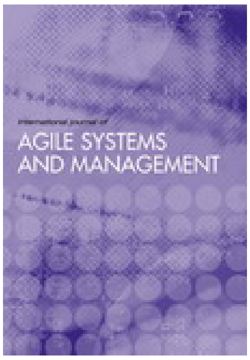

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A conceptual model of agile manufacturing in the shipbuilding industry for improving shipyard performance

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Abstract: The global shipbuilding market is very volatile and tends to have unfavourable impacts on shipyard performance. The shipyards must implement strategies to improve their performance. Agile manufacturing (AM) is one of the solutions to dynamic demand and high-level customisation products. It has been widely implemented in the manufacturing industry. However, the implementation of AM in the shipbuilding industry is limited. Therefore, the conceptual AM model in the shipbuilding industry is developed with adjustments to essential variables relevant to the shipyard characteristics to enhance the shipyard's ability to respond to unpredictable markets and fluctuating demand. This paper concludes that the conceptual AM model in the shipbuilding industry consists of three blocks, namely: 1) fluctuating demand as a driver; 2) agile manufacturing as a manufacturing strategy (MSA) consisting of seven key variables: technologies, empowerment, customer focus, supplier relationship, manufacturing system, organisational culture, and core competence; and (3) shipyard performance as output.

Keywords: agile manufacturing; shipbuilding industry; company performance; fluctuating demand; MSA; manufacturing strategy; market competition.

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1 Introduction

Global business competition with uncertain and unpredictable conditions has become a challenge for business activities in various industrial sectors today, including the shipbuilding industry. The shipbuilding industry has specific characteristics that differ from the common manufacturing industry, which are capital-intensive, labour-intensive, and technology-intensive industries, as well as the jobs obtained by customer orders (customised job order type) (Mandal, 2017). In addition, the shipyard industry also has unique characteristics in the aspect of relatively long delivery times (2–3 years), tradeable of ship products, high product variations, dynamic market changes, and limited new ship stock products (OECD, 2017). So that the shipbuilding industry is greatly affected by market-changing conditions, changing needs, and the number of orders from customers. Meanwhile, market conditions of new shipbuilding constantly fluctuate due to influenced by several factors, including economic growth, world trade sea traffic, world oil prices, world steel production levels, exploration and utilisation of natural resources, and sea utilisation for recreational activities (Hossain and Zakaria, 2017; Bruce, 2021).

Concerning the publication of the annual review of shipping and shipbuilding markets (BRS Group, 2020), the global new shipbuilding orders were volatile from 2010–2019. From 2010 to 2012, there was a significant decrease from 129.9 million DWT (2010) to 46.7 million DWT (2012). The best market conditions occurred in 2013–2015, with new ship orders averaging 123.9 million DWT annually. However, market conditions worsened again in 2016, with a total of new ship orders of only 32.8 million DWT. Market conditions in 2017–2019 have also not improved, with new ship orders averaging 82.2 million DWT annually. Even the COVID-19 pandemic that began to occur in early 2020 and spread throughout the world had an impact on decreasing new ship orders at global shipyards (BRS Group, 2020). Meanwhile, the world's new shipbuilding market share is dominated by the 'big three' ship industry countries: China, South Korea, and Japan. In 2019, the three countries could control 95.5% of the world's new shipbuilding market share (China 45.4%, South Korea 28.1%, and Japan 22%). The remaining market share was obtained by Europe at 1.9% and other countries at 2.6%, including the shipyard market share in Indonesia, which is still below 0.5% (BRS Group, 2020; UNCTAD, 2021).

From the perspective of production output, the United Nations Conference on Trade and Development/UNCTAD (2021) published that shipbuilding production output in the world in 2019 increased from 58.04 million GT to 65.91 million GT, or an increase of 13.56%. The production output of new shipbuilding mainly contributed by three giant countries, such as China, amounting to 23.07 million GT (a slight decrease of 0.82% from 2018), followed by South Korea of 21.67 million GT (a drastic increase of 48.12% from 2018), and Japan of 16.24 million GT (a rise of 12.47% from 2018). Meanwhile, the production of new ships by shipyards in Indonesia in 2019 decreased drastically from 0.163 million GT to 0.11 million GT, a decrease of 32.52% from 2018. Meanwhile, in Vietnam, the production of new shipbuilding in 2019 increased from 0.48 million GT to 0.56 million GT, a rise of 15.40% from 2018. Table 1 shows the production results of new ship construction in 2018 and 2019.

