PRODUCT LIFE CYCLE DATA MANAGEMENT AND ANALYTICS IN RAMI4.0 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 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 I4.0 standards. A furniture factory in Selangor, Malaysia was chosen to implement the Value Stream Mapping aspect if MCM and key production metrics such as process time, Work-In-Progress time, and manufacturing throughput were successfully recorded.

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 Reference Architecture Model Industrie 4.0 (RAMI4.0), 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 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 and is related to data created in the development of the product such as CAD drawings and customer requirements. Once the product has been developed and enters production, it becomes an instance, containing data such as unique production identification or manufacturing process information. (VDI and ZVEI, 2015). This data 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.

1.1 Value Chain and Value Stream

The concept of the value chain, introduced by Michael Porter in 1985, describes every business as nine generic categories of activities (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).

1.2 Industry 4.0 Reference Architecture Model

The RAMI4.0 model was introduced in 2011 by Zentralverband Elektrotechnik- und Elektronikindustrie eV. (ZVEI) and Plattform Industrie 4.0 and serves as an 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.

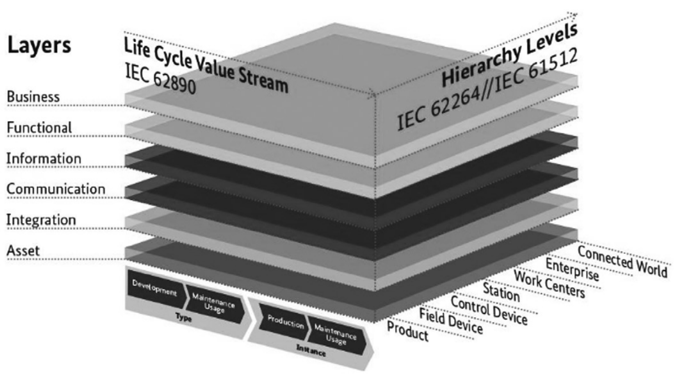

Figure 1: Map of key aspects of I4.0 (Plattform Industrie 4.0 and ZVEI)

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).

There is a large amount of data generated by the interactions between these stakeholders (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 collected is also used in the Life Cycle Value Stream axis.

With the proliferation of IoT and other information technologies, 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 highly developed 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.

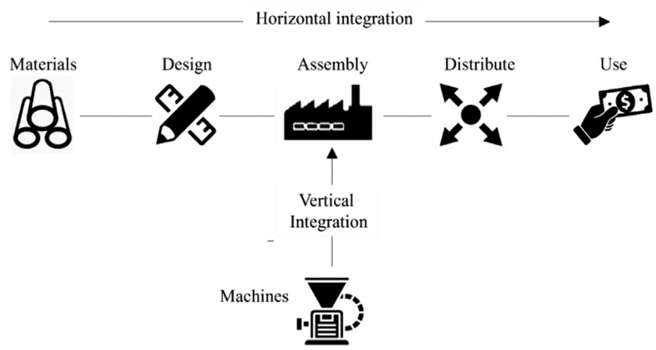

Figure 2: The horizontal and vertical manufacturing chain

The real-time nature and comprehensiveness of the data and the means that quantitative tools and methods benefit 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 can 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.

