analogue vs digital data collectors. Analogue images are available only locally; storage and transformation are difficult. Digital images can be easily shared, stored and transformed.

### 1.1. Digitisation of the Maritime Environment Brings Challenges

Digital data is more easily analysed, stored and shared. However, the more data that is available to collect, the more data tends to be collected. Digitisation provides the opportunity to improve maritime autonomy and domain awareness through improved cooperative sharing and analysis of data. Many questions remain about which data are important and which are not. We still strive to collect all data in all environments, which tends to overwhelm our analytical- and decision-making systems.

### 1.2. Digitisation Improves Industry

Digitisation has enabled autonomous shipping, better tracking of cargo containers, more strategic deployment of naval assets, improved underway capabilities for both military and business, and other improvements in the greater maritime industry. However, these capabilities have attendant costs and risks. As we move to a fully digital environment in the commercial shipping industry, enabling technologies and systems must be in place. For any nation or organisation not yet digitised, there is a cost of entry into the digital world, and all nations face the ongoing cost of maintaining digital systems. There are also risks, such as cyber malevolence, which must be confronted to ensure the integrity of data.

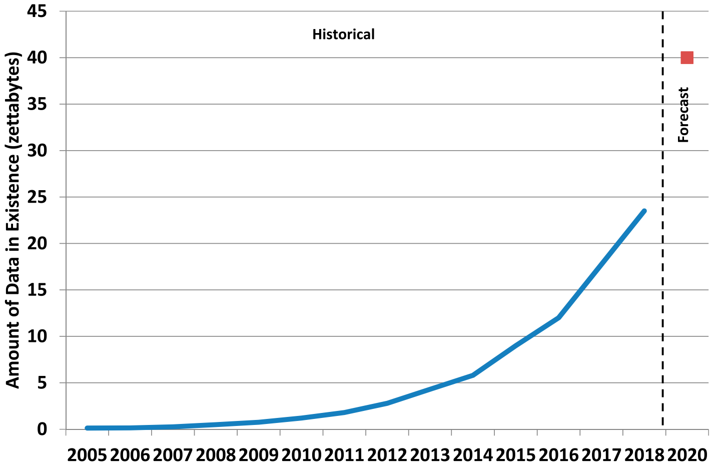

**Fig. 1.** Increases in Generated Data.

## 2. Growing Data

The amount of data available to decision makers has increased over time. The types of data that can be collected and analysed have also changed. The increase in data and change in types of data both pose significant challenges. Using data to make decisions (tactical or strategic) requires appropriate tools and processes. Because data-collection techniques and tools have grown over time, a comprehensive data framework was (and remains) absent. There is a misconception in the world today that data collection is the same as information. In reality, as more and more data are collected, the task of using that data to generate useful information gets more difficult. Figure 1 shows the trend of increasing data.[456]

Current estimates are that by 2020, 40 zettabytes of data will exist. One zettabyte is equal to 1 trillion gigabytes. This is nearly double the amount of data that exists today (in 2018) and represents an exponential increase. This accelerated rate of creation of data must be properly managed.

The three key issues that precede any data-analysis task are:

1. The service has needs;
2. Data sources offer raw data;
3. Data tools offer the potential to turn raw data into useful information.

Without analysis, the needs, sources and tools are separated. Analysis can link these three pieces together to form useful information.

## 3. Naval Maritime Environment

Navies around the world are dealing with increasing data. The US Navy has been a leader in developing and implementing digital systems. In 2013, there were 210 sensor platforms in the US Navy.[7] That number increased to 310 in 2016, and is expected to reach around 400 in 2020. Ships, submarines, broad area maritime surveillance (BAMS), Boeing P-8 Poseidon aircraft and wideband global satellite (WGS) represent some of the many military platforms that the US Navy relies upon for its maritime domain awareness (MDA).

The maritime environment has been undergoing digitisation for the past several decades. The goal, of course, is to continuously improve MDA.[8] The change happened, however, with no plan in place and over a long period of time. There are also a growing number of commercial and civilian platforms, along with partners, which can provide additional data to improve MDA. It is important to include these “nontraditional” data sources in modern approaches for MDA.

