Integrated execution and materials management

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Integrated Execution and Materials Management (IEMM) is a holistic approach to streamline and optimize supply chain operations, combining real-time data-driven decision-making from the execution environment with efficient materials management. Every year mining organizations write off materials due to damage, loss, or expiry. This paper aims to address ways to reduce the risk in under- or over-stocking of critical items and get close to just-in-time materials ordering. By leveraging advanced technologies such as interoperability, data analytics, and execution systems, IEMM provides visibility and control over the entire supply chain by linking directly to execution and planning systems. Adopting IEMM empowers organizations to stay competitive in a dynamic business environment, ensuring the right materials are available at the right time and place, leading to better resource allocation and overall operational excellence.

INTRODUCTION

This paper aims to discuss the integration of materials management with short interval control to unlock value in supply chain operations. The topics covered include an introduction to the concept, the potential value to be unlocked, the importance of system integration, the role of short interval control and a conclusion summarizing the benefits of this approach.

In the Deloitte State of Mining Trends 2023 [3], key themes emerged related to technology advances. This includes items like building resilient supply chains and using system thinking to drive next-level operational excellence. This paper aims to highlight what is possible by linking materials and supply chain management to operational planning.

Planning within mining companies has evolved a great deal in the last few decades with the start of the 4th Industrial Revolution. This means greater access to information and more systems available to solve operation problems. Unfortunately, the increase in tools available to mining companies highlighted a greater need for inter system communication. On any mining site you will find a combination of planning-, modelling-, equipment tracking-, material tracking-, and supply chain systems. These systems are supported by various applications including Excel and various dashboard functionalities.

Enterprise resource systems added to the complexity and Gartner [4] reveals that over 40% of services companies will unify core processes like financials, human resources, procurement, and operations into a single suite by 2026. Enterprise systems were historically disconnected from the planning and scheduling environment. The planning and scheduling environment is managed by mine planning and operational teams, and ordering and planning of materials is decoupled from this process. This will generate vast amounts of data.

Mining companies aim to reduce the stock at hand to lower risk of damaged spares as well as items going to waste due to not being used. Often this stock on hand can be represented as a percentage of stock required at any given time over a monthly period. There is a fine balance between stock at hand to keep the operation running smoothly and having too much.

By employing a system thinking approach to execution and resource planning along with various interoperability platforms available, these systems can now be connected into a single source that is readily available to various mining departments, without the requirement for manual file and data transfers. This approach will be able to quantify the short medium- and short-term stock requirements.

Mine technical systems have been changing the way data is accessed and distributed within an operation. Where once systems were seen as a standalone system, interoperability concepts have allowed systems to start sharing data between platforms on a system-to-system basis or system to central network basis. This has allowed solutions to be built that expand on the capability of a single system and start to leverage information from multiple systems into a single holistic solution. This materials management paper aims to provide not just a single solution but aims to highlight what is possible with system integration.

This paper will not only focus on technology and processes but also touch on the role the human plays in the successful adoption of information systems.

INTEROPERABILITY CONCEPT

Interoperability is a new concept and means "the ability of computer systems or software to exchange and make use of information". It also means the ability of military equipment or groups to operate in conjunction with each other but that is for another day. In its simplest form it means data from different vendors can be combined into a single source by means of connection over a wide area network or local area networks.

Interoperability is because of the Fourth Industrial Revolution where connected system and the Internet of Things came to the fore. A means to connect disparate applications together to solve a single problem was required. The Drawing Exchange Format or DXF file as known in the computer-aided drafting was the first truly interoperability standard that allowed mining software packages to make data available between systems. However, this format was a static file-based solution. To share information, it had to be manually created, exported, saved to a location, and then manually imported on the other side. Meaning that if any changes were made to the original data, the previous file would be out of date.

Questions arise about the current physical state of an operation, wondering if it's as up to date as when the original creator of the data was involved. Without a robust naming convention, this understanding becomes even more challenging; there could be a mismatch of up-to-date information. Interoperability solved this problem by moving away from static file-based concepts and into a live single feed or stream of data to a single platform from where data can be accessed and utilized.

Moving from syntactic to semantic interoperability[2]

As soon as systems started communicating with other systems, the language used started changing as well. What start as a file-based communication system, evolved into models that both the sender and receiver could read without translation. This is where the terms syntactic and semantic communication models started being addressed.

