A PROPOSED RAMI4.0 PRODUCT LIFE CYCLE FRAMEWORK USING THE MANUFACTURING CHAIN MANAGEMENT PLATFORM

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ABSTRACT

The RAMI4.0 model consists of three axes; the Layers axis, the Hierarchy axis, and the Life Cycle Value Stream axis. This model unifies the various aspects of I4.0 to allow data generated from manufacturing and business activities to be shared effectively. The Manufacturing Chain Management software aims to provide a platform where all three axes and their associated data are tightly integrated and can be used to provide I4.0 connectivity as well as insights into the manufacturing supply chain. A data framework is proposed whereby the data from these activities can be collected and used to make more insightful decisions about an organisations value chain, value stream, and the life cycle of their product portfolio. The MCM platform is aimed at SMEs, which generally has lesser financial ability to invest into I4.0 technologies. Hence, the MCM platform is designed to be flexible and scalable whilst maintaining compliance with international I4.0 standards.

Keywords: RAMI4.0, product life cycle, value chain analysis, value stream mapping, manufacturing chain management

1.0 INTRODUCTION

Product life cycle management (PLM) is the process of managing a product from its conception through to its disposal. The effective management of a business's product portfolio allows it to stay competitive and sustainable (Cohen and Whang, 1997). In the RAMI4.0 model, the product lifecycle is further developed and its integration with other business and production activities more fully defined. This is captured in the product lifecycle axis of the I4.0 model and defines products and components in a way that allows it to be traceable throughout its lifecycle. The Bass diffusion model was introduced in 1969 and is used even today to predict the adoption of new products, thereby forming the product life cycle (PLC) curve. It has been shown that the PLC curve can be used to predict future demand. This helps organisations make better decisions regarding supply chain and inventory and is especially useful when coupled with acquisition of real-time or near real-time data (Hu et al., 2019).

In the context of RAMI4.0, the PLC contains two separate but related concepts, the type, and the instance. The type refers to the product as it is being developed. Data created in the development of the product may include CAD drawings and customer requirements Once the product has been developed and enters production, it becomes an instance. Data related to the instance may include unique production ID or servicing and maintenance reports. (VDI and ZVEI, 2015). This data in itself provides value. For example, data on user experience can be collected from instances and used to develop an improved product type. Type data can be easily shared to stakeholders e.g., product specifications being shared to a manufacturer. The ease of collecting and distributing data allows more stakeholders to create value. The governing standard for the treatment of type and instance, and the handling of related data is IEC 62890, which recommends that product types and instances be represented as UML objects.

1.1 Value chain and Value stream

In 1985, Michael Porter introduced the concept of the value chain. Every business can be described as nine generic categories of activities. This series of activities is termed the value chain (Fearne et al., 2012). In contrast, value streams are used to conceptualise the manufacturing activities related to the product. Developed from the Toyota Production System and subsequent Lean Manufacturing tenets, value stream mapping has been shown to be effective in applying and validating implementation of lean manufacturing principles (Gurumurthy and Kodali, 2011), as well as identifying and tracking metrics of interest (Faulkner and Badurdeen, 2014).

ECLASS is a standard developed and maintained by the ECLASS association and is concerned with the standardised digital representation of products across the supply and manufacturing chain. It is part of the push by the European Commission to develop the data economy. Using ECLASS facilitates the storage and exchange of product engineering data between entities, which benefits both the product type and instance (Fimmers et al., 2019). Another standard that relates to product development is AutomationML. AutomationML stores product data such as dimensions, kinematics, and other geometry related information. As such, it is particularly suited to sharing product engineering data (Kiesel and Beisheim, 2018).

1.2 Industry 4.0 Reference Architecture Model

The Reference Architectural Model Industrie 4.0 (RAMI4.0) model was introduced in 2011 by ZVEI and Plattform Industrie 4.0 and serves as the architectural model for the implementation of Industry 4.0 (I4.0). Figure 1 shows a map of the most important aspects of I4.0, visualised as a 3-dimensional map. The three axes of the model are the Layers, Hierarchy Levels, and Life Cycle Value Stream.

The Layers axis concerns the data generated from products and processes, the access and usage of said data, and its relation to various business functions. The Hierarchy Levels axis describes the relationships between various manufacturing process and machines. This relationship exists not just within a single factory, but also between entities, such as the relationship to suppliers and customers. The Life Cycle Value Stream axis is related to the development, production, and maintenance of products and services. Data created during these processes can provide value to other stakeholders. Thus, the proper management of said data is important in maintaining useability (VDI and ZVEI, 2015).