Table 1 Production results of new ship construction in 2018 and 2019

Description	*2018*	*2019*	*Deviation*
	(Million GT)		(%)
World new ship production	58.04	65.91	+13.56
China	23.26	23.07	–0.82
South Korea	14.63	21.67	+48.12
Japan	14.44	16.24	+12.47
Europe	2.03	2.33	+14.78
Indonesia	0.16	0.11	–32.52
Vietnam	0.48	0.56	+15.41
Other countries	3.04	1.93	–36.51

Data processed from UNCTAD (2021).

The market share of the shipbuilding industry constantly fluctuates with a high level of uncertainty, customised job orders, and customer-driven characteristics. Therefore, the shipyards must develop a manufacturing strategy (MSA) to survive amid a highly fluctuating competitive and market-change environment. The shipyards need improvement in adapting and responding quickly and effectively to changing competitive circumstances and customer demands in an environment that continuously changes rapidly and unpredictably. The MSA that is considered appropriate is agile manufacturing, which is defined as the ability to respond quickly and effectively to market changes controlled by customer demand to survive and thrive in an environment of competition and unpredictable change (Gunasekaran, 1999).

Implementing AM in many manufacturing industry sectors successfully addresses the challenges of changing market competition for some reasons:

1 AM is the result of the evolution of the MSA paradigm in the manufacturing industry that continues to develop and to answer the challenges of rapid global market changes (Goldman et al., 1991)

2 AM was born as a solution to unpredictable and dynamic demand problems with a higher level of mass customisation in the products (Sanchez and Nagi, 2001)

3 AM is focused on organisational operations with project characteristics and jobbing processes because the principle of the economics of scope can achieve mass customisation.

In contrast to the batch, flowline, and continuous type organisational operations, the superiority of the mass production concept is achieved by the principle of the economics of scale (Harrison, 1997).

Based on the background described above, the authors find a potential study gap: the conceptual development of the AM model in the shipbuilding industry and its impact on the company's operational performance. Furthermore, this paper will describe a literature review, methodology, a critical review of the existing AM model, a proposed conceptual AM model for the shipbuilding industry, and a conclusion and direction for future research.

2 Literature review

2.1 AM definition

Since 1991, many researchers developed the AM concept, including definition, framework, implementation, assessment, and impact on company performance. However, there is no consensus on the definition of AM. Potdar et al. (2017) reviewed 300 scientific papers from 1993 to 2016 and found 34 definitions with various perspectives of researchers. Some definitions focus on outcomes, not explicitly defining agility and how to implement it. For example, agility is dealing with dynamic situations in an aggressive change environment to achieve growth in a specific context. Agility is a strategy to win the market competition and profit through customer satisfaction, not efficiency or cost-cutting (Goldman et al., 1995). Kidd (1995) cited US Agility Forum Literature that agility is the ability to respond quickly and effectively to customer needs that are constantly changing and unpredictable. In addition, agility is the ability and capacity of an organisation to respond quickly and effectively to provide alternative solutions proactively to any market opportunity driven by changing customer needs (Nelson and Harvey, 1995).

While Kidd (1995) conveyed a more specific definition of operations, AM is built through virtual companies as joint operations of several companies with particular core skills, facilities, and resources that can be utilised through resource-sharing methods. This type of cooperation allows companies to be agile because organisations can be formed and changed quickly. An agile company can change and adapt quickly, reconfiguring the organisation and processes rapidly in response to market opportunities. Agile companies have integrated structures and processes in technology, organisation, and human resources to be competitive. Human resources as company assets need to be formed into dynamic teams according to the dynamics of changes and market needs to enable the process of transforming knowledge into products and services.

Yusuf et al. (1999) presented a more comprehensive definition of AM as the ability to explore the main factors of competitiveness (speed, flexibility, innovation, quality, and profit) by integrating resources and transforming knowledge into products and services according to customer needs in an immediate market competition environment. AM uses technology, human resources, and information systems to respond to market changes and unpredictable customer needs. Meanwhile, according to Gunasekaran (1999), AM is the ability to respond quickly and effectively to market changes controlled by customer demand to survive and thrive in an unpredictable, competitive, and changing environment. AM is a next-generation strategy integrating technology, management/ organisation, and human resources.

2.2 AM development

Since 1991, academics and practitioners have conducted many studies of agile manufacturing systems. Therefore, the authors conducted a literature study to discover the state-of-the-art of agile manufacturing concept. The review includes frameworks, key variables, implementation, assessment, and their impact on company performance. From 1991 to 2020, there were hundreds of publications related to the topic. Then, 22 scientific publications were selected as the primary reference for this research on conceptual AM model development in the shipbuilding industry.