Syntactic interoperability means the standardization of the communication between a software client and a server, but some form of decoding still has to occur on the receiving side. Examples of syntactic communication are Extensible Markup Language (XML) and Structured Query Language (SQL) formats. The example below shows the Open Geospatial Consortium (OGC) data format for spatial data that requires conversion to interpret data to a usable format on the receiving end.

WKB Data Type (OGC Compliant)
0x01082B0000040000000100000000000001016C0D6400000C0CB531B24410000000038B411C00100001CE5
BFD64000004021571B24410000000038B411C0000000E80EC0D6400000A059551B24410000000038B411C0
000000E80EC0D6400000A059551B24410000000038B411C0000000000100000002000000C5100000

Semantic[1] interoperability is the ability to automatically interpret the information exchanged meaningfully and accurately to produce useful results as defined by the end users of both systems. Semantic interoperability refers to not having to decode data from one system to the next. It uses the same data model at the origin as the destination. A semantic data model aims to add value to the data and present the data in a logical way. This can be seen as data that can relate to other data. This can also be seen as relational data. The use of semantic or syntactic data depends on the systems and data to be shared.

Example of data models

Data models represent an enterprise's data to be shared between systems and functions. The data model helps to identify the underlying structure in the context of the relevant business process. Mining companies are starting to build on the several ways data can be shared between systems, each with advantages and disadvantages. Depending on the data requirement, each model will provide advantages and disadvantages. There are many data models available within the engineering and financials sectors, but this paper will focus on a few main models being employed currently within mining companies. Figure 1 indicates the most basic structure, where files are shared between systems by exporting from one system and then imported into a second system. An example of this data is where a DXF file is exported from one mining software package and imported into another software package.

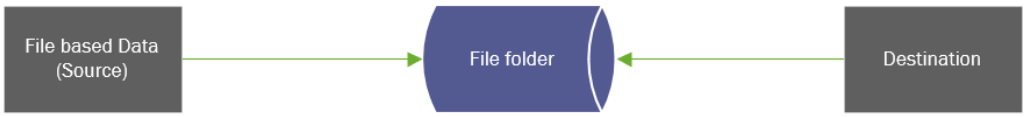

Figure 1. File-based data.

Another way of sharing data between systems is by using SQL to share data between systems. This requires both systems' data to either be available in a database management system or be converted into SQL language data. The process of converting data from file-based systems to SQL data can be automated. Systems will generate live views with the SQL environment and the ability to read will result in only current data being used, meaning that there is only one version of the truth and not multiple, static datasets. The process of extract-transfer-load (ETL) can translate data into a meaningful data model that can be translated by the receiver and destination. Figure 2 below highlights what a SQL data connection could look like as well as the process to convert data to a SQL format. The system below can also be seen as an application-to-application model where data is shared between two systems using similar data.

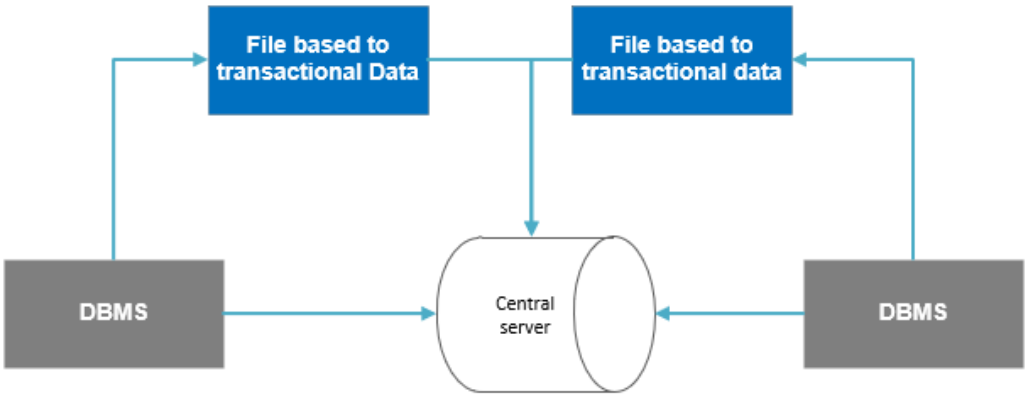

Figure 2. SQL to SQL data model.