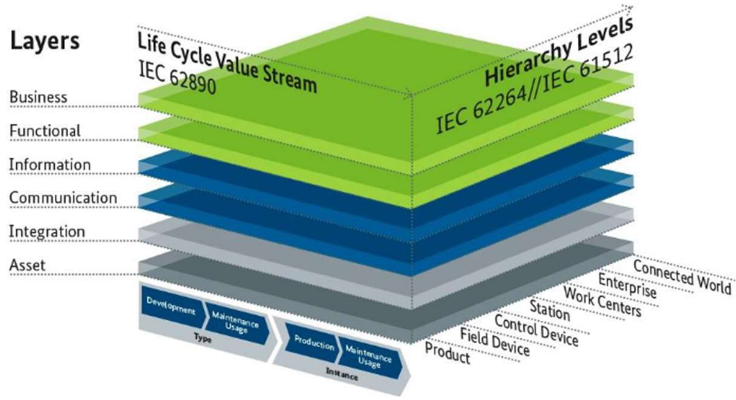

Figure 1. Map of key aspects of I4.0 (Plattform Industrie 4.0 and ZVEI)

The amount of data generated by the interactions between these stakeholders is immense (DigitalEU, 2020), which is further complicated by different and competing standards. One proposed solution to this is the use of the Asset Administration Shell (AAS). Proposed and maintained by Plattform Industrie 4.0 and ZVEI, AAS is an interface that standardises the structure of information about assets. Assets include tangible and intangible resources such as a machine, component, or service. The AAS connects the asset to the wider connected I4.0 world, and ensures compatibility and interoperability along the Layers and Hierarchy axes (Plattform Industrie 4.0, 2019). The data it collects and stores is also used in the Life Cycle Value Stream axis.

With the proliferation of IoT and other information technologies, Industry 4.0 (I4.0) is becoming increasingly viable and many companies are looking to implement I4.0 in their systems. Major software vendors such as SAP and Oracle offer high quality implementations of I4.0. However, their services are expensive, costing hundreds of thousands of ringgits or more per month (SAP, 2020). There is a market for I4.0 implementations on more modest budgets. In Malaysia, SMEs contribute 38.3% of national GDP and 66.2% of employment and make up 7.7% of the Malaysian manufacturing sector by GDP (SME Corp, 2018). This represents an opportunity for providing I4.0 consultation and software services at lower costs than more established vendors (Masood and Sonntag, 2020). While there is much research regarding specific aspects of manufacturing technology, there is a lack of research regarding the entire chain of manufacturing (Osterrieder et al., 2020). New strategies must be developed to help companies leverage the flexibility and customisation of I4.0 (Kumar et al., 2020).

2.0 MANUFACTURING CHAIN MANAGEMENT PLATFORM

The Manufacturing Chain Management (MCM) platform provides real-time data of processes in the horizontal and vertical manufacturing chain, driving value for the organisation. Figure 2 shows the vertical and horizontal manufacturing chain. The horizontal manufacturing chain includes all links in the supply chain from raw material to use and disposal. The vertical manufacturing chain includes all manufacturing and processing activities associated with the production of goods. The MCM platform provides a framework for data and information from all links to be shared with one another, fulfilling the purpose of the RAMI4.0 model.

The real-time nature and comprehensiveness of the data and the means that quantitative tools and methods benefit greatly from the MCM platform. Examples include quality control methods such as Condition Monitoring, allowing manufacturing process data to be more quickly collected and analysed (Pethig et al., 2017).

The product lifecycle axis of the model also benefits from this framework. The product type benefits from up-to-date information in its conception and development (Suarez-

Fernandez de Miranda et al., 2020). Information such as customer requirements and manufacturing capabilities ensures that the product is suited to the market. As an example, having access to customer and market trends means that the product is able to meet customer needs more easily. Traditional customer requirements capture methods such as surveys as focus groups combined with data pulled directly from the horizontal manufacturing chain can better guide the type development process. Similarly, data easily available from all links in the manufacturing chain benefits the product instance. Lead time, material quantities, quality indicators, and demand forecasts are all information that can provide for more accurate planning of production.