2.3 AM framework and key variables

During the period 1991–2020, researchers have developed some AM frameworks and vital variables as follows:

1. Gunasekaran (1998) developed an AM framework with four enablers: value-based pricing strategies, investments in people and information, organisational changes, and cooperation.

2. Gunasekaran (1999) conducted an analytical study based on a literature review and produced an AM framework with four main criteria: strategy, technology, systems, and people.

3. Yusuf et al. (1999) developed an AM model with the core concept of agility. The core concept of AM consists of 4 critical factors: core competence management, virtual enterprise, capability for re-configuration, and knowledge-driven enterprise.

4 Ismail et al. (2006) developed an AM implementation framework that uses a bottom-up approach through three iterative implementation phases of the robustness of operation, responsiveness to customers, and proactive growth tactics. The agility performance indicators are clustered into five groups: product, process, people, operations, and organisation.

5 Dubey and Gunasekaran (2015) developed an AM framework with six important variables: technologies, empowerment, customer focus, supplier relationship, flexible manufacturing systems, and organisational culture.

6 Kumar et al. (2019) developed an AM framework with a comparative analysis of 17 AM frameworks published from 1998 to 2017. The result concludes that the AM framework is a building with seven pillars, namely: human resources, organisation culture, supplier, customer, innovation, concurrent engineering, and information technologies; it has management support as a strong foundation; and the roof of the building consisting of 6 elements of performance indicators include customer, financial, business, operational, employee, and supplier. The eight critical success factors also were confirmed by a literature study on 37 scientific papers published by six journals from 1990 to 2019 (Kumar et al., 2020b).

2.4 AM implementation

The authors highlight previous research on implementing AM in the manufacturing industry and its impact on company performance. For example, Inman et al. (2011) see that many manufacturing companies are adopting lean practices such as JIT and TQM to reduce costs and improve quality. However, many competing companies also apply the same thing, so many lose out. Therefore, many companies are starting to adopt agility practices to improve their ability to respond quickly to customer requests so that many companies become agile. Goldsby et al. (2006) confirmed that lean strategies produce the lowest costs or highest services when demand is stable and predicted with high accuracy and for finished goods with low value and low cost. Besides that, it confirmed the opinion of Narasimhan et al. (2006) that lean actors have 'made-to-stock' operations while agile actors have 'made-to-order' processes.

Most literature indicates that AM intends to improve performance. However, there is not much-documented research on the impact of AM on operating performance (Nabbas and Abdallah, 2018). Some researchers indicate no significant impact of AM on operating performance (Narasimhan et al., 2006) and limited research on the impact of AM on business performance. In contrast, Vazquez-Bustelo et al. (2007) and Inman et al. (2011) found AM to have a positive and significant impact on business performance, while Jacobs et al. (2011) found that AM has a negative and insignificant impact on performance growth. However, research on the impact of agility on business performance is a limitation. Because of this conflict, Nabbas and Abdallah (2018) conducted a study of different industries in Jordan and concluded:

1 AM directly impacts business performance as the outcome, not limited to operational performance; so this result aligns with Vazquez-Bustelo et al. (2007) and Inman et al. (2011) but contrary to Jacobs et al. (2011)

2 AM does not have a significant impact on the cost; therefore, AM is not a cost reduction strategy

3 cost and delivery performance are not related to business performance; while

4 quality and flexibility performance has a positive and significant impact on business performance.

Khalfallah and Lakhal (2020) studied and concluded that

1 lean manufacturing practices have a direct relationship with AM except for JIT production

2 AM has a positive impact on operating performance

3 lean manufacturing practices do not contribute directly to operating performance, but this relationship is significant when through AM

4 the results are not significant on some variables in financial performance, raising the question that the research conducted is not appropriate to describe the impact of AM, TQM, JIT-production, JIT-procurement, and TPM variables on financial performance.