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

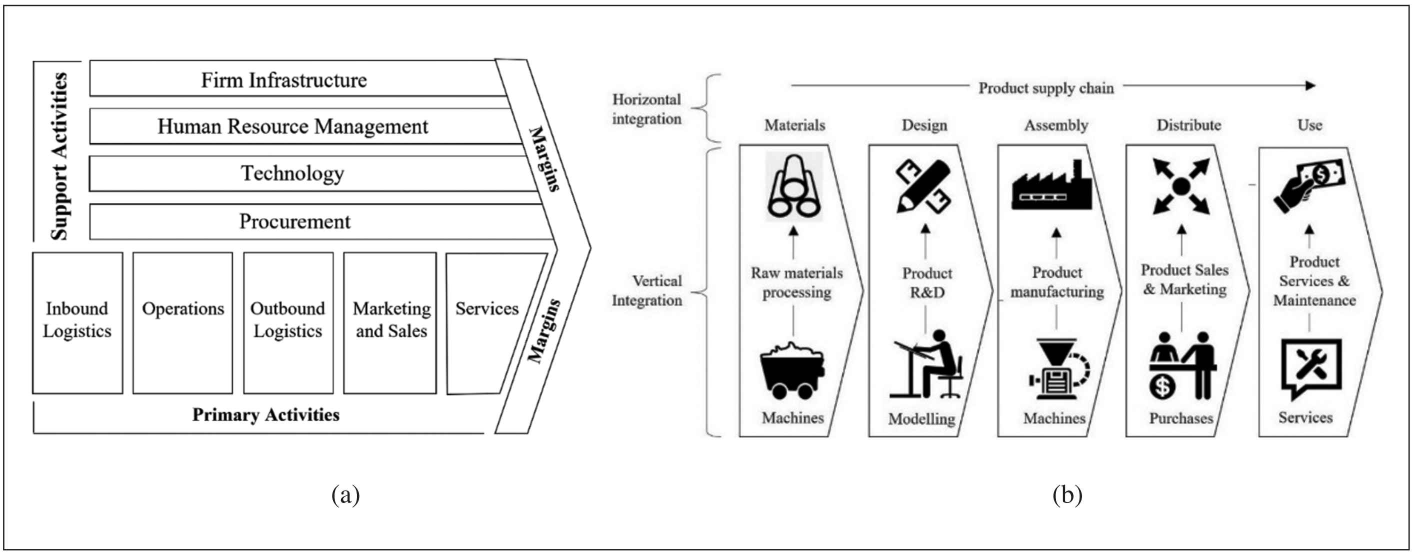

Figure 3: (a) Porter's Value Chain model for organisations and (b) integration of horizontal and vertical manufacturing chains for real-time data collection

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.

The value chain is the characterisation of an organisation's business activities into nine categories, illustrated in Figure 3(a). 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). Activities along the value chain are represented in Figure 3(b), illustrating the different actions and the eventual goal of increasing margins for the company, and thusly the value to the customer.

3.0 METHODOLOGY

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. 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).

A manufacturer of furniture in Selangor, Malaysia was chosen as a test bed for the implementation of a customised MCM system. Using a mobile application, manufacturing process data was recorded and stored in the AAS. The application also provided a platform for operators to view and assign work orders, serving as a pseudo-Manufacturing Execution System. The data collected was processed to provide performance indices of the manufacturing facility. This is further discussed in section 4.4.

4.0 RESULTS AND DISCUSSION

4.1 Data Standardisation and Representation

Figure 4 shows a representation of a generic juice product. 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

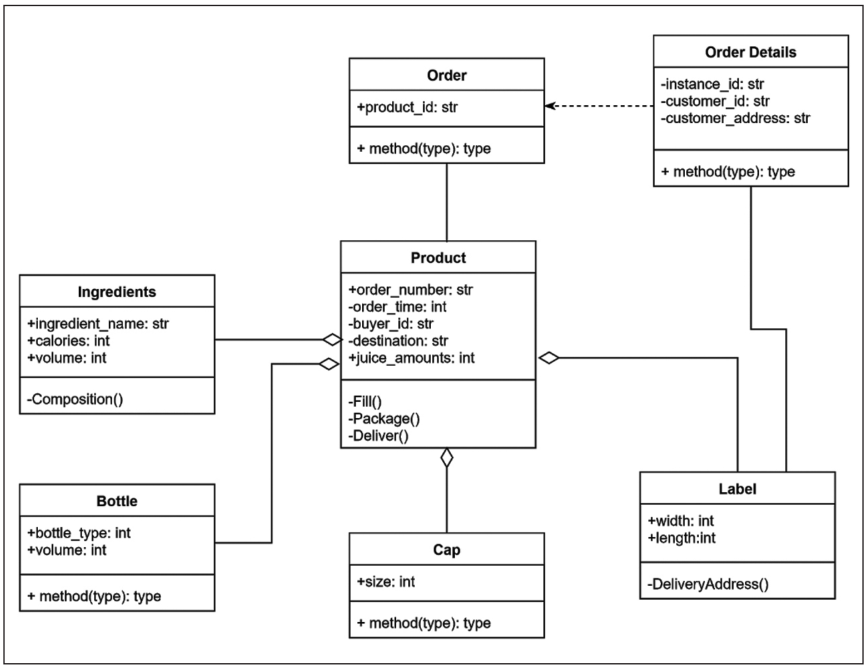

Figure 4: Generic juice product represented as UML object per IEC 62890

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 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.