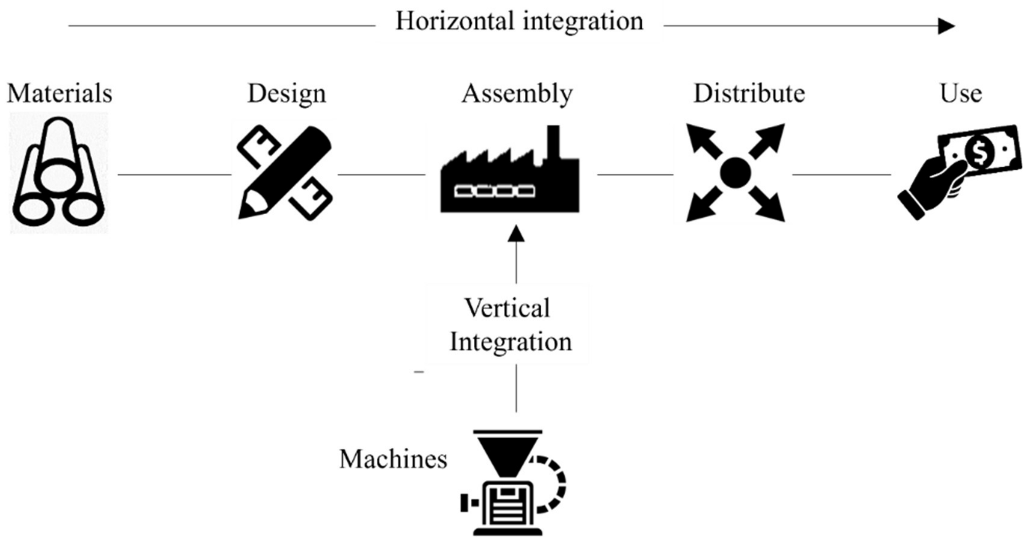

Figure 2. The horizontal and vertical manufacturing chain

Qualitative methods, though requiring human input and judgement, can still benefit from real time data. Two such qualitative methods, value chain analysis and value stream mapping were selected as possible candidates for integration into the MCM product life cycle framework. Both methods will be more effective with the advantage of real-time data providing a more accurate snapshot of the current state of the organisation.

Value Stream Mapping (VSM) is the process of mapping processes that occur in the manufacturing of a product. This mapping can reveal inefficiencies in the manufacturing process, and the manufacturer can take steps to reduce wastage, thereby increasing value to the customer. The usefulness of VSM is in identifying and tracking metrics that of most interest to the company (Gurumurthy and Kodali, 2011). Examples of metrics include Work-in-Progress time, lead time, and material handling time.

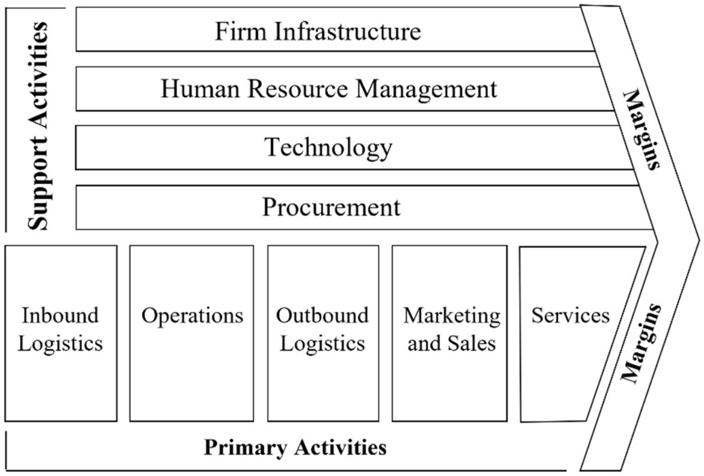

Figure 3. Porter's Value Chain model for organisations

The value chain is the characterisation of an organisation's business activities into nine categories, namely, (i) Inbound logistics, (ii) Operations, (iii) Outbound logistics, (iv) Marketing and Sales, (v) Service, (vi) Procurement, (vii) Technological development, (viii) Human resource management, and (ix) Firm infrastructure. Each of these activities create value for the organisation, and similarly to VSM, an analysis of these activities can help the organisation increase value for the customer (Koc and Bozdag, 2017). The value chain is represented in Figure 3, illustrating the different activities and the eventual goal of increasing margins for the company, and thusly the value to the customer.

3.0 METHODOLOGY

Figure 4 shows the various activities in the horizontal supply chain and their associated sub-activities. All products and processes, or assets, communicate with the interconnected world through the AAS. The AAS ensures that the data generated and sent is useable throughout the entire manufacturing chain.