The lack of a coherent digitisation plan means that as greater amounts of data have been collected that need processing, available resources have been getting increasingly stretched. The collection of data in the maritime environment has, historically, been done in a decidedly ad hoc manner. That is, no data framework has been in place for the collection, storage and use of data in the maritime environment. As a result, effective utilisation of the data that is collected can be challenging. Whether or not a framework is used, maritime services need to determine:

1. What is desired from the data;
2. What data is desired;
3. What data structure and management is necessary;
4. Security and quality concerns;
5. How to store the data;
6. How to analyse the data;
7. Who the leaders are that require the data.

Most of the available time is spent finding the proper data, and transforming it for analysis. Some estimates state that data collection and transformation take up 80% of available time, and analysis is left with only 20% of the time.[9] One way to save time and improve effectiveness is to address the means by which data are collected and transformed.

Extract, transform, load (ETL) and extract, load, transform (ELT) are two methods of data analytics. In the maritime environment, ETL vs ELT could be the difference between seeing an issue and not seeing it. ETL is a process in which data are "pulled" from the data source, transformed into a format that is useful for analysis, and then saved to data storage for later analysis. An example diagram for ETL is shown in Figure 2.[10]

ELT, on the other hand, is a process where data are pulled from the data source, and then loaded into an analysis package like those offered by Oracle and Microsoft. Once loaded, transformation and analysis occur. This process can make use of parallel computing found in modern analytic capabilities. A diagrammatic depiction of ELT is shown in Figure 3.[11]

Both ETL and ELT are used for a variety of purposes, including data mining and business intelligence. To determine which method is better, analysts need to understand the intended task and the purpose of the analysis. For example, a task could be to search through data feeds for a specific term. If the data are intended to be used in real time, for example, to let an analyst know that the term has been mentioned so they can act in real time, real-time processing is required. If the intent is to collect the data for non-real-time purposes (such as a report), real-time data are not required. Additional questions for analysts to ask include:

