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Creating and Managing Mega-Data on Sydney's Mega-Projects

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ABSTRACT

Sydney's mega-projects demand increasingly more from surveying, monitoring, navigation systems and other technologies. NorthConnex is a 9 km long series of twin-tube road tunnels in Sydney, NSW, currently under construction by the Lend Lease Bouygues Joint Venture. This paper outlines how a variety of clever and effective systems have met the challenges of data management across a project of this scale. On NorthConnex, there are a multitude of examples of how things are being done in new ways. Surveying systems are being challenged by such large projects: both in the checking of and dissemination of design data, but also in the capture and processing of as-builts and monitoring data. Private mobile communication networks and underground WiFi systems are the end-point in supporting many initiatives, and there are many yet to be realised by such an open and well-adopted platform. Navigation and machine automation systems drive these tunnels ahead. Such systems now move the machine hardware and the navigation systems even closer, providing an ideal platform for machine control and integrated data capture. Today, underground crews can capture data in the tunnel and perform processing and checks of the data with a few clicks, then approve and send the data to office teams instantly.

KEYWORDS: *Tunnelling, monitoring, 12d Model, automation, navigation.*

1 INTRODUCTION

NorthConnex is a 9 km long series of twin-tube road tunnels in Sydney, NSW, currently under construction by the Lend Lease Bouygues Joint Venture (NorthConnex, 2019). The tunnelling portion of this project involved, at its peak, the use of 20 road headers for tunnel excavation (a record in Australia at the time). For most of the construction period, all these machines were used simultaneously and operating on a 24/7 schedule, requiring a correspondingly high amount of construction survey support for set-out, as-built, conformance and much more.

In addition to the tunnelling, other construction activities include the project's northern and southern interchanges, comprising 3 km of roads and multiple bridge widenings. As such, the project requires the creation, capture and verification of an extraordinary amount of design, survey, deformation monitoring and construction work, under constant time, cost and quality pressures. This paper outlines how a variety of clever and effective systems have met the challenges of data management across a project of this scale.

2 THE CHALLENGE OF MEGA TUNNEL PROJECTS

2.1 Survey Data Management

2.1.1 Survey Specifications and Quality Assurance

Adherence to survey specifications (e.g. G71 Construction Surveys – see RMS, 2018) and best-practice procedures by large-scale civil contractors has traditionally been quite low. NSW Roads and Maritime Services (RMS) has recently indicated that it is taking a hard-line approach to the way surveying is managed on projects and committed itself to conducting more extensive and frequent audits. NorthConnex, as a large, high-profile project, was held to a high standard of quality assurance and adherence to the specifications, requiring innovative solutions in survey procedures. Traditional surveying practices and workflows would not meet those needs.

2.1.2 Survey Teams

Due to the size and scope of the project, up to 75 surveyors were required at peak periods. These surveyors came from a wide range of backgrounds with high variation in:

- Survey coding standards (if present at all).
- File and model naming conventions.
- Data management procedures (formal or otherwise).
- Skill level and experience.
- Minimum levels of acceptable quality.

The project needed to adopt novel ways of managing a diverse survey workforce to ensure a consistently high-quality and time-efficient output.

2.1.3 Field Procedures and Survey Deliverables

Management of design and survey data has traditionally been quite poor and of an informal nature on even the largest infrastructure projects. Design information is often poorly controlled once issued, with surveyors and others having various revisions, sometimes out-of-date. Furthermore, such design information is rarely controlled or handled in a way to prevent unauthorised alteration, allowing users to modify critical design information (deliberately or accidentally).

Building 3-dimensional models for set-out is often left to the surveyor, with inconsistent methods, results and occasional double-handling all typically present on projects, regardless of size. Centralised storage and consistent distribution of survey control was noted as being one of the most important objectives of this work. Similarly, field information is usually stored on the local drive of field tablets, offering poor data security and infrequent, unreliable or totally absent backup of a project-critical resource. There exists no consolidated, authoritative source of design or survey data from which to build, create important project documentation or act as a reference source-of-truth for the project. Figure 1 shows the challenging environment in which survey teams are required to execute their tasks.