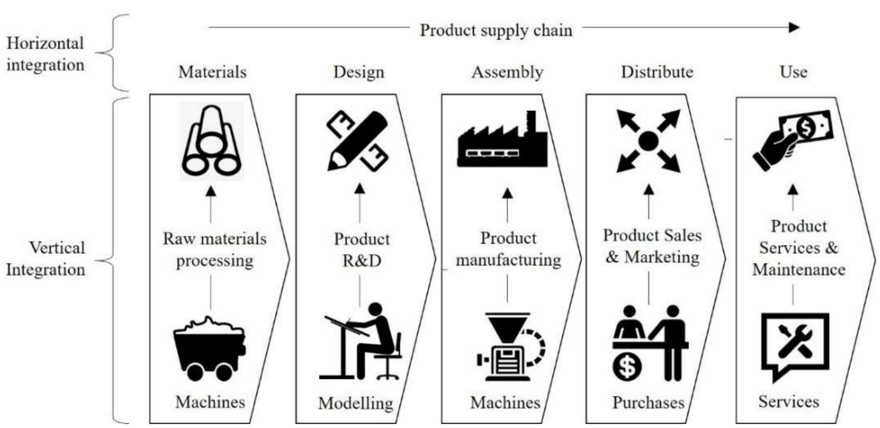

Figure 4. Integration of horizontal and vertical manufacturing chains for real-time data collection

The Asset Administration System (AASystem) is one of the functions in the MCM Platform. The AASystem provides an AAS for all assets in the manufacturing supply chain.

Another function, the Manufacturing Chain Broker (MCB), brokers the data across the different activities in the chain. This allows for complete transparency of manufacturing supply chain data, allowing it to be easily shared or processed for analytics uses. The fully integrated nature of the manufacturing supply chain data also creates a more holistic view of the system, as well as the effects of changes in one chain affecting other chains. Stakeholders across the manufacturing supply chain will be more agile, able to react quicker and more efficiently to changes (Gomez Segura et al., 2019). This is further discussed in section 3.1.

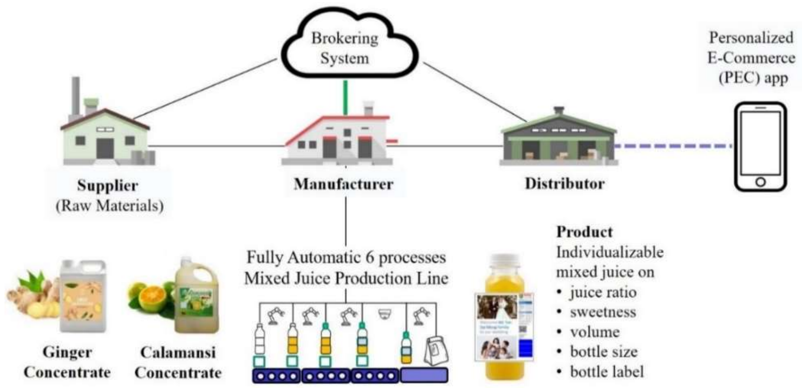

Figure 5. OMIS line layout

Figure 5 and Figure 6 shows the layout of the One-Piece Manufacturing through Individualization Solution (OMIS) line developed at TARUC. The OMIS line is a showcase demonstrating customisable manufacturing by integrating the vertical and horizontal manufacturing supply chains. The line consists of six processes to produce mixed fruit juice bottled in two sizes. The line processes are loading, filling, capping, printing (labelling), unloading, and packaging. These processes are fully automated, and the manufacturing line is connected to the raw material supplier and supplier through the MCB, allowing orders to be initiated and delivered without additional input. In this manner, data is traceable in real-time, subject to data sovereignty rules.