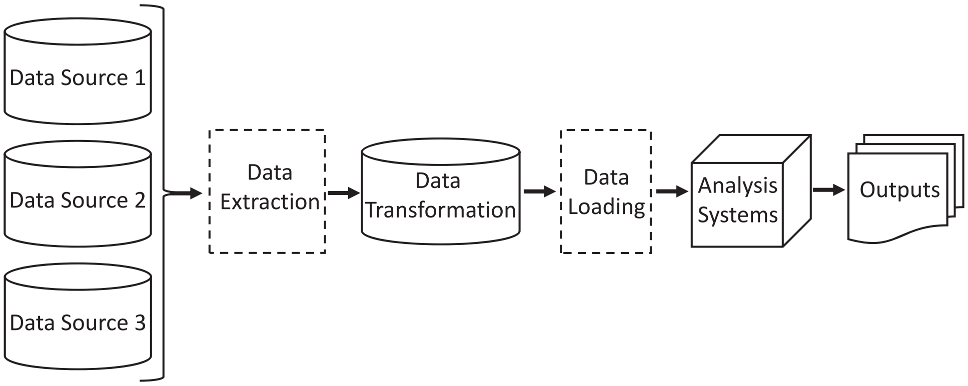

**Fig. 2.** Extract, Transform, Load (ETL) Diagram.

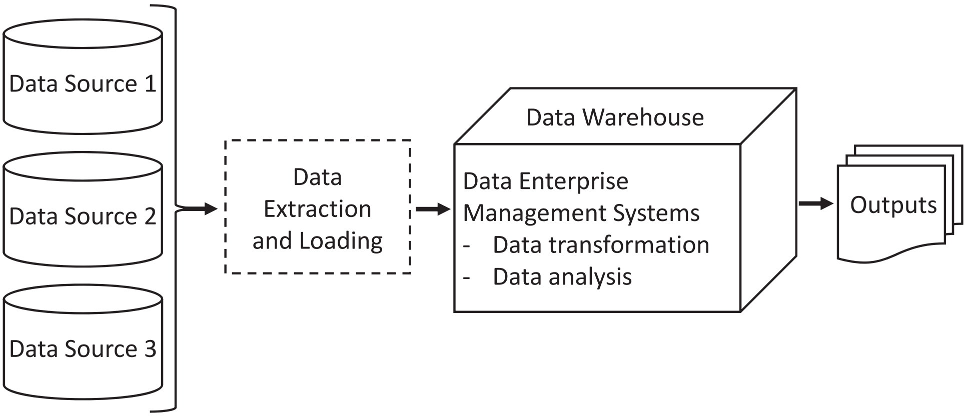

**Fig. 3.** Extract, Load, Transform (ELT) Diagram.

- Is the context of the term important, or simply that it was mentioned?
- Does the analyst want to know who mentioned the term, or simply that it was mentioned?
- Does the analyst's organisation own a large data warehouse? Do they have data analysis capabilities like Oracle SAP, Microsoft Dynamics, or even open-source capabilities like MySQL?

Though not a maritime data source, Twitter can be used as an example of a real-time data source from which data can be extracted. Twitter offers options for extracting data. Among them is streaming application programming interface (API). Using streaming API, a user can deliver queries over an http connection.[12] The data returned from the search query can be fed into a database.

Assume an analyst wanted to understand how many times a specific term was referenced in tweets. Using the ETL method, tweets would be searched for references to the term. Any tweets found to contain a reference to the term would be loaded into a data warehouse. The data transformation and data warehouse structure would need to be defined prior to commencement of streaming. This would involve an enterprise data management (EDM) effort on the part of the organisation. Once in the database, analysis on the data can occur at the leisure of the data analysts. ETL would involve storing only tweets that are relevant. This option would require the analyst to maintain a constant http connection to Twitter, in order to save the desired data. This option also requires the analyst to understand the search query that is of interest prior to extracting data.

Using the ELT method, tweets would be streamed directly into a data warehouse. Once stored, the data would be transformed and analysed using a suitable software package such as those offered by Oracle, Microsoft, IBM and others. With modern services, like Oracle's Data Integrator Enterprise Edition (ODI-EE), ELT is becoming a more viable method for analysis.[13] Though use of a commercial service is certainly an option that is available, an EDM effort would still need to take place for the analyst to ensure proper procedures are followed. ELT would involve storing a large number of tweets, the majority of which are not of interest to the analyst. However, once the data is stored in a large database, the analyst could decide to perform additional searches.

In the naval maritime environment, where data is flowing relatively quickly, an ELT method using a centralised data warehouse could give analysts the advantage of reaching large amounts of data in a relatively useful format. Currently, very little of the collected data, around 5%, reaches analysts.[14] Bandwidth and connectivity limitations result in data that is hard to download and share. For example, downloading 1 TB of data using the WGS network, at 40,000,000 bits per second, takes 3 days. At this speed, downloading and locally analysing data poses a major challenge. Analysis is largely done locally and is thus bereft of a wide view of the needs of the navy. For this reason, data (sensor) fusion is difficult. Even without considering data-fusion issues, analysts will find it nearly impossible to download, transform and utilise the data being collected.

## 4. Commercial Maritime Environment

Much like the manner in which the naval maritime environment has become digitised, the commercial/mercantile maritime environment, too, has been digitised in order to improve awareness. A more important issue, however, for the commercial maritime environment is digitisation for a future with paperless cargo, and even for autonomous shipping. For countries that desire to operate fully digital ports, and companies that desire paperless operations, there is a cost of entry into the digital environment. Digital systems have replaced other tracking and inventory systems. Digitising for cargo and shipping requires acquisition of data systems. Investment in digitising supply chains enables companies to take advantage of technologies. PriceWaterhouseCoopers (PWC) measured a 4.1% annual increase in efficiency.[15] This increase in efficiency eventually builds and generates a positive return on investment (ROI), but a positive ROI may not be immediately seen. Data systems have associated costs, and these costs are determined by scale, application and maintenance needs.