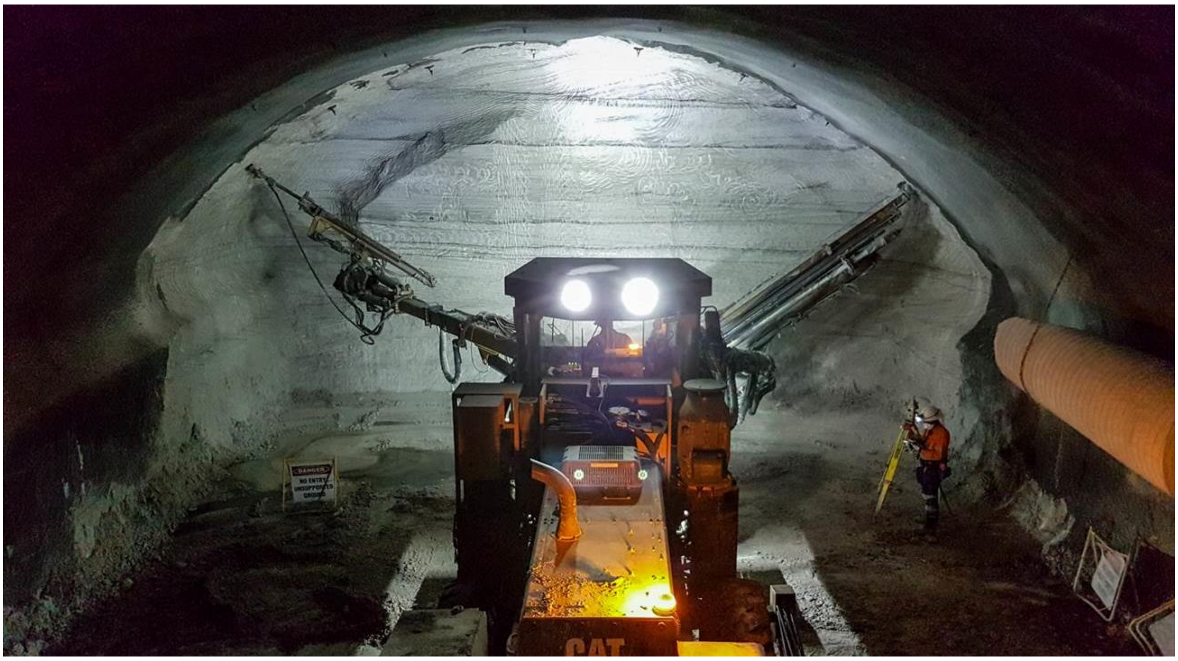

Figure 1: Bolting, grouting, survey as-builts and convergence monitoring in close proximity.

2.2 Monitoring Data

A complex monitoring program was developed within the design documentation for NorthConnex. From a survey perspective, significant responsibility existed for the regular and reliable collection of tunnel convergence data by manual means. Similarly, surface monitoring arrays above tunnels in low cover areas or near third-party assets required regular measurement in difficult-to-access environments.

A multitude of automated systems was required to manage accessibility, safety, resource limitations and notions of real-time, continuous data collection. Requirements for disseminating the data to engineering teams and Permit To Tunnel meetings (PTTs) were regular and voluminous.

2.3 Navigation Systems

Data for road headers and bolters had to be prepared, checked and distributed to multiple sites, with multiple machines on each site. Many impediments to this exist:

- Multiple machines.
- Changing plans by site teams.
- Multiple machine geometries need to be considered.
- Keeping data held by survey teams synchronised with that on the machines.
- Keeping both above in sync with changes to excavation class.

Figure 2 illustrates the proposed construction methodology and technology systems.