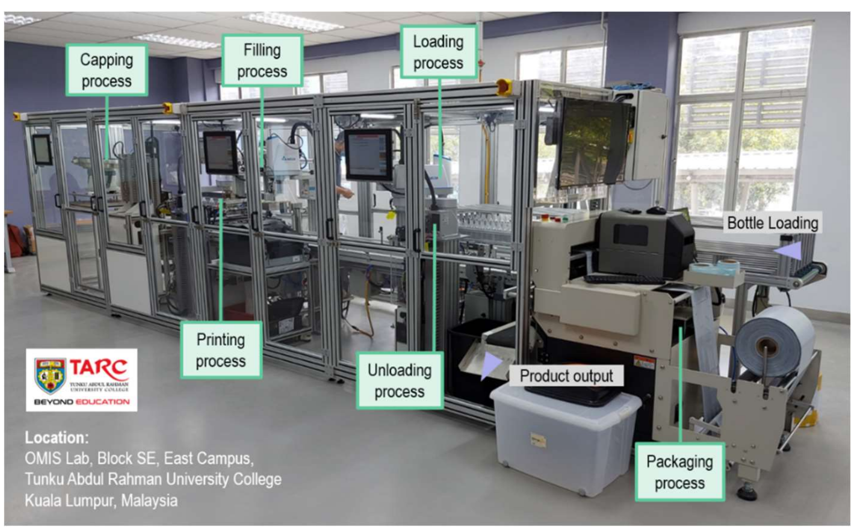

Figure 6. OMIS line at TARUC

4.0 DISCUSSION AND RECOMMENDATIONS

4.1 Data standardisation and representation

Figure 7 shows a representation of a product on the OMIS line. Per the UML standard, each object has its own class name, attributes, and functions. The same asset exists on the MCM AASystem, stored as a JSON object. This can then be translated into a UML object per IEC 62890 standard. Conversion to other standards such as ECLASS and AutomationML can be achieved with similar means. The UML diagram does not only show product data, but also relationships. The connections indicate the relationship between different elements of the data framework, such as the data and functions of components that make up the fruit juice product. In this example, the Ingredients, Bottle, Cap, and Label all have their own UML object, storing unique information about that component. They are also connected to the final Product, indicating an aggregation relationship. Another example is the relationship between the customer Order Details and the Order as well as the Label. Some but not all of the data about the Product is shared with the Order and subsequently the Order Details, whilst the Order Details itself has its own unique data. Some data fields are also shared with the Label object. In this manner, the UML object diagram can display the relationship the product has with the entire vertical and horizontal manufacturing chain in an intuitive manner. This also illustrates the distinction and the link between type and instance. Both objects can be represented with the UML object diagram, and the data stored in this format will also facilitate sharing among shareholders in the integrated manufacturing chain.

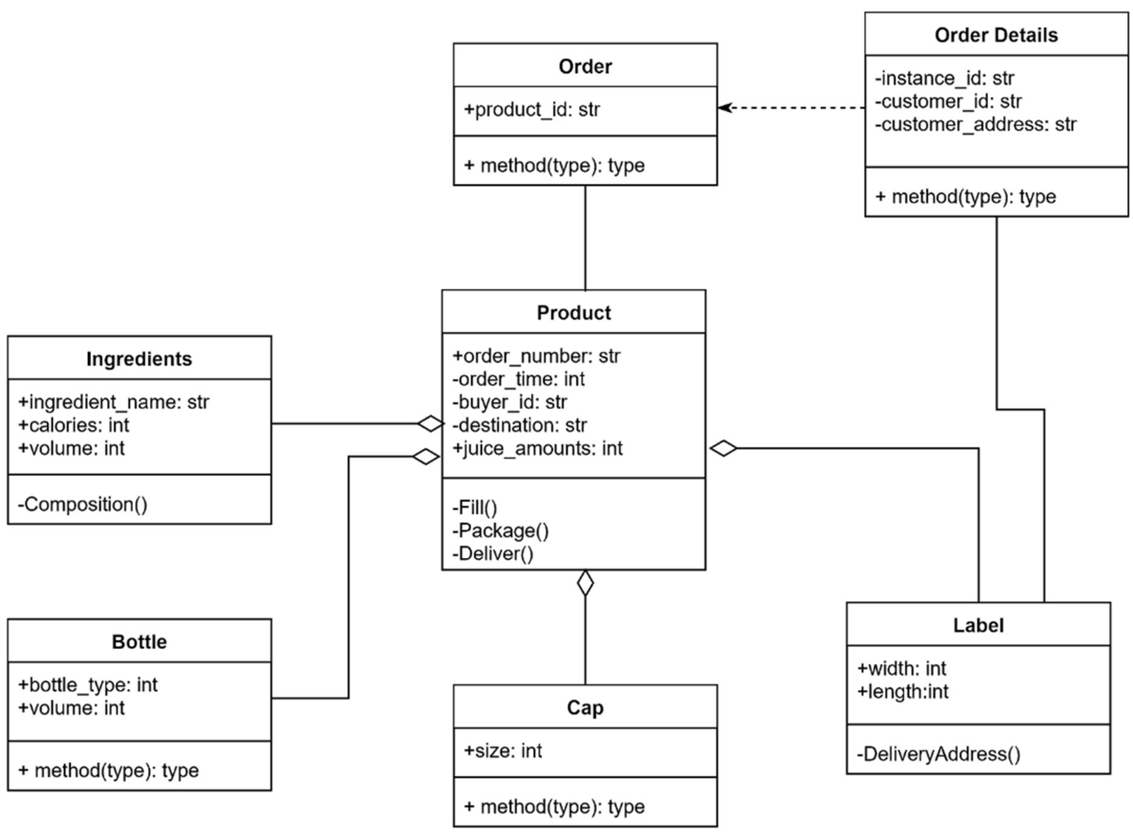

Figure 7. OMIS line product represented as UML object per IEC 62890

The MCM platform also provides visualisation capabilities. Using these capabilities to present relevant information provided by the PLC data framework will allow the user to monitor key metrics and potentially make more informed decisions. The three key functions that the PLC data framework will provide are PLC analytics, Value chain analytics, and Value stream mapping. All three will benefit from a dashboard that summarises the generated information and recommendations.