Striving for a paperless future for cargo is frequently a goal of digitisation in the commercial maritime environment, but digitised shipping is information intensive. It requires:[16]

- High data quality;
- Complete sensor coverage;
- Common data standards;
- Wireless tracking;
- Sensors;
- Data systems.

The pieces need to be in place. The data systems include the waybills, the linkages between systems, and others. Beyond a paperless future, digital systems enable autonomy. Ships themselves are becoming autonomous. Putting the pieces in place allows for different levels of autonomy. Figure 4 shows the levels of autonomy.[17]

Digitisation in the maritime environment has enabled autonomous shipping. Norway is planning to introduce an autonomous freighter in 2018, with autonomous operations commencing in 2020.[18] The freighter, while estimated to cost three times what a ship

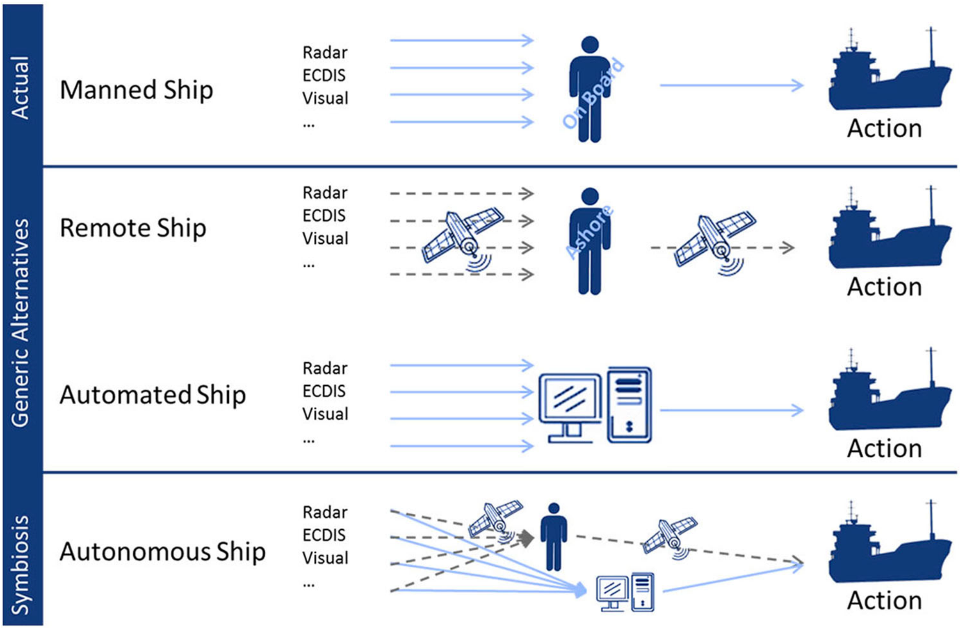

**Fig. 4.** Levels of Commercial Shipping Autonomy.

of that size typically costs, is estimated to save 90% in operating costs. The investment is expected to return a positive ROI within a short time. Computer programming, with the appropriate sensors and communication systems, allows for shipping autonomy.

As with all digital systems, vulnerabilities exist. Incomplete sensor coverage, datalink disruptions, inconsistent data systems and other internal threats exist. Externally, the data systems are vulnerable to the same cyber threats as any data system. For this reason, development and maintenance of the data systems that enable digitisation and all levels of autonomy must have a focus on data security and data integrity.

