Integrative Feedback Loops: Optimised tunnelling with digital platforms to improve efficiency, safety, and sustainability through a paperless Permit-To-Tunnel process.

K. Macintosh
John Holland, New South Wales, Australia

R. Hawkey, J. Walton
Deswik, Queensland, Australia

P. Gaylard
John Holland, Queensland, Australia

ABSTRACT: As the global push for net zero accelerates, hydropower is regaining prominence. The Kidston Pumped Hydro Project in Australia showcases innovation in this space through the Integrative Feedback Loop (IFL), developed by John Holland and Deswik. Originally designed for mining, Deswik's software suite was adapted to civil tunnelling to enhance the Permit-To-Tunnel (PTT) process. The IFL integrates real-time data—geological mapping, convergence monitoring, and as-built survey scans—into a digital, automated platform supporting observational tunnelling. This enables dynamic design optimisation, improves safety, enhances stakeholder communication, and boosts resource efficiency. The system's visual and data-driven approach reflects the industry's shift toward digitisation and sustainability. This case study highlights how combining advanced software with best-practice processes can transform tunnelling operations, offering a model for future hydropower and infrastructure projects.

1 INTRODUCTION

1.1 *Permit to Tunnel (PTT)*

The Permit to Tunnel (PTT) system was developed to manage and document ground conditions, monitoring data and ancillary tunnelling activities. It was introduced in response to major tunnelling incidents in Sydney, Australia, including a fatal rockfall and a tunnel collapse between 2006 and 2008. The PTT ensures compliance with safety regulations by requiring regular inspections and adjustments to ground support methods based on monitoring, inspection and testing data collected during excavation and progressively thereafter. Implemented in Australia, starting with the Airport Link Tunnel in 2009, the PTT helps ensure tunnelling operations adhere to approved designs and allows observational adjustments to tunnelling activities based on ground conditions. It has been utilised in several major projects, such as Sydney's Westconnex and Metro projects, and it has a notable record of avoiding ground support-related fatalities. (Salcher et.al, 2023). This case study considers the application of the PTT process for New Austrian Tunnelling Method (NATM) excavation processes such as Drill and blast, Road header, and other manually excavated tunnelling. It does not consider the application of the PTT to TBM or pipe-jacked tunnelling methods.

Below is a summary of the key Permit to tunnel detail; for further information, refers to Salcher et al., 2023. The PTT process is traditionally conducted as a meeting at set time intervals; a common time domain would be considered permit coverage for a 24-hour period. Whilst often customised to project need the PTT addresses the following outcomes (but not limited to):

- Ground conditions:
  - Projected geological conditions – captured from preconstruction data and validated as excavated geological mapping (in accordance with NATM).
  - Ground support requirements – based on as-excavated geological mapping and other PTT inputs considered holistically.
- Instrumentation & Monitoring (I&M):
  - Convergence and deformation monitoring
  - Project specific instrumentation readings (Surface and/or underground)
- Ground support-related Quality & As-constructed/executed documentation:
  - Excavation reports
  - Rock Bolt/anchor - Pull/proof tests and grout testing
  - Shotcrete thickness reports and adhesion testing
  - Survey control checks to validate alignment.
- Ventilation & Atmospheric Data:
  - Ventilation readings to confirm the excavation extent is adequately ventilated
  - Planned ventilation changes and/or ventilation-related tasks managed through isolated ventilation management procedures.
- Planned works for the permit period:
  - Planned excavation extent (often recorded in chainage)
  - Proactive - Ancillary support tasks to support tunnelling.
  - Reactive – Ancillary tasks to support tunnelling

1.2 *Limitations to the PTT Process*

The PTT process was reviewed, contrasting its evolution from its 2006-2008 needs inception to its application in tunnelling in Australia in 2024. This review was conducted as a workshop with subject matter experts in tunnelling, underground survey, mining, and Geotechnical Engineering. The IFL working group sought to improve data management through PTT; Figure 1 illustrates the improved PTT framework for information and data control as a result of the IFL being implemented. The findings, specifically focused on the PTT process's strengths and limitations, were then summarised into three (3) key limitation themes (LT). The case study sought to solve these limitations themes by introduction of the IFL:

LT1 - Time/resource draw as a result of an increase in tunnelling production rates and scope complexity:

The traditional PTT process is typically documented using conventional word processing files for each permit period and heading. As tunnelling operations scale up, with multiple tunnel headings active concurrently, the manual management of the PTT— including daily data reviews—can become resource-intensive. For example, during the Sydney Rozelle Interchange project, over 20 tunnel headings were active simultaneously, the administrative demands of implementing the PTT procedure were particularly complex. This complexity has led to the establishment of dedicated PTT staff, resulting in increased project resourcing costs.