The role of the IEC and other standards mentioned in the RAMI4.0 model is to maintain interoperability with the wider connected world. Adherence to these standards ensures that any organisation utilising the MCM platform will communicate not only with other MCM platform users, but also with users of any compliant I4.0 platform. The Smart Manufacturing Standards Map was developed to address the issue of the large amount of overlapping fields in the three axes of the RAMI4.0 model (ISO, 2020). Figure 8 shows an example of a Smart Manufacturing 'block' detailing product life cycle activities, associated data, and their governing standards. These blocks comprise the mapping of activities across the supply and manufacturing value chain, serving as a reference for stakeholders to maintain data standards.

Block	Sub-block	Characteristic
Life cycle	Product type life cycle	Marketing
		Development
		Sales
		Obsolescence support
	Product instance life cycle	Manufacturing
		Transport and stock
		Use
		Retirement
	Production system life cycle	Concept
		Design
		Implementation
		Use
		Retirement

Figure 8. Example of a Smart Manufacturing block (adapted from IEC63306)

The processing of data generated by the different transactions in the data framework is also of importance. Data volume, variety, traffic intensity and criticality must be considered whether from a hardware and software perspective. Care must be taken to ensure the stability and consistency of data processing in the manufacturing and supply chain (Raptis et al., 2019).

4.2 MCM Product Life Cycle Framework

Figure 9 shows the product life cycle data framework of the MCM platform. The cycle starts from the vertical and horizontal manufacturing supply chain and is concerned with increasing value to the organisation. The data framework is generic and can be used for any manufacturing entity. The three key functions are applicable for any process and manufacturing chain. It will be up to the adopter to decide which key metrics are most useful for their organisation. The generic nature of the framework also offers customisability and scalability. This is important in attracting organisations who are looking for effective and sustainable solutions for their I4.0 adoption (Mittal et al., 2018). The function of the framework is to present information about the organisation to stakeholders. The information is given in three contexts, namely (i) PLC, (ii) value chain analytics, and (iii) value stream mapping.