However, this research has ignored dynamism, hostility (Vazquez-Bustelo et al., 2007), and differentiation (Hallgren and Olhager, 2009) as essential AM drivers. Therefore, further research should include dynamism, hostility, and differentiation as critical drivers of AM. Meanwhile, to determine the impact of AM practices on business, Kumar et al. (2020a) studied and concluded:

1 there is a positive relationship between business performance and the AM enabler

2 AM enablers have a significant impact on business performance

3 the period of AM implementation has a substantial effect on the success of AM implementation

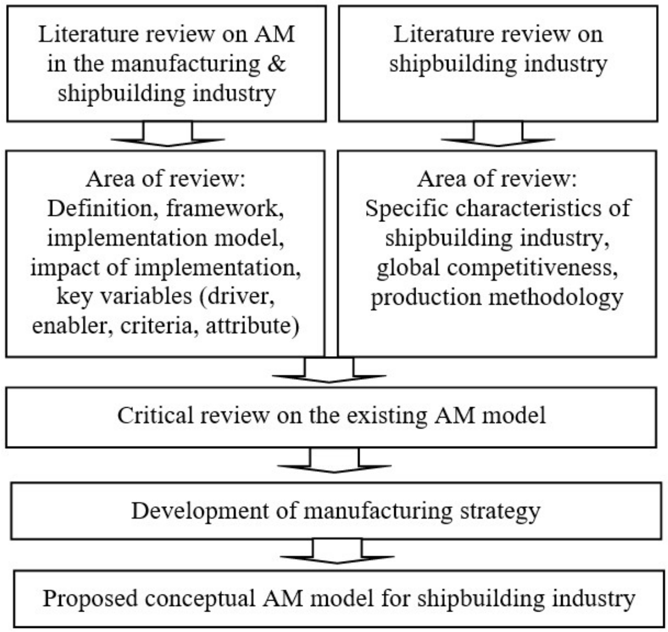
4 AM implementations have a high success rate.

Researchers have developed several methods to measure the level of agility implementation in the company. For example, Vinodh et al. (2008) and Raj and Vinodh (2014) developed an assessment method for the level of agility implementation in electronic companies in India using the scoring method (maximum 1000) referring to the assessment model at the Malcolm Baldridge National Quality Award. Meanwhile, Atiq-Ur-Rehman (2017) developed the analytical hierarchy process (AHP) method to determine the relative importance level among agility enablers.

3 Methodology

To formulate the conceptual AM model in the shipbuilding industry, the authors have conducted a literature review of the existing AM model, a comparative analysis of essential variables and AM models by considering the specific characteristics of the shipbuilding industry, critical factors of shipyard competitiveness, and new ship production technology according to the systematic methodology illustrated in Figure 1.

Figure 1 Methodology of conceptual AM model formulation



4 A critical review of the existing AM model

Considering the number of AM models and the shipbuilding industry's unique characteristics, the authors critically reviewed the existing AM model to determine the gap and develop a proposed AM model appropriate for the shipyard industry.

4.1 Overview of the existing AM model

The authors critically review the existing AM model and its suitability for the shipbuilding industry. Many scientists worldwide have studied AM frameworks and implementations. During 1991–2019, 37 studies related to AM applications in several industrial sectors in several countries (Kumar et al., 2020b). At least 205 manufacturing companies in Tunisia show that agile manufacturing positively impacts operational performance (Khalfallah and Lakhal, 2020). On the other hand, implementing agile manufacturing shows a positive relationship to company performance in 154 manufacturing companies in India. The implementation of agile manufacturing significantly improved company performance indicators (Kumar et al., 2020a).

Although there is much research related to the framework and implementation of agile manufacturing in various sectors of the manufacturing industry worldwide, and it has a positive impact on operational performance and business performance, including Dove (1992), Gunasekaran (1998, 1999), Yusuf et al. (1999), Zhang and Sharifi (2000), Ramesh and Devadasan (2007), Raj and Vinodh (2014), Dubey and Gunasekaran (2015), Sindhwani and Malhotra (2016, 2017), Nejatian et al. (2018), Kumar et al. (2019, 2020a). However, research on developing frameworks and implementing agile manufacturing in the shipbuilding industry is still limited. Moura and Botter (2012) conducted a case study of implementing agile manufacturing in the shipyard. The study concludes that integrating the shipyard's design, planning, and manufacturing functions is essential for AM implementation. In addition, accurate and complete information on the products, production processes, and operations, including manufacturing technology, is required. Therefore, all product flow and information bottlenecks should be minimised.

Furthermore, Dubey and Gunasekaran (2015) developed an agile manufacturing framework with empirical validation on the manufacturing industry in India, including the shipyard industry, as part of the research object. Research with literature study methods and empirical studies produces an agile manufacturing framework built by six essential variables: technologies, empowerment of workforce, customer focus, supplier relationship management, flexibility, and organisational culture. However, the study has not measured the impact of agile manufacturing implementation on company performance. Meanwhile, Jagusch et al. (2020) published the implementation of agile production at the pre-fabrication stage of a new ship construction project in one of the shipyards in Germany using three enablers: strategy, technology, and systems. The result confirmed that the three agile manufacturing enablers run effectively in the pre-fabrication process of shipbuilding, avoiding errors and making time more effective and productive.