LT2 - Risk related to human interaction with data and PTT development:

The review and processing of PTT data, often stored in various storage locations and formats, heightens the risk of human error during data consolidation. Transfer errors from data compilers often require reactive corrections during PTT meetings due to manual transfer errors. Additionally, the traditional PTT process re-quires manual data handling for other outcomes, such as quality or safety, resulting in key information being duplicated in other processes, leading to inefficiencies.

LT3 - Transferability of technical information into a format that non-technical personnel can access and understand:

A critical consideration for the PTT process is its communication and accessibility to both the technical audience and the operational workforce. While the PTT is an effective tool for summarizing excavation status, its ability to convey accessible technical information is limited. The data presented is often in a raw format, which is not easily comprehensible for workforce personnel, thereby impeding its ease of access and utility for individuals who perform non-technical roles.

2 DEVELOPMENT OF THE INTEGRATIVE FEEDBACK LOOP (IFL)

Considering the three limitation themes, the IFL was developed leveraging the Deswik mining solution software platform. The Deswik spatial solution software, together with its Mine Data Management (MDM), Mapping, and other applications, provided adequate customizability and leveraged Deswik's extensive experience in the mining industry to capture learnings with reasonable learnings transferability.

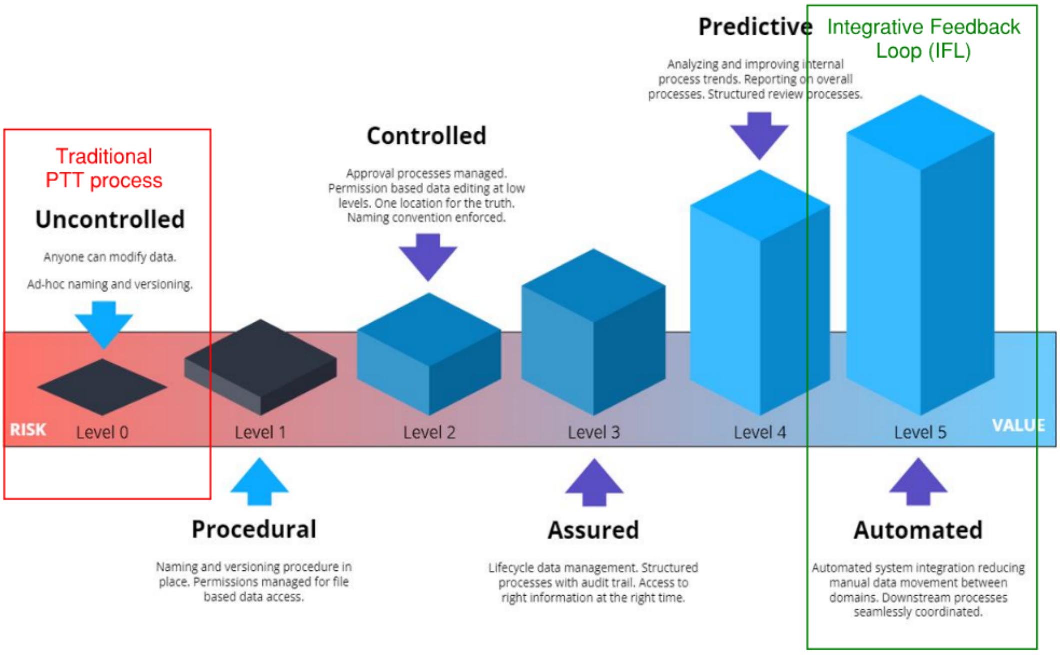

Figure 1. Pre and post implementation of the IFL from the traditional PTT process.