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 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 5 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

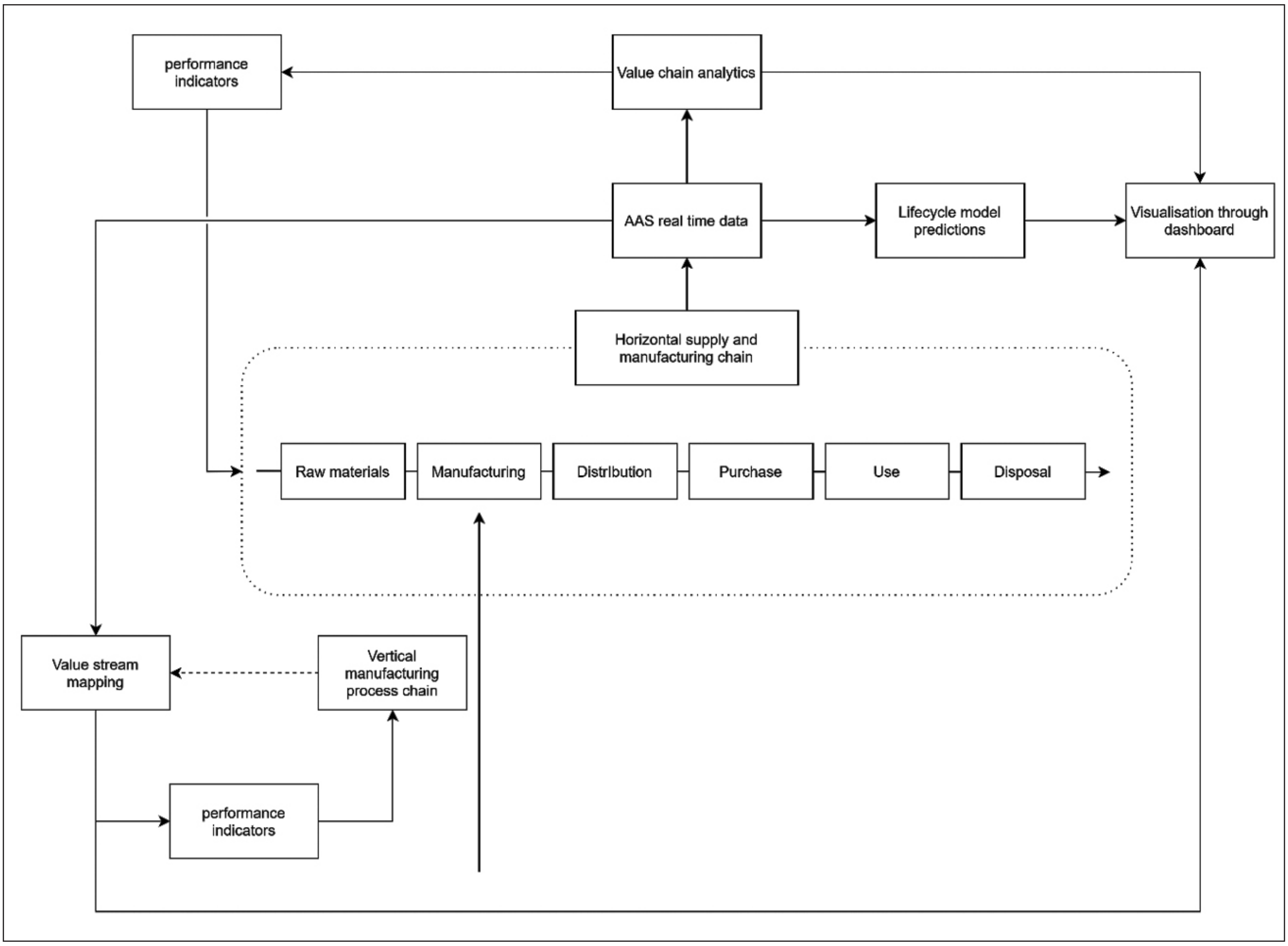

Figure 5: Manufacturing Chain Product Life Cycle Data Framework

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 PLC, value chain analytics, and value stream mapping.