A more complex model is where data from various sources are required to solve a cross-functional problem. An example could be where materials data from an enterprise system is required to interact with mine planning or execution data to provide a live data view for materials. For this model various applications or functions require data for varied reasons. There is no one-to-one relationship between systems. The model employed is called a data lake model. A data lake is a central data repository designed to store structured, semi-structured or unstructured data. Semantic or syntactic formats could be utilized within the data lake and each application will decode the data required. Figure 3 below shows where operational planning data, enterprise data for materials, equipment sensor data and application data are combined to be used in a central reporting platform. Each data provider will provide data in a native format and applications will ETL to ensure the data is in a usable and logical format.

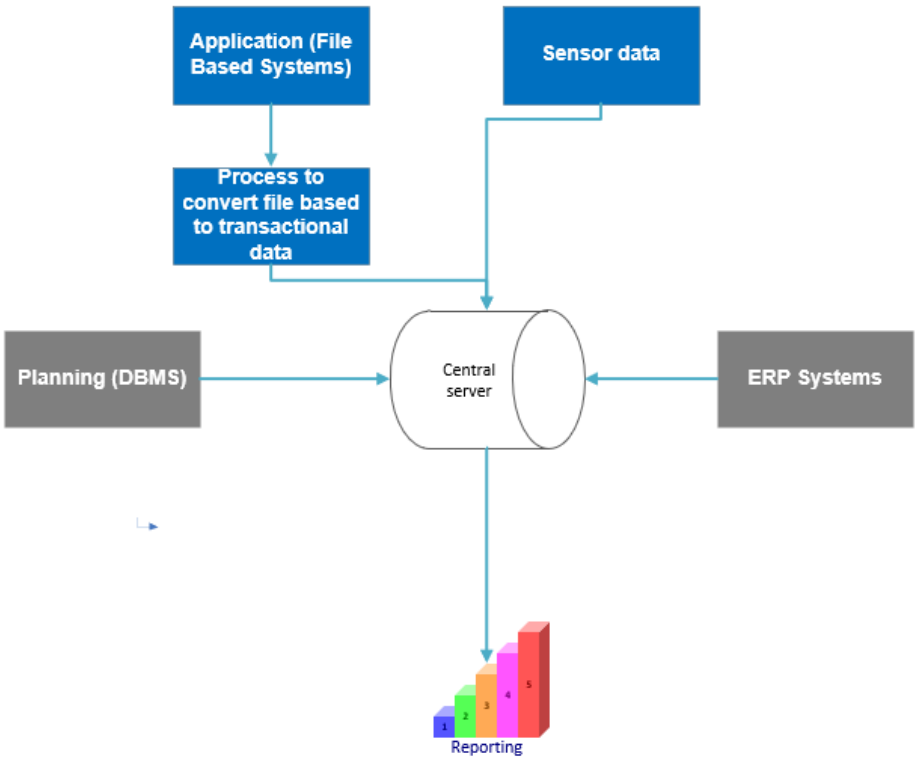

Figure 3. Data lake model.

Many different data models exist, and mining companies will continue to expand knowledge and use of the various systems. Companies like Amazon Web Services or Microsoft Azure provide data lake options for a cloud-based solution. The following is a brief list of data models in use today:

Hierarchical Data Model
This model represents data in a tree-like structure, with one root element and multiple levels of child elements branching out. Each child element has only one parent, while a parent element can have multiple children. This model is commonly used in file systems and XML documents.

Network Data Model
The network model is an extension of the hierarchical model, allowing child elements to have multiple parent elements. It forms a complex network of interconnected records, enabling more flexible relationships between data entities.

Relational Data Model
This model represents data as tables (or relations), where each row (or tuple) contains a unique record, and each column represents an attribute. Relationships between tables are established using primary and foreign keys. The relational model is the foundation of most modern relational database management systems like MySQL, Oracle, and PostgreSQL.

Entity-Relationship Model
The Entity-Relationship (ER) model is a high-level data model that helps in designing databases using entities (objects), attributes (properties), and relationships (associations). Entities are represented by rectangles, attributes by ellipses, and relationships by diamonds in an ER diagram.

Object-Oriented Data Model
In this model, data is represented as objects with attributes and methods (functions). Objects can inherit properties and behavior from other objects, enabling code reusability and modular design. This model is commonly used in object-oriented programming languages like Java, C++, and Python.