To address LT1 (time and resource draw), the working groups focus was to assess what data inputs were driving PTT outcomes and how handling of the data could be optimized and where possible automated. The table below summarizes the transition from traditional PTT data collection ('Uncontrolled' in Figure 1) to the optimized IFL data storage and collection model (Automated in Figure 1):

Table 1. Comparison of uncontrolled and automated PTT processes

PTT Inputs	Traditional PTT Data collection (Uncontrolled)	Integrative Feedback Loop (Automated)
Ground Conditions	As-Excavated Geological Mapping- Conducted on paper-based mapping form or through a geological mapping application on a tablet or similar.	Integration of the Deswik Mapping tool integrates geological mapping into a live space to review in the IFL model during the PTT. Data is processed in the cloud and automatically uploaded into MDM, digital model and the PTT.
Instrumentation & Monitoring (I&M)	Often taken through manual data reads from equipment or hosted on a cloud platform. I&M applies to both in-tunnel and surface monitoring, depending on the project's needs.	I&M data sets are drawn into the IFL from feed sources stored in the Deswik MDM repository and reported on the PTT through smart process mapping data extraction from the source.
Ground support-related Quality & As-constructed/executed documentation	Collected through either manual recording of data in paper-form or through a survey such as lidar or point-and-shoot collection, saved and attached to quality work lots to demonstrate conformance to design requirements.	Quality data sets are drawn into the IFL from feed sources stored in the Deswik MDM, observable in the model and integrated into the PTT. Any survey files are uploaded by the survey team into MDM where the data/files are integrated into the digital twin model and PTT.
Ventilation & Atmospheric Data	Data is often collected manually and recorded on a word processing document	Ventilation data sets are drawn into the IFL from feed sources stored in the Deswik MDM and reported on the PTT through smart process mapping from the source.
Planned works for the permit period	Completed manually on a word processing document each permit period.	Completed in the digital PTT for each permit period and then workflowed. Once complete, users sign the PTT digitally to approve/acknowledge excavation to proceed. This enables remote users to interact with and monitor the PTT.

Once initiated, the MDM workflow automatically guides users through the tasks relevant to their specific roles. This ensures that all necessary steps of the PTT are completed before the workflow progresses, while also establishing traceability. With the updated IFL data storage and collection model, the redundant processing of data and files used to populate the PTT has been reduced. Responsibility for feeding the PTT is now distributed among different working groups

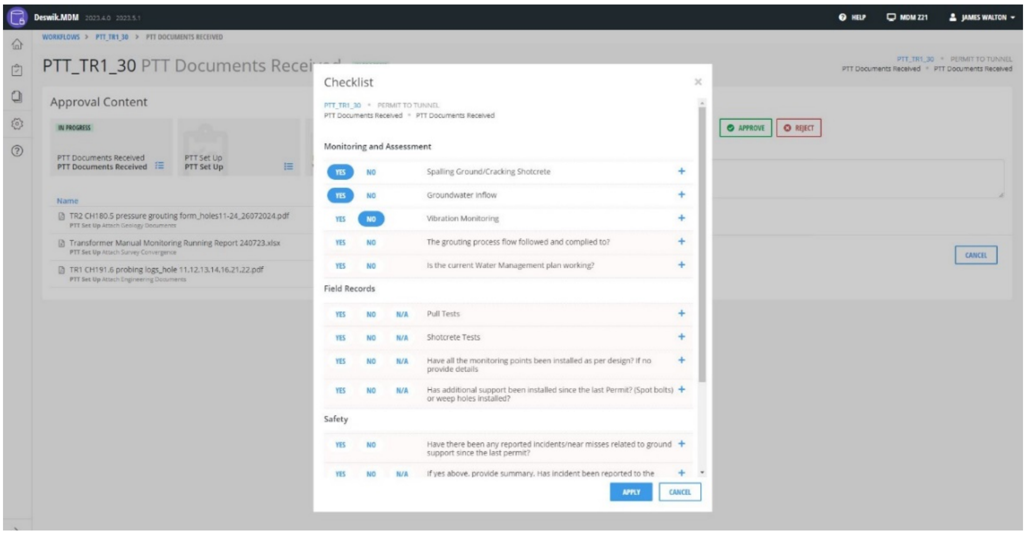

Figure 2. Comparison of uncontrolled and automated PTT processes

(e.g. Survey, geotechnical, Engineering), each contributing the necessary data within a 24-hour period after the previous PTT update. This allows accumulated improvement of the common data model by various subject matter experts, rather than relying on a single resource to compile information from multiple sources. Figure 2 & 3 illustrates the IFL PTT Deswik interface during development and testing.