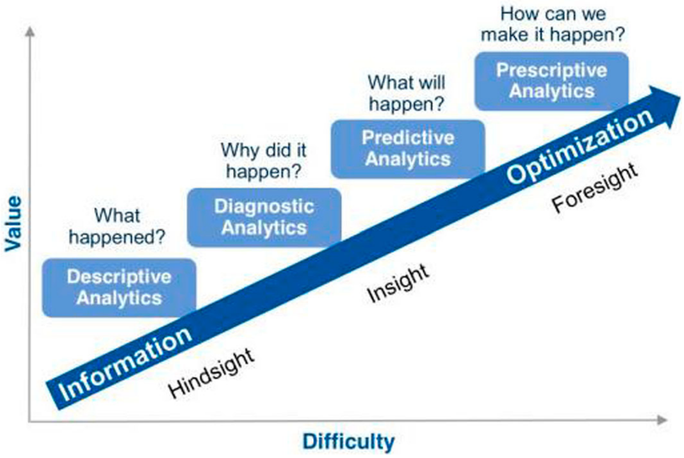

**Fig. 5.** Value and Difficulty of Analysis.

## 5. Data Analysis

Different types of analysis have different levels of difficulty. Before beginning, the service or organisation needs to ask if the goal is to describe what has already happened, or if the goal is to predict what may happen in the future. Descriptive analytics and predictive analytics are two very different types of analysis, but both make use of available data for learning lessons. Figure 5 shows the relative difficulty and value of the different types of analysis.[19]

As predictive analysis is more difficult than descriptive or diagnostic analyses, resources will need to be available to analysts in terms of money, manpower and time. However, both start with raw data that is used for data mining and the arranging of data into a useful database format.[20]

## 6. Big Data

The concept of big data is relatively new and foreign to many analysts. Traditionally, problem solvers would approach a solution by a three-stage process:

1. Identify the problem;
2. Identify the data needed to solve the problem;
3. Solve the problem.

This traditional approach, while still valid, does not take advantage of the benefits of big data. In the world of big data, the data itself comes first. Then, using a variety of modern analytic tools, problems and questions can be developed.

Data sets can be described using a method called the “three Vs” of big data. Big data is data that has volume, variety and velocity. The data can be large, may come in different

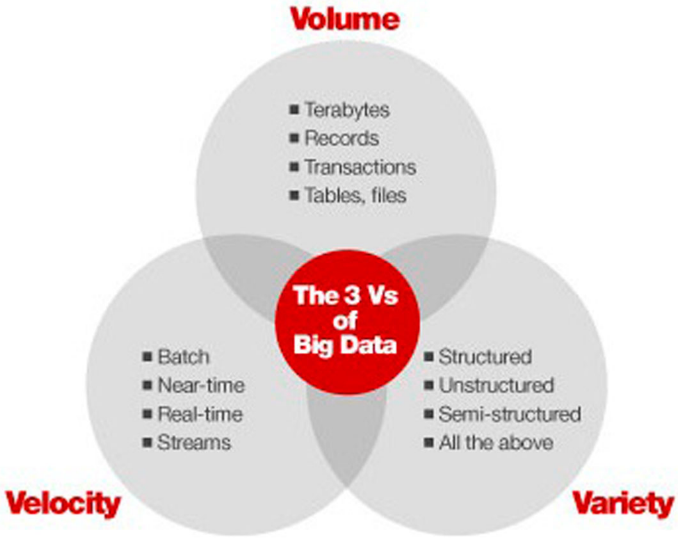

**Fig. 6.** The three Vs of Big Data.

forms, and are typically very quickly developed. Figure 6 shows the three Vs of big data, and some of the qualities that big data has.[21]

The big data approach brings to the forefront some questions that are different from traditional data analysis. First, for a data collector, how do you know what data to collect prior to asking the question? Then, for an analyst, how do you know what question to ask before the data is collected? While collecting data first and then asking the question runs counter to traditional problem-solving, it is how big data can have an impact on decision making. Analysts utilise data first to explore possibilities, and then iterate using knowledge collected from ongoing analysis of the data. It is the use of data to determine what questions can and should be asked which sets the approach for big data apart from traditional analysis. The more data a user has access to, the more likely they are to discover problems, which leads to asking further questions.

This paper has discussed the increasing amount of data being generated. However, the size of the data, as shown in Figure 7, is only part of what makes big data different. The speed at which data are generated and collected, as well as the variety of data being generated, makes the tools used to collect, store and analyse big data diverge even more sharply from more traditional analytic tools.