NoSQL Data Models
NoSQL databases use various data models to manage unstructured, semi-structured, or distributed data. Common NoSQL data models include:

- Key-value stores: These are the simplest type of NoSQL databases. Every single item in the database is stored as an attribute name (or 'key'), together with its value. Examples of key-value stores are Redis, Voldemort, and Dynamo.
- Document databases: In these databases, data is stored in documents, which are grouped together in collections. Each document can have an entirely different structure. MongoDB and CouchDB are examples of document databases.
- Wide-column stores: These store data as columns instead of rows and can quickly aggregate enormous amounts of data. They are excellent for analytics. Examples include Cassandra and HBase.
- Graph databases: These are used to store information about networks, such as social connections. Graph databases include Neo4J and Giraph.
- Time-series databases: These are optimized for handling time-series data, i.e., data that's indexed by time (a datetime or a datetime range). Examples: InfluxDB, OpenTSDB.
- Search engines: They provide more complex query capabilities and are optimized for searching text, often across large amounts of data. Examples include Elasticsearch and Solr.

EXECUTION OF THE PLAN

Mine planning can be broken into four distinct planning horizons, namely: strategic, tactical, operational and contingency. Contingency planning includes more detailed action items related to changes in specific conditions or unexpected events and will be excluded from this paper. The primary focus of this paper is to highlight how material management can be improved within the operational planning phase. The operational planning phase relates to the day-to-day issues such as resource assignment. This planning horizon will have detailed objectives with concrete deadlines and task assignments.

The term 'task assignment' will be a key term in linking materials to a specific task. In a project, on which this paper is based, materials are linked to specific tasks that needed to be performed. This can also be called short interval control. According to the Global Mining Guidelines Group[5] short interval control is "a structured process for identifying and acting on opportunities to improve effectiveness and efficiency of mining processes (production, development, and services). The intended outcome is a continuous improvement loop of improving productivity and wasting less time."

Establishing an accurate task structure
Short interval control relies on increased accuracy for day-to-day planning. This includes drilling down tasks into subsequent work packages. Work packages are a mining activity broken down into smaller activities. Mining an end could be broken into drilling, blasting, loading. These activities are work packages. A mining task from a planning perspective as an example will be capital development. This capital development activity will then be broken up into smaller work packages. For this capital development to be completed the following items will be added as sub-tasks:

- Primary Support - development
- Development marking
- Development drilling
- Drill suspension holes

- Development charging
- Development blasting
- Development loading
- Development trucking
- Development scaling
- Development loading - scaling
- Development trucking – scaling

The above is an example of a work package. When completed, the entire operational work package could end up looking like the representation in Figure 2 – which shows how main activities are broken down into sub-activities for accurate work prediction.