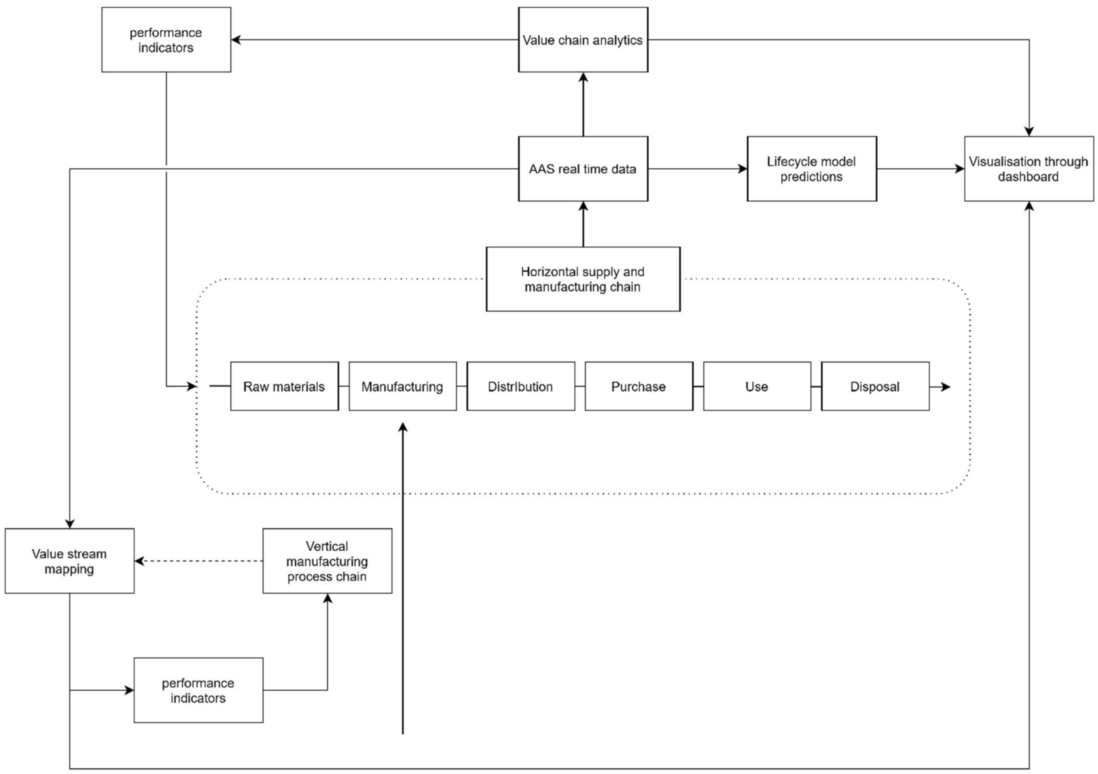

Figure 9. Manufacturing Chain Product Life Cycle Data Framework

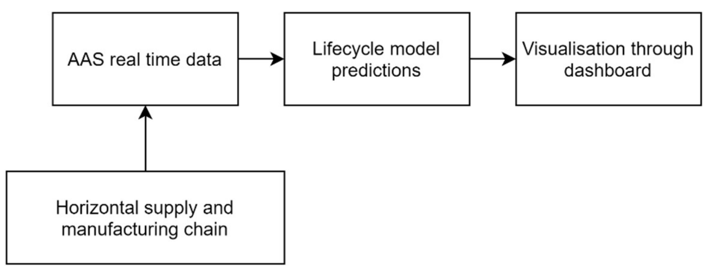

Figure 10. Product life cycle prediction framework

An area of research to be explored is the potential for real-time analytics to positively affect the PLC, illustrated in Figure 10. It has already been shown that sufficient modelling can improve demand forecasts. An extension to that is to use feedback from the integrated vertical and horizontal manufacturing chain to extend the PLC. The data to drive this improvement can come from any source within the manufacturing chain. With the OMIS line, the main source of data of interest is manufacturing processes. This is due to the fully automated nature of the line. This gives an advantage of data being easily available and representing the full line with little need for further input.

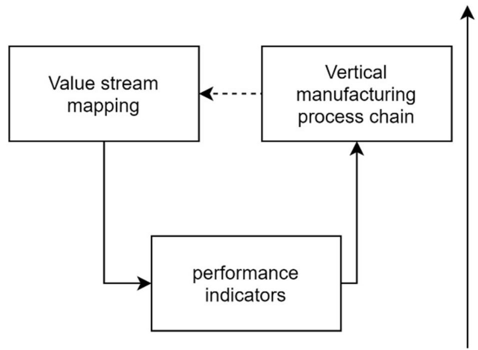

Figure 11. Vertical manufacturing chain feedback cycle

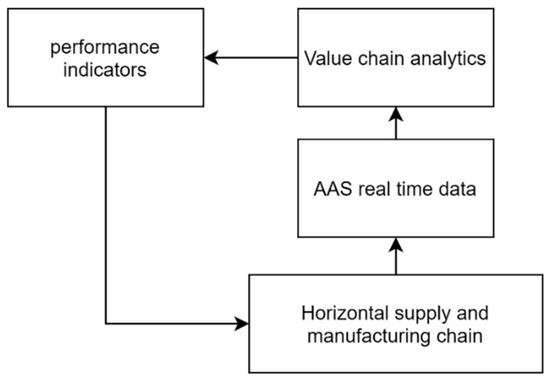

Figure 12. Horizontal manufacturing chain feedback cycle

Value chain analytics also shows promise in providing continuous improvements to the horizontal manufacturing chain. Insights provided by the real-time data can be directly applied to the organisation. Similarly, value stream mapping can benefit the vertical manufacturing chain. VSM combined with the PLC data framework is particularly powerful, as the data framework will be able to provide a complete and real-time snapshot of the manufacturing processes. This, together with AutomationML, means geometry and dimensional information will also be inputs. Key metrics revealed by VSM can then be used to track manufacturing performance. These actions take the form of feedback cycles, as they continuously improve the performance of the manufacturing supply chain, illustrated in Figure 11 and Figure 12

5.0 CONCLUSION

The aim of this data framework is to enable the sharing of data generated from the vertical and horizontal axis of the RAMI4.0 model. The real-time data will provide a snapshot of the current state of the organisation. This data will be processed through value chain analytics, value stream mapping, and product life cycle modelling in order to generate insights that will provide value for the organisation and customer. The visualisation and dashboard tools of the MCM platform will be used to present these insights.

It has been shown that the three presented methods are individually capable of tracking metrics to provide improvement to the company. However, an integrated platform that targets these three key axes of the RAMI4.0 model has not been proven. The MCM platform with the data framework is the first proposed solution that aims to fulfil this need.

This integrated platform will be of great value to manufacturing SMEs. They will be to obtain a clearer picture of their organisation, enabling better informed decisions. The platform will connect them to other stakeholders in the I4.0 manufacturing supply chain, providing even more opportunities and competitive advantages.