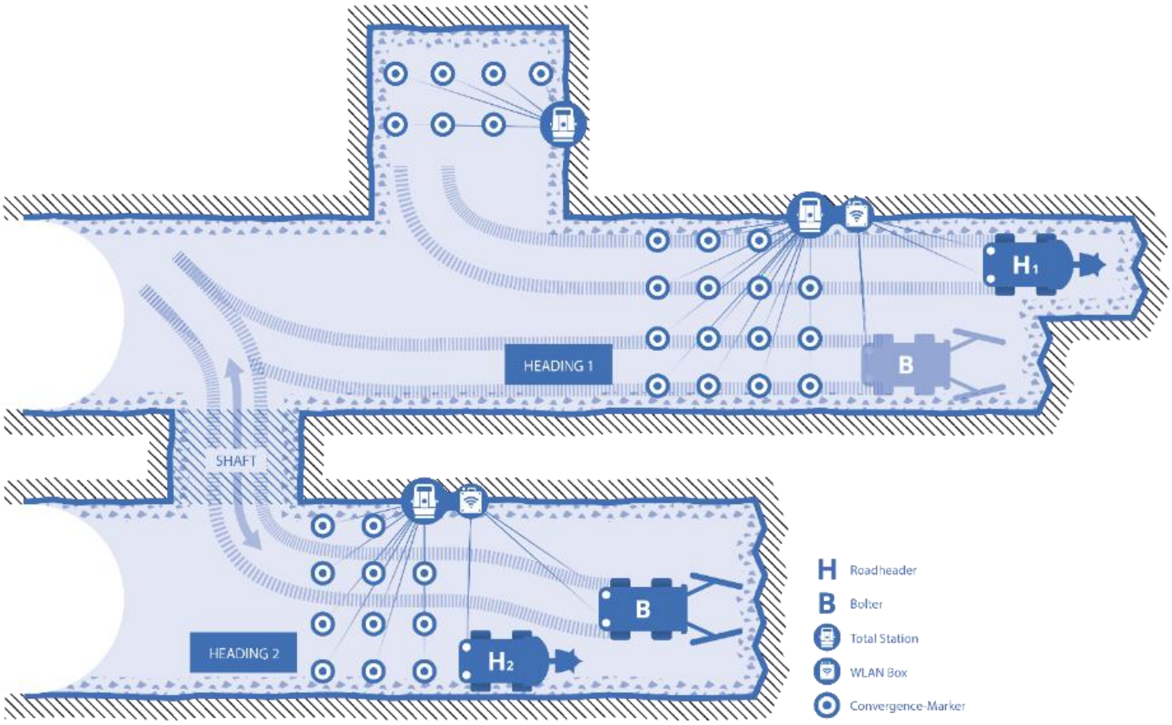

Figure 2: Proposed construction methodology and technology systems.

3 MEETING THE CHALLENGE

A strategic instrumentation and software plan was developed to base all survey work on a single platform of high-end ruggedised field tablets running 12d Model software with 12d Field exclusively used during the construction phase. This was recognised as being the ‘beating heart’ of the survey system upon which all other decisions would be based.

3.1 Survey Data Management

3.1.1 Distributed Data Model

A single, consistent platform allowed for efficiencies to be gained from streamlining of training, support, customisation and procedures whilst still being able to cover all the needs of the surveying function. The adoption of such an approach allowed for the seamless and traceable transfer of rich data amongst the survey team.

3.1.2 Centralisation of Data Storage and Processing

In order to simplify the management, control and issue of the large amount of survey data, the concept of a Central Data Model (CDM) was created. The CDM comprises 12d Model projects for design, survey, utilities, tunnel, imagery, cadastral and survey control marks. Customisations for 12d Model, 12d Synergy, third-party software, help documents and training tutorial videos were also stored in the CDM. Each aspect of the CDM can then be further split to allow for finer control, easier management and the future size of the projects.

Primarily, the CDM provides:

- A single, centralised source of truth for all data.
- A secure, managed, version-controlled and backed-up source of field work and design data.

- A formal, consistent workflow for data management on the project.
- A live, as-built model of the entire project, assembled as surveys are completed, rather than the traditional method of building an as-built model at the end of the project.

3.1.3 Customisation of 12d Model and Field Processes

The entire 12d Model was customised to best suit the project requirements and streamline workflows. Providing a consistent interface across the project helps a diverse survey workforce provide identical outputs, regardless of skill level. All field work processes were reviewed to allow for:

- Easier use (i.e. touch-friendly, small-screen-friendly) on field tablets, e.g. using tick boxes, minimising typing and automatic population of fields.
- Compliance with survey-specific quality standards (RMS G71 Construction Surveys) and providing an audit trail for all data.
- Standardised naming conventions, inputs and outputs.
- Off-line use (i.e. with no network connectivity).

As an on-going process, the project goal is to have the surveyor in the field as much as possible, being able to produce and deliver reports, plots and calculations, and make assessments without leaving the site. Processes are continually reviewed based on surveyor feedback and assessed against key performance indicators. Any future enhancements can be automatically delivered to all surveyors, allowing for productivity gains to be realised immediately.