An area of research to be explored is the potential for real-time analytics to positively affect the PLC, illustrated in Figure 6(a) and (b). 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. 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.

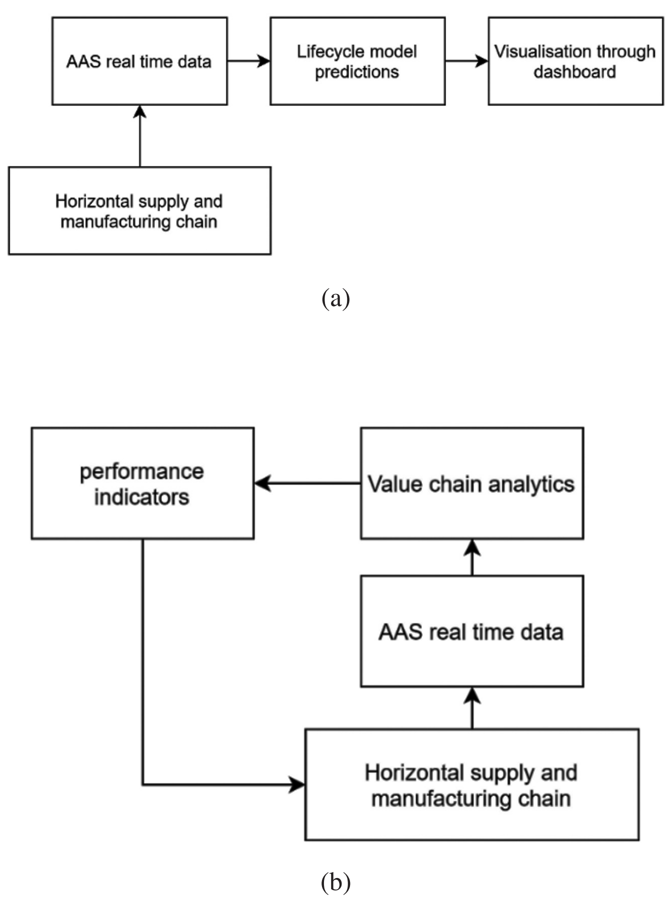

Figure 6: Product life cycle prediction framework and horizontal manufacturing chain feedback cycle

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. 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 7.

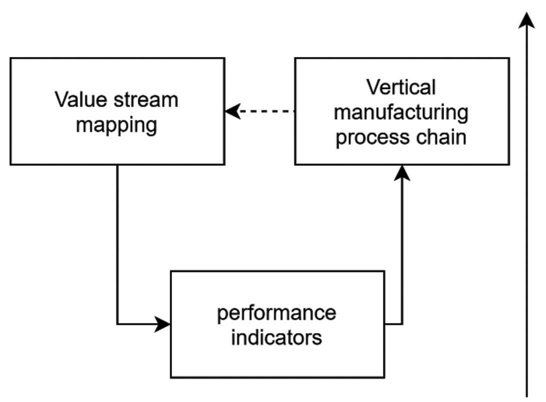

Figure 7: Vertical manufacturing chain feedback cycle

4.3 Value Stream Mapping in the Life Cycle Framework

The vertical manufacturing chain feedback cycle deals with the internal manufacturing cycle of the organisation. By tracking various metrics, the performance of different parts of the manufacturing chain can be enhanced. Indicators such as defect rate (Psarommatis *et al.,* 2021), Work-in-Progress volume (Woschank *et al.,* 2020) and process lead time (Chowdhury *et al.,* 2016) have been shown to be effective improving production performance.