To address LT2 (Human Error Risk), the same approach as LT1 was used, with a focus on minimizing human interaction with raw data. Raw data is now directly uploaded into the MDM platform and fed into the PTT automatically. For critical information requiring review, the MDM workflow tool allows data to be reviewed and accepted before integration into the PTT. For example, peer review of tunnel mapping or survey/instrumentation data can be done prior to inclusion. Implementing the IFL significantly reduces human handling and processing of raw data by feeding it directly into a digital model, thus lowering the risk of error and data disruption.

In developing the IFL solution for LT3 (Transferability of Technical Information), the working group leveraged the flexibility of Deswik's customizability to improve the visualization of the PTT for both technical staff and the workforce. Each PTT displays the current excavation cut along with key data inputs, providing a comprehensive summary of the excavation as a single source. This enhanced visualization offers non-technical personnel better access to understand the planned work during the permit period and the excavation's current safety status (see Figures 3,4 &5 for an example of a cut summary in the IFL). The 3D model-driven PTT allows interactive discussions during meetings, enhances planning, and enables non-technical staff to export views of the tunnel as excavated, facilitating visually supported communication and instruction to the workforce.

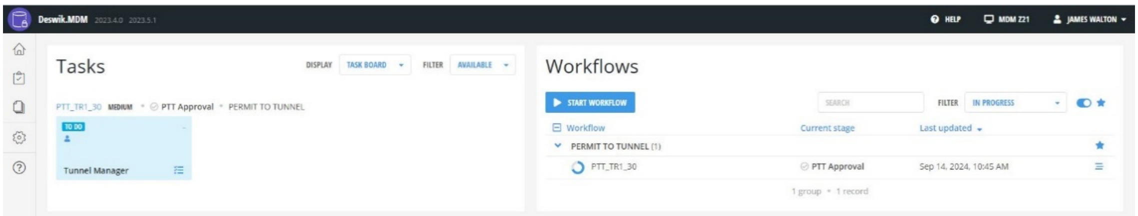

Figure 3. Deswik workflow interface for the PTT.

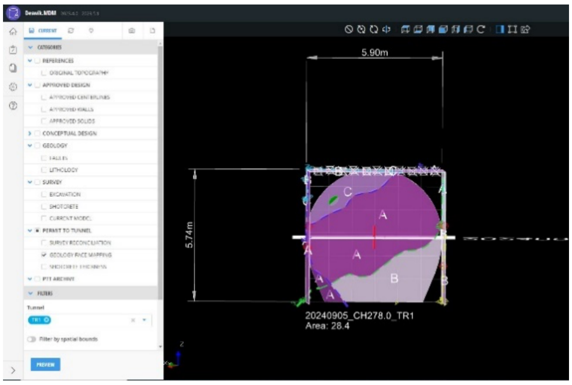

Figure 4. Cross section of geological mapping imported from the deswik mapping tool

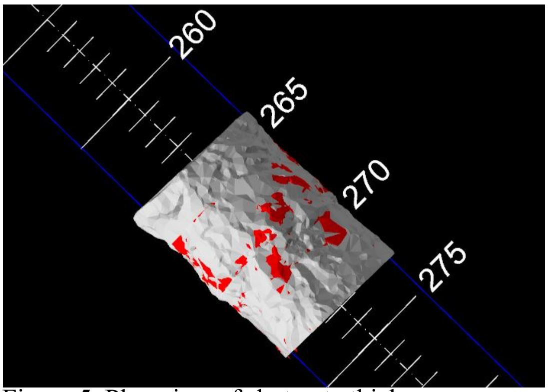

Figure 5. Plan view of shotcrete thickness scan overlay

Live testing of the IFL was conducted on an in-flight pumped hydro project in Australia, successfully validating the effectiveness of the digitalized process. The IFL PTT was tested alongside the traditional PTT process, focusing on a single heading to demonstrate its efficiency, with the expectation that the same approach could be easily adapted for multiple headings within the software. Testing the IFL in parallel resulted in fewer instances of human error during data input and reduced the administration time for PTT end users by distributing input responsibilities across key project teams with implementation automation of data processing.