Although the NorthConnex project is unique in being one of the first projects in Australia to have a WiFi network available in the tunnels, all field procedures and processes have been developed on the worst-case assumption that no network connection will be present.

This presents unique problems and requires innovative solutions in providing the surveyor with the most up-to-date design and survey information to build and also receiving data collected in the field. Solved through the adoption and customisation of 12d Model and 12d Synergy software, our selected solution performs the core functions required for this project.

3.1.4 Survey Specification and Quality Assurance

All submitted field work data has an assigned quality class, reflecting its adherence to the requirements of the RMS G71 specification (RMS, 2018). When exported, a report file summarises the submitted data, including how and why it met or failed the specifications and the quality class assigned. This provides the user with immediate feedback as to the quality of their survey, allowing them to correct or redo their survey to meet project requirements, before it is reviewed by managers. This quality class record travels with the submitted data as it travels through the survey workflow. At each step, various macros and processes add extra data to record the progress and actions taken at each step: export, post-processing, review, approval or rejection and, finally, import into the CDM. This provides an extensive and thorough audit trail that successfully meets the RMS and project quality requirements with no extra effort required from surveyors or managers.

By automatically assessing data for quality standards, the review process by managers is streamlined and greatly improved. The corresponding reduction in time spent managing and reviewing data means that more time can be spent on other, more important aspects of surveying for the project. Assessment of the quality of surveys also allows managers to identify deficiencies in training or skills and provide remedial training, action or revise processes.

3.1.5 New Features and Innovation

This project has contributed to the development and testing of new features and functionality for multiple contributing suppliers. It is leading the industry on many such features, including:

- Tunnel scans (using Leica's MS50 instrument).
- Tunnel set-out, including from trimesh objects.
- Tunnel conformance plots and reports.
- Tunnel definitions on alignments.
- Conformance analysis and assessment on scans using 'heat maps'.
- Management of point cloud data.

3.2 Monitoring

3.2.1 Monitoring Point Density

In its peak implementation on the project, rail monitoring points were installed at a density of 2.4 m on each rail for approximately 150 m in the North Shore rail corridor. Three Leica TM30 total stations provided monitoring datasets every 2 hours, with the ability to be triggered for continuous measurement if required. Track monitoring calculations take observations to approximately 400 monitoring prisms and covert them to over 1,000 virtual measurements, which are consistent with Sydney Trains monitoring limits for top, line and twist.

The choice of monitoring target shows that not all technology is found in silicone and software. Behind all survey data are the measurements themselves, and their integrity. The KODABlock track monitoring target (Figure 3) was pioneered for, and tested on, the NorthConnex project based on expectations of (1) a long monitoring period, (2) extremely close scrutiny of data, and (3) likely interactions with track maintenance and construction crews. The outcome was extremely successful in that (1) the target system was installed quickly and safely, and (2) despite damage to the mounted prism by various sources (including tamper machines), the block itself remained in place and allowed simple replacement of a new prism to within ±1 mm of the previous mark.

Figure 3: KODABlock track monitoring target.

3.2.2 Storage and Management of Data

All monitoring data for the project is stored within the Kronos Instrumentation and Monitoring Database (KIMDB) system. The KIMDB system features a Microsoft SQL Server database and a desktop and web client for management and viewing of data.

The KronosCollect data format specification provides a clear, outward-facing interface for the easy uploading of data directly into the system. For example, this allowed the convergence monitoring data from field tablets to be exported directly to the '3D_MR' data format and directly loaded into Kronos via FTP continuously as new files were generated.

3.2.3 Assess and Approve

Convergence monitoring is a tunnel construction process, which identifies settlement or straining of newly constructed tunnel for the purposes of design verification and safety. Many methods exist, but commonly survey targets are anchored through the tunnel shotcrete lining into the excavated rock and regularly measured via total station techniques.

Very soon into the excavation phase of the project, the survey management teams realised the importance of standardising even further the workflows for tunnel convergence monitoring. Several problems emerged, including (1) small errors in point naming meaning that data was either allocated to incorrect points or not at all, and (2) surveyors were nervous about blindly loading data into the KIMDB based on no knowledge of previous movement or whether marks had been disturbed by construction activities.