Big data is envisioned as providing sources of unstructured data that an organisation can use to generate useful and actionable information.[22] Using big data, and the tools that are designed for analysis, an analyst is able to derive complex multivariate relationships that would not be possible without modern, complex data analytics methods. Application could improve customer experience in a business, or it could be used to perform tactical analysis in the military. In business, tools like Tableau, RapidMiner, Hadoop, Splunk and a considerable number of others are available for business intelligence. These tools, or tools like them, could also be used for the real-time analysis of maritime data. Figure 7 shows the amount of data that the US Navy expects to see, from a variety of sources, in the future.[23]

As can be seen in Figure 7, the amount of data increases exponentially as the navy acquires new sensors. The maritime environment is increasingly dealing with data that

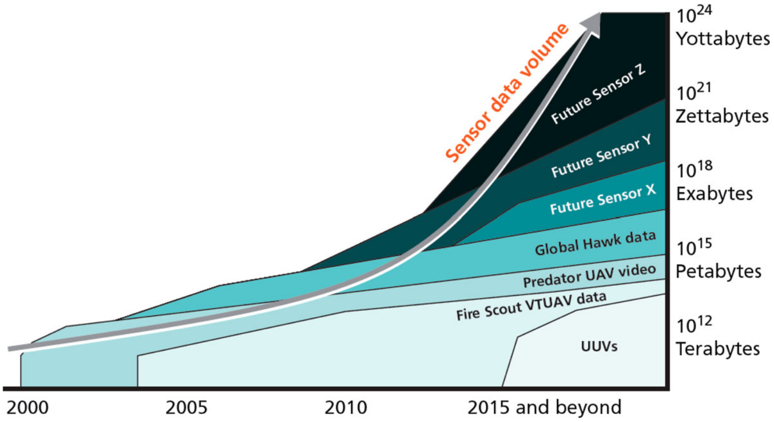

**Fig. 7.** Increase in Data as Navy Sensors Increase. UUV: unmanned undersea vehicle; VTUAV: vertical take-off and landing tactical unmanned air vehicle; UAV: unmanned aerial vehicle.

is unstructured, large in size and quickly collected. It requires data fusion and sensor fusion for actionable information, which requires a suite of tools that are more advanced than traditional data analysis tools. It also requires analysts who understand the tools, and data warehousing that enables the use of the data for real-time decision-making.

## 7. Developing Frameworks

As discussed earlier, the lack of a coherent digitisation plan means that greater amounts of data have been collected and are in need of processing, in turn meaning that available resources have been stretched. Developing a governance framework to utilise data is a major step in analysis. Poor data governance can lead to pitfalls in data collection and utilisation. The *Data Management Association Guide to the Data Management Body of Knowledge* (DAMA-DMBOK) is an example of a data governance framework that can be used when envisioning, planning, executing and operating a data system. The DAMA-DMBOK framework is shown in Figure 8.[24]

**Fig. 8.** DAMA-DMBOK Framework.

The DAMA-DMBOK framework includes data architecture management as well as its development, operations management, security management, warehousing, and quality management. It is unlikely that any framework such as this was used as a basis for developing the analytic capabilities of a digitised maritime environment, in either the naval or the commercial realm. The process of how digitised systems were developed as technology precludes the use of a cohesive data governance framework. An important part of having a digital environment is maintaining the integrity of the data systems. Even the most well-thought-out data system can become obsolete if the system is not properly maintained. DAMA-DMBOK represents a data-governance framework. Together with data governance comes the systems development life cycle (SLDC). Both are necessary. The SLDC includes design, coding, testing, maintenance, planning and analysis using a data system. SLDC (Figure 9) and the DAMA-DMBOK (Figure 8) are important, as they show the cyclical nature of both data-governance and life-cycle development.

A very important aspect of data systems is the need for those data systems to be maintained. Maintenance of a data system is often overlooked as it is considered to be a less "glamorous" step, but is highlighted in Figure 9.[25]

Once a database is developed and operational, the job of maintaining that database is key to continued operational viability, relevance and data quality. User feedback may result in changes to the database that must be planned, analysed, designed, developed, tested, implemented and then maintained.[26]

The use of frameworks such as those shown in Figures 9 and 10 helps decision makers to design a data-governance and system life-cycle plan that includes the necessary points. Without beginning with a standard framework, system designers may miss important pieces.