3 LESSONS LEARNT

The IFL has demonstrated its effectiveness in NATM tunnelling projects where high production rates, complex geometry, or multiple headings are managed under the PTT process. However, its efficacy appears to be limited in projects with single-heading excavations, slow production rates and/or minimal complexity. Further assessment would be needed to evaluate the true time savings and risk control in such cases. An unexpected but valuable outcome from LT3 was the benefit of viewing the model when analyzing the PTT and its interactions with multiple interfacing excavation headings. This allowed the working group to visualize geological features and monitoring information in a holistic manner, considering how each heading might interact geotechnically with the excavation scope. Figures 7 and 8 illustrate the advantages of model visualization when managing multiple headings and their interactions. The transfer of raw data from Deswik MDM to drive the PTT process was largely successful, though further refinement is needed to optimize how raw instrumentation and monitoring data are imported into the platform for improved inputs into the IFL.

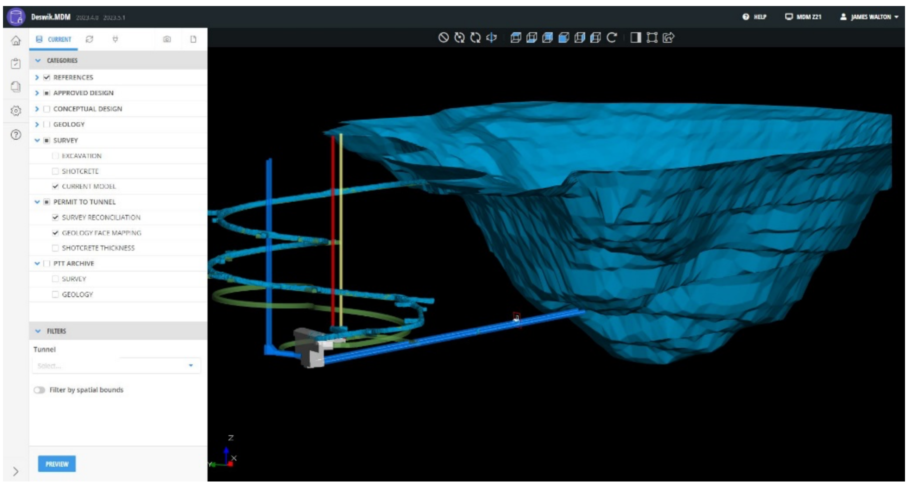

Figure 6. The whole model view showing the ability to review multiple headings in PTT holistically.

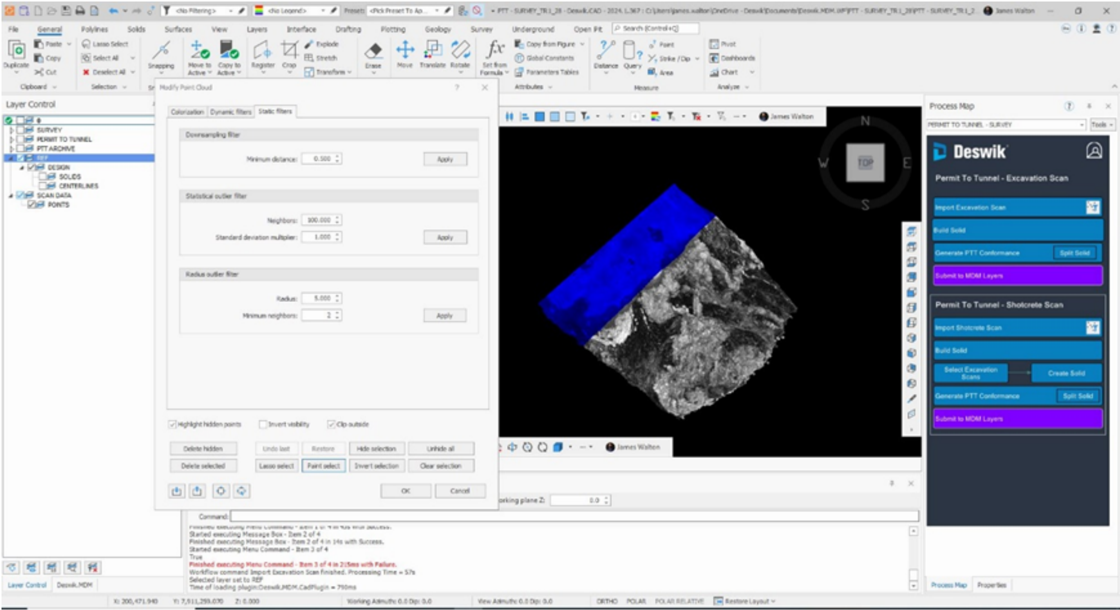

Figure 7. Plan view showing a high-resolution scan of ground conditions being meshed and imported in MDM.