To this end, a macro-driven application was developed that allowed a direct connection to the KIMDB. This allowed (1) automatic fixing of point names, (2) semi-automatic assessment of new measurements against previous trends, (3) proper establishment of new monitoring points, and (4) submission of data directly from the tunnelling face. In doing so, ownership of the data collection process was maximised before data was made quickly available to other disciplines.

3.2.4 Reporting

Extensive, regular reporting requirements existed for all monitoring data. Primarily, the reports are used as incoming information for PTTs, based on which decisions about the next phase of construction can be made. In most cases, these meetings are held daily, with monitoring data reports forming part of the permanent record for the project. As such, the accuracy, clarity and timeliness of generating of these reports is paramount to project success.

The KIMDB features an extensive automated reporting system in which packages of PDF reports are templated, grouped and executed at required intervals. Reporting templates are standardised based on common tunnelling workflows and based on the various different types of survey, geotechnical and monitoring data available.

3.2.5 Managing Monitoring System Deployment

Frequently overlooked with monitoring system deployments are a few key considerations that would assist with the management of systems:

1) Mechanisms often do not exist for the reassessment of monitoring requirements based on design changes or new information about geology, in-situ objects or third-party assets found. Often it is easy to do more than is specified, but very difficult to do less. Sometimes

the purpose of monitoring is vague, which hinders the ability of experienced professionals to apply their skills to the task at hand. Furthermore, often the method of monitoring is directly specified, rather than the purpose. Adding in the purpose (or intent) would allow alternative systems to be considered that would achieve the same objective.

2) Mechanisms for ceasing monitoring are often poorly defined, and as such, responsible parties are not confident in doing so. Similarly, well-defined mechanisms may exists, but people involved at the establishment of monitoring no longer fill the same roles, leaving new occupants hesitant to easily follow through the process.

The outcome of both of these scenarios is that a lot of work is completed that has no engineering merit.

3.3 Navigation

3.3.1 Large Number of Machines

The challenge of the large number of machines (20 road headers and 13 bolters) is slightly reduced by the division of the project to four main tunnelling sites which, for most of the construction period, remain unlinked. As such, the complexity of the data management task can be reduced.

Synchronisation of construction data across construction machinery and survey tablets is driven by the non-standardised environment in which changes to the data may be generated. Changes to the construction data model may be generated by (1) the PTT process in which a change of rock class is needed, i.e. changing the size of the tunnel and the bolting pattern dimensions as draped over that design tunnel, (2) changes of the construction phase in which benches are advanced and transitioned up to the top heading height, and (3) changes of the road header type which has different cutting heights, requiring changes in bench heights.

Bolters, while standardised in size and type on NorthConnex, are the most mobile of machines and are shared, generally, between two faces, but often more. As such, bolters require synchronisation with all relevant data in the area they are operating. An additional complication is that bolters often spend more of their time disconnected from the tunnel WiFi network while travelling or parked up and powered down.

Not all of these challenges were elegantly addressed, but ideas arising from these challenges currently form the basis of new ideas ready for implementation in 2019's new projects.

3.3.2 Construction Data

Conversion of design data to a constructible model for distribution to road headers and bolters comprised a significant full-time role. Initially, while the number of machines was low and systems were being developed, this remained a centralised role. Eventually, as the task both grew and matured, this was distributed out to the site survey team leaders.

The task of creating the constructible model for tunnelling machines requires the implementation of transitions, temporary headings and benches. In many cases, preparations need to be made for multiple rock class types. The generation of the constructible tunnel model is generally guided by the inherent characteristic of the navigation system software. On NorthConnex, this posed some limitation when the bench definition method was not optimised for handling frequent, complex changes as required by ramps and difference in machine reach.

Conversely, the supplied system provided some market-leading ideas. Worth mentioning is the advanced profile transitioning process (Figure 4), which provided techniques for creating and validating complex transitions in an easy-to-use desktop software package. Traditional methods required one-to-one element relationships to exist from one profile to the next, often requiring some pre-planning and a skilled user to implement in complicated situations. With the supplied software, many-to-many profile transitions were able to be managed easily and accurately.