## 8. Managing Data Analysis Workload

Navies need to have the ability to dynamically manage workload. In the US Navy, analytics specialists work on "local tasks". Allocation of tasks tends to be based upon which analysts

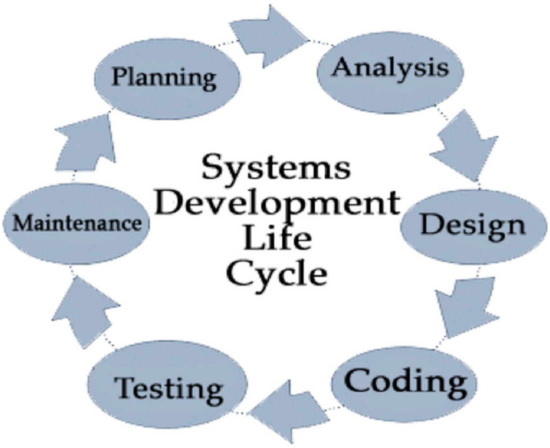

**Fig. 9.** The Systems Development Life Cycle. Source: Hina, "System Development Life Cycle", 2016, https://softwarekno.blogspot.com/2016/09/system-development-life-cycle.html

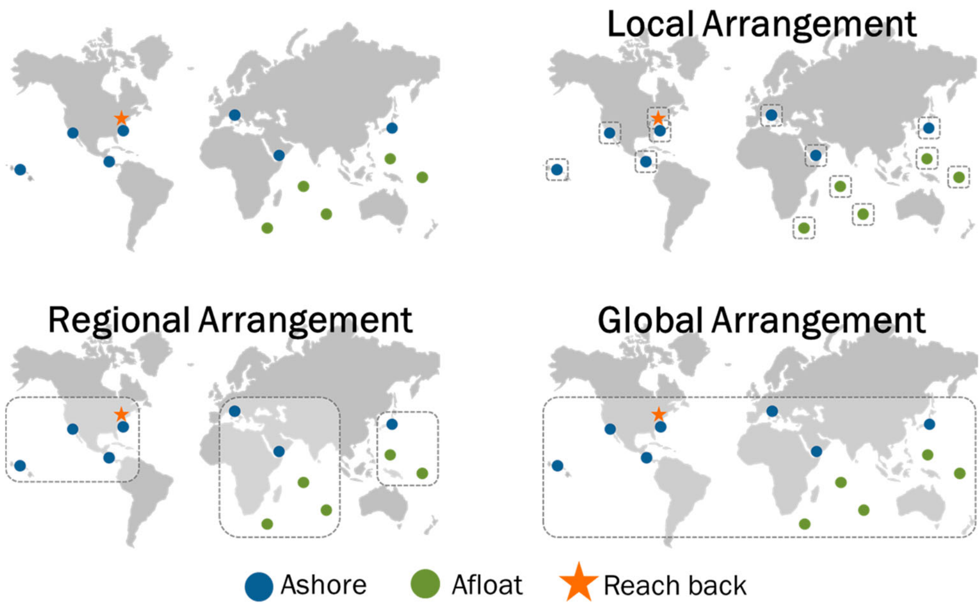

**Fig. 10.** Analyst Arrangements for the US Navy (Locations Are Notional).

are nearby or statically assigned. As can be seen in Figure 10, the US Navy has analysts around the world.[27]

Using the local arrangement model (top right of Figure 11), analytic specialists in one location can become quickly overwhelmed with tasks that may not necessarily be assigned to them. To better take advantage of movable digital data, tasking models that operate at the regional (Figure 11, bottom left) or global level (Figure 11, bottom right) outperform local model in terms of the productivity. Models in which tasks are automatically shared based on who is available to accept new tasking are better. Implementing a regional or global tasking model might buy the navy short-term improvement, but even the improvement shown in regional and global analysis needs more. Figure 11 shows the relative improvement of the regional and global over the local.[28]