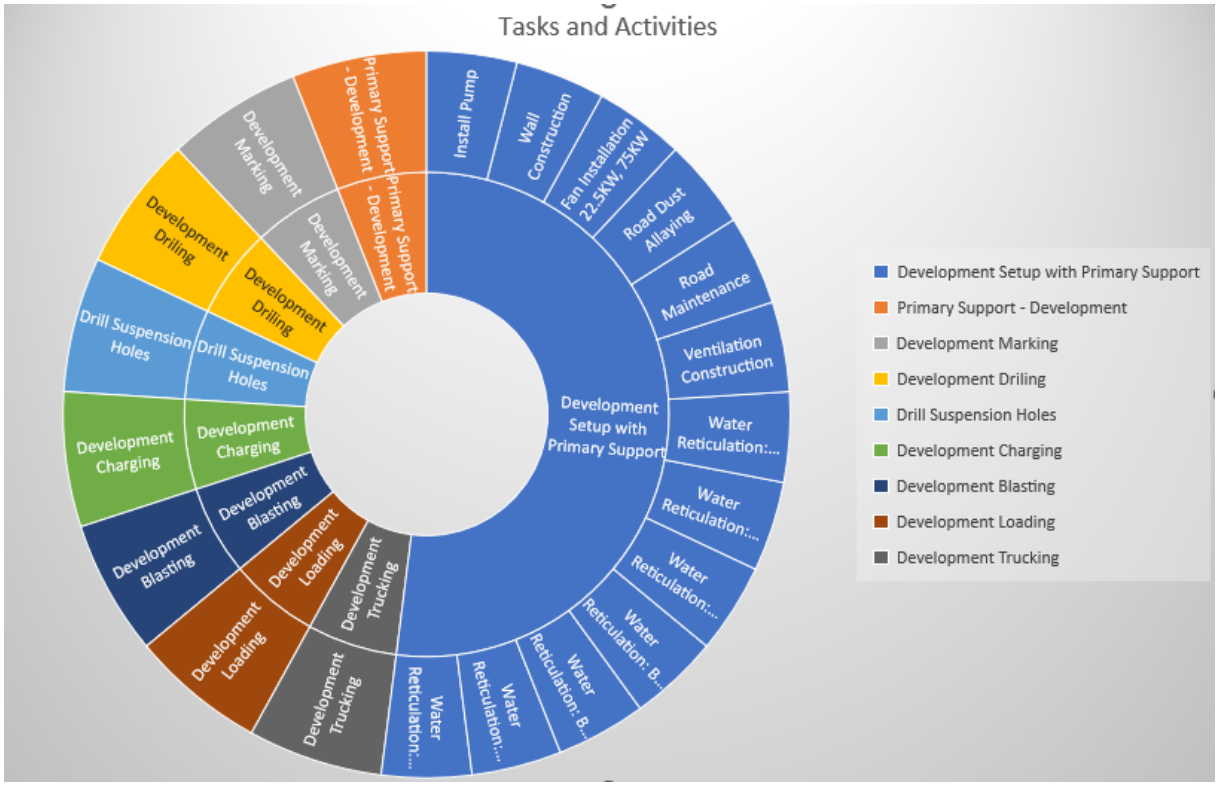

Figure 1. Sunburst representation of tasks and sub-tasks.

The demonstration of this proof of concept included 29 main tasks and a total of 252 sub-activities. Each activity then had materials assigned in the construction of a Bill of Materials. Table 2 indicates a standard bill of materials (BOM) design. The BOM is constructed for all materials required to be included in daily monitoring.

The source of short-term planning schedules can vary within operations, but the information contained within remains consistent. The schedule will contain fields including the following: task name, workplace, start time, resource, quantity, duration, predecessors and successors. The source could be anything from Excel to specific short interval applications. Interoperability tools will allow this schedule to be made available within a database environment, from where the link to the material and bill of quantities (BOQ) will be established.

Both the BOM and the BOQ are important documents that are used in project planning and management, but they serve different purposes and are used in different industries.

- BOM: This is a list of raw materials, parts, components, and the quantity of each needed to manufacture an end product. It's often used in the manufacturing industry. A BOM is more than just a shopping list; it provides the manufacturer with a detailed roadmap on how to build the product and also helps in inventory control, maintaining records, and purchase planning.
- BOQ: This is a document used in the construction industry that provides project-specific measured quantities of the items of work identified by the drawings and specifications in the tender documentation. It is typically prepared by a quantity surveyor or a cost engineer. The BOQ assists tenderers in the calculation of construction costs for their tender and is also used as a baseline to assess changes to the scope during the construction phase.

Establishing a material consumption baseline

For effective material management and the tracking thereof, a baseline for the materials linked to tasks needs to be created. An example would be that for a 3 m blast an advance team will require 10 square meters of mesh. In underground operations such as mining, a mesh is commonly used for safety purposes. This safety measure, often referred to as 'rockfall mesh' or 'rock mesh', is designed to prevent rocks and other debris from falling and potentially causing harm to workers or equipment. By looking at historical usage patterns, if available, a BOM can be constructed with a certain degree of accuracy and then improved on in subsequent months. This is an iterative process.

Table I. Creation of a bill of materials example

Task Name	Material Code (ERP)	*Description*	*Quantity*
Development Drilling	1000220	Roof Bolts	13
Development Charging	1023200	4.5m 2500MS Delay	6
Development Charging	1023201	4.5m 500MS Delay	6

BOM configuration is a critical component of the Integrated Materials Management (IMM) approach. By monitoring material flows and key performance indicators at regular, short intervals (e.g., hourly or daily), organizations can:

- Quickly identify deviations from planned material usage and procurement.
- Address operational issues or inefficiencies in near real-time.
- Make data-driven decisions to optimize material usage, minimize waste and reduce costs.

The BOM configuration can be done through a dedicated materials management enterprise resource planning ERP application or could be done within a database structure. It is essential to understand who the owner of the BOM will be and where the iterations of adjusting the bill of material structure will take place. During a proof of concept of this, the following information became clear. ERP is a type of software that organizations use to manage day-to-day business activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations. The ERP system integrates these various functions into one complete system to streamline processes and information across the entire organization.