REFERENCES

Cohen, M.A., Whang, S., 1997. Competing in Product and Service: A Product Life-Cycle Model. Manag. Sci. 43, 535–545. https://doi.org/10.1287/mnsc.43.4.535

DigitalEU, 2020. Strategy for Data | Shaping Europe's digital future [WWW Document]. URL https://digital-strategy.ec.europa.eu/en/policies/strategy-data (accessed 8.10.21).

Faulkner, W., Badurdeen, F., 2014. Sustainable Value Stream Mapping (Sus-VSM): methodology to visualize and assess manufacturing sustainability performance. J. Clean. Prod. 85, 8–18. https://doi.org/10.1016/j.jclepro.2014.05.042

Fearne, A., Garcia Martinez, M., Dent, B., 2012. Dimensions of sustainable value chains: implications for value chain analysis. Supply Chain Manag. Int. J. 17, 575–581. https://doi.org/10.1108/13598541211269193

Fimmers, C., Wein, S., Storms, S., Brecher, C., Deppe, T., Epple, U., Graeser, O., 2019. An Industry 4.0 Engineering Workflow Approach: From Product Catalogs to Product Instances, in: IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society. Presented at the IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, pp. 2922–2927. https://doi.org/10.1109/IECON.2019.8926979

Gomez Segura, M., Oleghe, O., Salonitis, K., 2019. Analysis of lean manufacturing strategy using system dynamics modelling of a business model. Int. J. Lean Six Sigma ahead-of-print. https://doi.org/10.1108/IJLSS-05-2017-0042

Gurumurthy, A., Kodali, R., 2011. Design of lean manufacturing systems using value stream mapping with simulation: A case study. J. Manuf. Technol. Manag. 22, 444–473. https://doi.org/10.1108/17410381111126409

Hu, K., Acimovic, J., Erize, F., Thomas, D.J., Van Mieghem, J.A., 2019. Forecasting New Product Life Cycle Curves: Practical Approach and Empirical Analysis. Manuf. Serv. Oper. Manag. 21, 66–85. https://doi.org/10.1287/msom.2017.0691

ISO, 2020. ISO/IEC TR 63306-1:2020 Smart manufacturing standards map (SM2) — Part 1: Framework.

Kiesel, M., Beisheim, N., 2018. AutomationML in a continuous products life cycle: a technical implementation of RAMI 4.0. Presented at the AutomationML User Conference, p. 4.

Koc, T., Bozdag, E., 2017. Measuring the degree of novelty of innovation based on Porter's value chain approach. Eur. J. Oper. Res. 257, 559–567. https://doi.org/10.1016/j.ejor.2016.07.049

Kumar, M., Tsolakis, N., Agarwal, A., Srai, J.S., 2020. Developing distributed manufacturing strategies from the perspective of a product-process matrix. Int. J. Prod. Econ. 219, 1–17. https://doi.org/10.1016/j.ijpe.2019.05.005

Masood, T., Sonntag, P., 2020. Industry 4.0: Adoption challenges and benefits for SMEs. Comput. Ind. 121, 103261. https://doi.org/10.1016/j.compind.2020.103261

Mittal, S., Khan, M.A., Romero, D., Wuest, T., 2018. Mittal et al. 2018 - A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). J. Manuf. Syst. 49, 194–214. https://doi.org/10.1016/j.jmsy.2018.10.005

Osterrieder, P., Budde, L., Friedli, T., 2020. The smart factory as a key construct of industry 4.0: A systematic literature review. Int. J. Prod. Econ. 221, 107476. https://doi.org/10.1016/j.ijpe.2019.08.011

Pethig, F., Niggemann, O., Walter, A., 2017. Towards Industrie 4.0 compliant configuration of condition monitoring services, in: 2017 IEEE 15th International Conference on Industrial Informatics (INDIN). Presented at the 2017 IEEE 15th International Conference on Industrial Informatics (INDIN), IEEE, Emden, pp. 271–276. https://doi.org/10.1109/INDIN.2017.8104783

Plattform Industrie 4.0, 2019. Details of the Asset Administration Shell Part 1. Federal Ministry for Economic Affairs and Energy.

Raptis, T.P., Passarella, A., Conti, M., 2019. Data Management in Industry 4.0: State of the Art and Open Challenges. IEEE Access 7, 97052–97093. https://doi.org/10.1109/ACCESS.2019.2929296

SAP, 2020. SAP Estimator Tool. URL https://www.sap.com/sea/products/cloud-platform/pricing/estimator-tool.html (accessed 5.15.20).

SME Corp, 2018. SME Annual Report 2018.

VDI, ZVEI, 2015. Status Report - RAMI4.0.