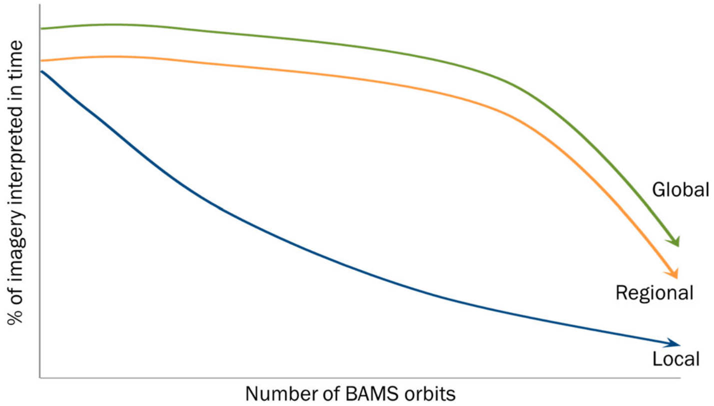

**Fig. 11.** Imagery Interpreted in Time vs Number of BAMS Orbits.

As can be seen in Figure 11, regional and global analysis show an improvement, for a time, over local analysis. An issue within the US Navy is that databases are unconnected. This is due to many factors, but partially due to the lack of a data-governance plan and the era in which many of the databases were initially developed. The result is that analysts must learn about the databases, what they contain, how to access them, and how to analyse. Even after an analyst learns all the databases he or she may need to use, the analytic arrangement can still be a limiting factor. Even the "regional" and "global" have an eventual decline, which means more needs to be done. Changes to how workloads are managed are not, on their own, a sufficient long-term solution to the Navy's big data challenge. To be complete, a solution must involve changes in four dimensions. Solutions must include:

1. People;
2. Tools and technology;
3. Data and data architectures;
4. Demand and demand management.

To operationalise, secure connectivity for data-sharing is necessary. Recommendations for the US Navy include adopting the cloud approach. The Navy should design its next generation of intelligence, surveillance and reconnaissance (ISR) tools and systems to work with the current distributed "cloud" concept employed by other agencies in the US government.[29] Integrating and leveraging an already-developed distributed cloud architecture will enable some reach-back for analysis and help analysts cope with the increasing variety and volume of data, thereby improving their ability to help commanders make better decisions. This information architecture should be sufficient to meet the growing volumes of data that will need to be harvested and thus enable viable tasking, collection, processing, exploitation and dissemination (TCPED) operations in the future.

Outside of the US Navy, further utilisation of Command, Control, Communications, Computers, and Intelligence ($C^4I$) infusion centres for maritime cooperation can and should be studied. This should be done beyond white-shipping, but potentially using the same concepts that organisations use to share white-shipping data. For the goal of enhancing MDA, the development of a data-sharing agreement such as the 2016 "statement of intent" between the USA and UK could be used as a good next step.

Only when global data management is coupled with investments in people, tools and technology, data and data architectures, and demand and demand management, will the US Navy be on a more sustainable path for data analysis.

## 9. Conclusions

This paper has discussed how rapidly the amount of collected data has grown over time, the impact on the naval and commercial maritime environments, analysis, big data, how frameworks can be used to design data systems and how the US Navy manages its data analysis workload. The ultimate goal of data utilisation in the maritime environment is to improve maritime domain awareness. MDA has always been the goal of adding data collection systems to the maritime environment, from the earliest sonar and radar to modern sensor systems. Collecting, storing and analysing data have an associated cost.

Models for and investments in data-infusion centres ashore are in place in critical maritime regions around the world, and the demand for them will likely grow in the coming years. If data is being collected and not used, then funds are being utilised to collect data for no real purpose. The value of data is not in the amount which can be collected. Rather, it is the value of the information developed using the collected data. Data, in its raw form, has little value. Actionable information, developed using that same "raw data", has very substantial value. Sustained collaborative work with global analysis to ensure ongoing relevance and efficient accessibility is the key to successful digitisation across the maritime community.

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