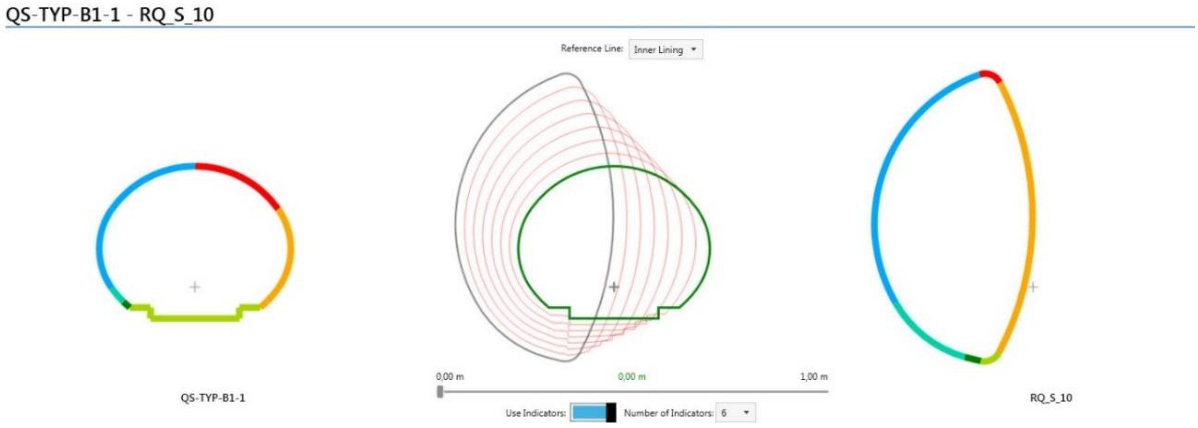

Figure 4: Advanced tunnel transitioning method and interface.

4 FUTURE APPROACHES

Lessons learnt are inevitable on projects of this size, length and complexity. The approaches mentioned in this section feature in the systems developed for, or currently in the bidding stage for, 2019's new road tunnelling projects.

4.1 Management Approaches

One needs to be prepared to implement systems which are flexible and acknowledge the stage and maturity of the project. Initially, when underground communications systems are either not present or not fully implemented, the idea of carrying full datasets is relevant. Then, when projects develop, and it is possible to rely upon communications networks, benefits are seen in a more on-demand approach in terms of the area of work, but also the task involved (e.g. monitoring data only when performing convergence readings). It is also important to acknowledge how new or developing systems can challenge the experience of specialist tunnel survey contractors.

4.2 Reactive Construction Model

Concepts have been developed to provide real-time design at the construction face. Distribution of the data is via site IP networks, often held at edge devices in key locations underground. By implementing such systems, the project can expose simple methods for changes to be made without the exhaustive delays surrounding communications delays, approvals, implementation and then distribution of the data. The responsible party makes changes to the design using a simple interface and the changes are version-controlled, and reflected to road headers immediately. Bolt patterns are re-generated and then distributed to bolters whenever they are nearby and require bolt patterns to work.

This approach potentially creates a liability of having to preconfigure all possible future options. Optimising this process should be possible based on expected ground conditions. Looking further ahead, approaches for even further parametrising profile data may simplify the definition of many rock class types.

4.3 Volume Logging

Traditionally, excavation progress is tracked via ‘maximum face chainage reached’. This can have limitations, least of which are (1) varying face size, and (2) uneven or curving faces. This means that in many cases the amount of work done is vague, or incomparable to other work areas, or is simply inaccurate. Properly assessing the true productivity of different teams and machine types becomes difficult when faced with this.

Enhanced representations of construction progress are possible through volume logging. Such approaches are not intended as a replacement for survey-grade as-builts, but instead as a valuable spatial output with sufficient accuracy for project management purposes. Known implementations have been developed since as early as 2005 by some suppliers but, to date, use by the industry is limited. Of course, generating the data is one milestone, but modern methods of dissemination and reporting via web and mobile systems might be the technology these ideas need for greater adoption in practice.

4.4 Information Systems

Modern data visualisation systems (like Tableau) are suitable for distribution and representation of many under-utilised or previously unavailable information sources. Many commercial and open-source systems can integrate real-time enterprise solutions with static or manually uploaded data sources like CSV or Excel. In this way, there are a multitude of options for incrementally improving the value of these systems by adding in additional and historic data (e.g. shift rosters, shotcrete delivery records, road header pick consumption and rock class). These all add additional dimensions, from which insight can be extracted about the construction process (Figure 5).