4.4 MCM Implementation and Preliminary Results

A manufacturer of furniture in Selangor, Malaysia was chosen as a test bed for use of VSM in the context of MCM to track their manufacturing process. The manufacturer uses a system of containers and tracks to transport material throughout the shop floor from station to station for processing. The following key metrics were recorded using the MCM platform customised for the manufacturer; process time for individual manufactured parts, loading time to individual containers, material usage, and Work-In-Progress time between processing stations. Using these metrics, the performance of manufacturing line and individual operators was obtained.

Figure 8 shows the planned or expected manufacturing performance of the operators versus the actual recorded manufacturing performance of the operators. The performance is indicated by manufacturing throughput, which is calculated as the components produced divided by the total time taken. Figure 9 shows the recorded working time of each individual operator, allowing the manufacturer to calculate labour costs for each part. For both cases, the increased traceability of processes is useful in keeping track of manufacturing performance and expenditure. The data shown is a portion of the full record and anonymised for confidentiality.

num.	Operator 1	Operator 2	Operator 3	components produced	planned process time	actual process time	planned throughput	actual throughput	performance measure
1	A	B		300	30	32	10	9.38	-6.25%
2	A	B		300	30	31	10	9.68	-3.23%
3	A	B		45	15	16	3	2.81	-6.25%
4	A	B		555	20	21	27.75	26.43	-4.76%
5	A	B		600	15	14	40	42.86	7.14%
6	A	B		300	15	16	20	18.75	-6.25%
7	A	B		600	30	29	20	20.69	3.45%
8	A	B		300	15	14	20	21.43	7.14%
9	A	B		600	40	42	15	14.29	-4.76%
10	A	B		150	20	18	7.5	8.33	11.11%
11	A	B		150	20	21	7.5	7.14	-4.76%
12	A	B		300	20	22	15	13.64	-9.09%
13	A	B		300	1	0.98	300	306.12	2.04%
14	C	D	E	50	1	1	50	50	0.00%
15	C	D	F	50	1	1	50	50	0.00%
16	C	D	F	45	1	1	45	45	0.00%
17	C	E	F	5	1	0.98	5	5.1	2.04%

Figure 8: Planned versus actual operator throughput

Operator 1	Operator 2	Operator 3	normal working hours	overtime working hours	Operator 1 Total wages	Operator 2 Total wages	Operator 3 Total wages	Total cost per order item	order item quantity	labour cost per piece
A	B	E	04:33:00	00:30:00	RM41.41	RM41.41	RM49.69	RM132.50	300	RM0.44
C	D		01:41:00		RM14.47	RM16.22	RM0.00	RM30.69	100	RM0.31
A	B	F	02:27:00		RM19.14	RM19.14	RM19.78	RM58.06	150	RM0.39
C	D		02:27:00		RM21.05	RM23.61	RM0.00	RM44.66	150	RM0.30
C	D		04:57:00		RM42.54	RM47.70	RM0.00	RM90.23	300	RM0.30
C	D		00:45:00		RM6.45	RM7.23	RM0.00	RM13.67	45	RM0.30
C	D		00:37:00	04:17:00	RM60.51	RM67.85	RM0.00	RM128.36	300	RM0.43
C	D		09:35:00	00:19:00	RM86.44	RM96.92	RM0.00	RM183.36	600	RM0.31
B	E	F	05:03:00		RM39.45	RM47.34	RM40.77	RM127.57	300	RM0.43
B	E	F	04:57:00		RM38.67	RM46.41	RM39.96	RM125.04	300	RM0.42
B	E	F	09:30:00	00:36:00	RM81.25	RM97.50	RM83.96	RM262.71	600	RM0.44

Figure 9: Manufacturing process time and operator wages

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 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.

Work to validate these findings are underway with the implementation of value stream mapping and the Manufacturing Chain Management Platform being used to identify and track key performance indicators at a furniture manufacturing plant located in Selangor, Malaysia. Preliminary results are promising for the suitability of customised I4.0 solutions for manufacturing SMEs to measure the performance of their facilities. ■

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