Table II. Prediction mode updates

Month	Materials Predicted	*Materials Used*	*Accuracy*
Month 1	2515	3170	126%
Month 2	3315	3520	106%
Month 3	3211	3420	107%

Table II above shows that iterations of the model and review each month of average material usage will slowly start closing the gap between prediction and actual usage. The proof of concept above focused on only 36 different consumables including explosives, explosives consumables like timing accessories, mesh, ventilation equipment, electrical cable and a few more.

The materials adjustment and reconciliation rely on two key elements: 1: The quality of the plan for the duration ahead and 2: The quality of the material prediction model. Both these elements will play a critical role in ensuring the predicted usage accuracy. Iterations and reviews conducted at the end of each month enable the refinement of this model, specifically tailored to the materials required for a given month. Once the materials needed on a daily, weekly, and monthly basis have been finely tuned, this model can then be applied to a yearly budget. The accuracy and the time needed to construct this budget will consequently improve.

The biggest advantage that a materials management system will drive is removing the reliance on human input for the prediction and start moving to a prediction model, as driven by actual mine planning parameters.

LINK TO ENTERPRISE RESOURCE PLANNING SYSTEMS

ERP software is a critical component of an IMM system. IMM involves managing the entire supply chain of an organization, from raw materials to finished goods. ERP software provides a central platform for managing all aspects of the supply chain, including inventory, production, sales, and logistics. It helps to ensure that all departments have access to the same information in real-time, enabling efficient decision-making and reducing the risk of errors. ERP also plays a crucial role in automating key processes, such as purchase order creation and inventory management, which can improve accuracy and reduce costs.

ERP systems responsible for supply chain management are mostly database-based systems. Systems like SAP and Dynamics 365 use databases to store information. SAP uses its proprietary database system called SAP HANA, while D365 uses Microsoft SQL Server. The DBMS is responsible for storing, managing, and retrieving data used by these systems.

As ERP systems are already database-enabled, the BOM and execution schedules can be brought together in a single database platform through interoperability processes to complete the communication chain.

From there the information can be combined into a single dataset that can be utilized to both view the estimated model, but also track against the actuals. The report can be constructed on a reporting platform like Power-BI and up to date reports available at all times. Table III below is an example of such a report. This automated reporting platform will replace the reliance on static data sources like Excel and will always be up-to-date based on the planning information provided.

Table III. Bill of quantities for each activity

Name	TaskType	MaterialName	Price(R)	Numberof	Cost
DDEC001	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250
Drill_Drive 335	Development Charging	INNOFEX, 25KG MULTIBAG	350	12	4200
Drill Drive 315	Development Charging	INNOFEX, 25KG MULTIBAG	350	12	4200
E_XC335	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250
E_XC315	Development Charging	INNOFEX, 25KG MULTIBAG	350	15	5250

CONCLUSIONS

IMM is an essential strategy for companies aiming to strengthen their value proposition through streamlining supply chain operations. This method amalgamates key functions like procurement, inventory management, logistics, and production planning into a unified system, thereby enhancing material flow within the organization.

Effective deployment of this strategy necessitates a culture shift towards cross-functional collaboration within the organization, coupled with strategic investments in technology infrastructure and software platforms like SAP and Dynamics 365. These systems, crucial for successful materials management, provide the ability to accurately monitor inventory levels, track material flows, and plan production schedules.

Value creation stands at the core of IMM. The strategy facilitates this by increasing efficiency, heightening customer satisfaction, and cutting costs. By consolidating various functions within an organization, businesses can reduce duplication of efforts, enhance material flows, and decrease the time and expense related to the production process. Superior inventory management and procurement practices also contribute to reducing inventory levels, minimizing waste and improving working capital.

In essence, IMM is a key strategy for organizations striving to optimize their supply chain operations, boost their value proposition, and maintain a competitive edge. It demands an organizational cultural shift, technology infrastructure investment, and cooperative approach. By unifying contrasting functions, businesses can improve efficiency, lower costs, and optimize material flow, ultimately adding value for their customers and stakeholders. Therefore, embracing IMM is crucial for any company aspiring to stay competitive in today's fast-paced business landscape.

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Paul Ehlers, a seasoned Technology Executive, drives innovation in the mining sector as the Technology Executive with MineRP. With over two decades in the field, he has a deep understanding of the challenges in mining and a keen eye for technological solutions. Paul has overseen successful digital transformation through system integrations thinking and building new value driven solutions. Paul is a regular contributor to mining industry working groups Outside of work, he enjoys any type of sports and spending time on the beach with his family.