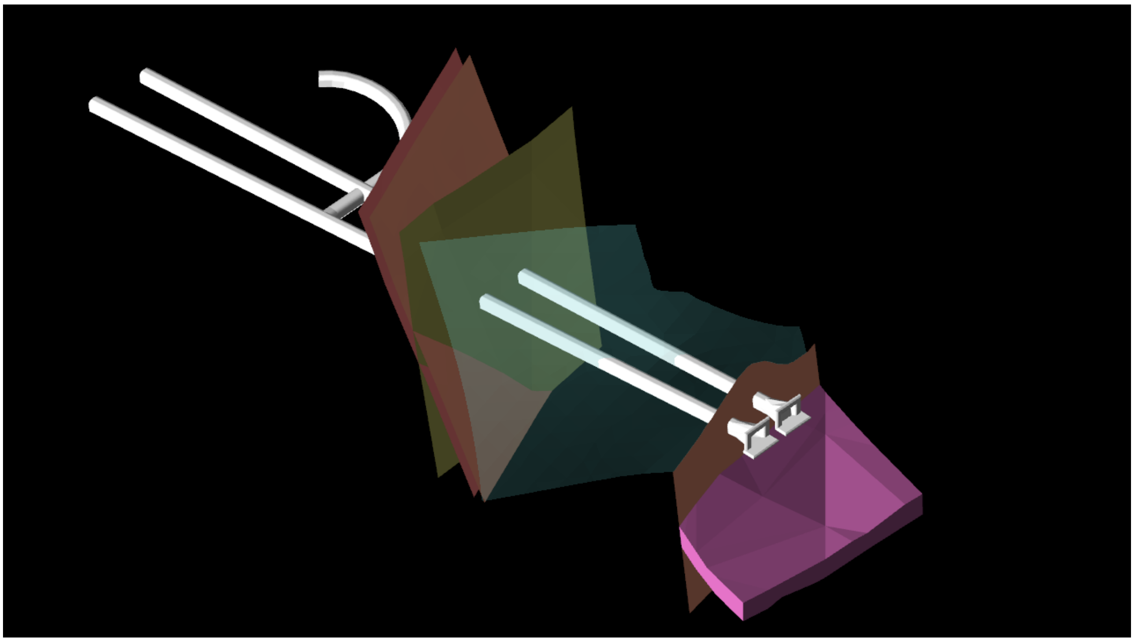

Figure 8. Example of geological model that is validated through the PTT process.

4 CONCLUSION

This case study aimed to review the traditional PTT processes in Australia and explore whether innovative technological approaches could enhance the safety-critical role it serves. As the Australian tunnelling industry evolves, with increasingly complex project scopes, there is a growing need for the PTT process to adapt accordingly. The rise of geometrically complex tunnelling projects, particularly in the re-emerging Pumped Hydro industry, highlights the demand for improved excavation control methods and the integration of technologies from other industries. The implementation of the IFL system represents a significant step towards digitalising key tunnelling processes, including PTT, to align with the industry's rapid growth. The IFL system offers an enhanced user interface and provides several key benefits validated through live testing during this study:

- Increased Efficiency: Rapid access to spatial data and workflow management ensures real-time critical data validation.
- Enhanced Safety: The platform facilitates model-based spatial interaction, reducing the need for human exchange with raw data, and optimises geotechnical assessment tools for safer tunnelling outcomes.
- Sustainable Data Management: The system allows for seamless data transfer between projects and serves as a single source of truth for legacy information, both during and after project completion.

These improvements underscore the need for modernizing tunneling processes to keep pace with the growing technical demands of the industry.

5 REFERENCES

M Salcher, Y Bai, M Trim, R Bertuzzi & B Vidler, 2023, The Permit to Tunnel process adopted on Australian infrastructure Projects, Australasian Tunnelling Conference November 2023, New Zealand