5 CONCLUDING REMARKS

Collection of tunnel construction data is happening at ever-increasing scales – both spatially and temporally. Projects measure more and more of our constructed objects, to a higher density, and more often. Managing data continuously and from the beginning of the project, to a high standard, is a crucial determinant of success.

In the future, spatial professionals will need to continue their efforts towards assisting other disciplines in understanding data, its accuracy and its limitations. Conversely, a challenge exists for spatial professionals to gain comfort in providing data that is useful, but not necessarily at the highest of standards, rather than providing no data at all (e.g. excavation volume estimation systems).

Despite all the work done to date, and the massive changes, there are still many opportunities waiting to be exploited, with significant benefits to be had. The importance of implementing systems that are open or customisable through database connectivity standards, Application Programming Interfaces (APIs), macro programming languages and innovation-centric design of systems cannot be understated. Due to the large amount of up-coming work (in Sydney alone), projects and companies working in this sector find fertile ground for continuous and confident innovation.

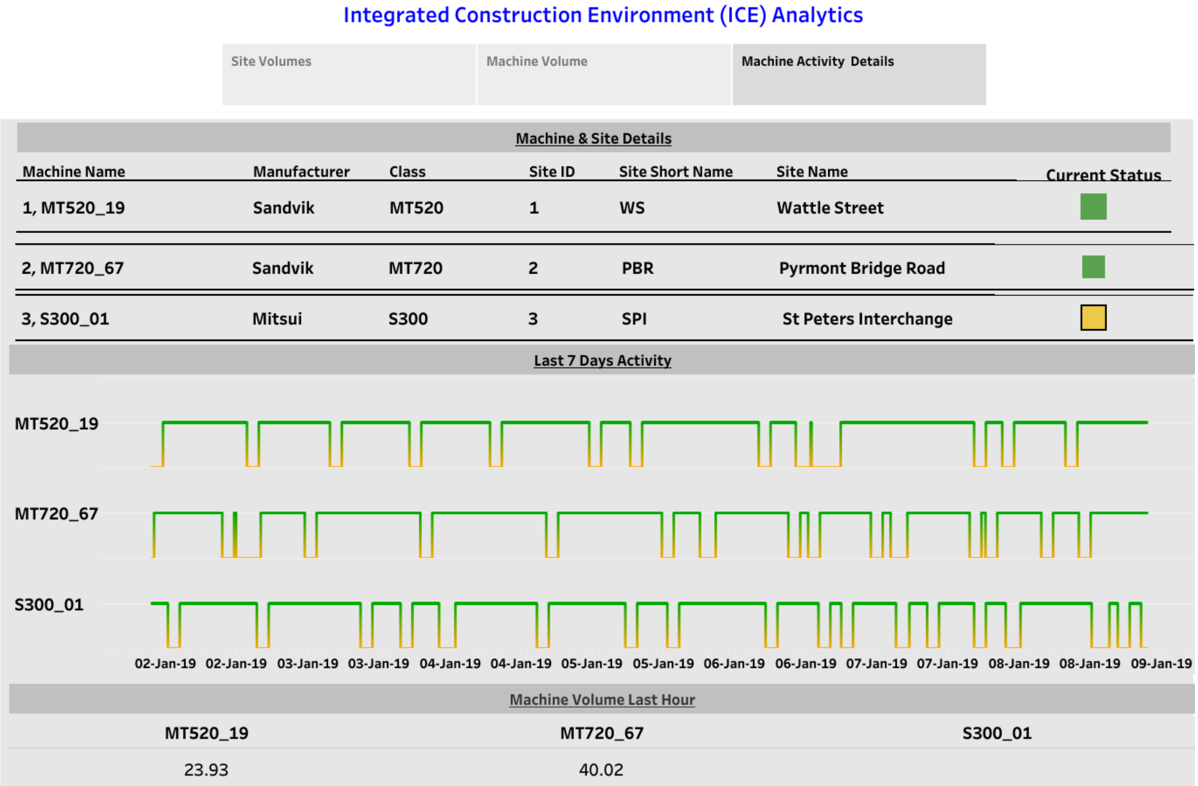

Figure 5: Prototype Integrated Construction Environment (ICE).

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