Finally, Kumar et al. (2019) developed more specifically that eight main variables: human resources, organisation culture, supplier, customer, innovation, concurrent engineering, information technologies, and management support, affect the success of AM implementation, which has a positive impact on six performance indicators: customer, financial, business, operational, employee, and supplier. On the other hand, Yusuf et al. (1999) concluded that the success of AM implementation is four core agility: core competence management, enterprise partnership, capability for re-configuration, and knowledge management. Given the characteristics of the shipyard industry as a customised job order business with a high level of customisation different from the common manufacturing industry, an analytical review is needed to determine the specific AM main variables following the shipyard industry business.

4.2 Crucial aspects of developing the AM model in the shipbuilding industry

The crucial aspect that should be considered in developing the AM model in the shipbuilding industry is the shipbuilding business process, which starts from translating customer needs into ship design, procurement of main equipment and materials, fabrication, assembly, erection work, installation, testing and commissioning of systems and sub-systems, finishing work, and ship delivery to buyers, as well as after-sales service during the warranty period. Therefore, the authors propose seven essential variables in the conceptual AM model for the shipbuilding industry, including technologies, empowerment, customer focus, supplier relationship, manufacturing system, organisational culture, and core competence. In addition, the indicators of each dimension are to be selected based on the results of a comparative analysis of all indicators developed by previous studies, and the specific characteristics of the shipyard industry are also to be taken into account.

The shipbuilding strategy is undoubtedly different from the manufacturing process of other manufacturing industries, whose products are massive, such as the automotive industry. In the shipbuilding industry, the possible customisation on every manufactured unit (a ship), in contrast to the other manufacturing industries, it is possible to have multiple units on the same customisation. Therefore, agility in the process must be an inherent requirement in the AM model of the shipbuilding industry. The manufacturing systems developed in the manufacturing industry, such as flexible manufacturing systems, need to be adapted with several modifications tailored to the characteristics of the shipyard industry. Furthermore, the latest production methodology with modular methods needs to be implemented in the modern ship industry to produce effectiveness and efficiency in the shipbuilding process so that the completion of ship construction is faster and more efficient to increase the competitiveness level in global competition (Agarwala, 2019).

Shipbuilding industry competition in obtaining ship orders applies globally. Therefore, developing the AM implementation model should consider many factors related to global competition in the shipbuilding industry. One crucial factor that needs to be owned by the shipyard industry is core competence, where the ability of shipyards to innovate and improve so that they can quickly respond to customer requests is important because ship orders are customised according to customer wishes. In terms of cost structure, building a new ship can reach 75% of material costs (Bruce, 2021). In addition, the application of modular methods in shipbuilding requires accurate specifications and material arrival schedules to avoid rework and production delays. Therefore, the supply chain factor is vital in completing ship construction on time, cost, and quality. Therefore, shipyards should continuously build long-term supplier relationships to build mutual trust.

The following three aspects were identified as the most important reasons for developing a specific AM model in the shipbuilding industry:

1 the shipbuilding is classified as an engineer-to-order (ETO) business with highly customised products following customer requirements (customised orders)

2 the speed of change in the shipbuilding market is getting faster than ever due to customer requirement of faster delivery, better quality, and competitive price, so the shipyards shall emphasise the speed response to win the competition (Song et al., 2011)

3 specific AM model brings several benefits to shipyards, including faster response to market changes, improve quality, increase flexibility, enhance innovation, and reduce costs (Kaitlynn et al., 2019).

In addition, some papers reported a model development linked to agile manufacturing systems and corporate sustainability that is relevant and supports the proposed model's vital factors. Rauch et al. (2017) developed a distributed manufacturing (DM) network framework for smart and agile factories. The framework presented the evolution stages of DM factory models, starting from standardised and replicable, modular and scalable, flexible and reconfigurable, and finally, a smart and agile DM factory. At the same time, Peruzzini and Pellicciari (2017) created a human factors assessment model for sustainable manufacturing. Their model defines early human factors integrated with established cost and environment assessment models to increase manufacturing process sustainability. From a strategic perspective, several characteristics, such as the strategic business management agenda that contains aspects of sustainability, the quality management system owned by the company, and the signing of voluntary commitments to sustainable development, affect the company's sustainability strategy (Kai et al., 2017).

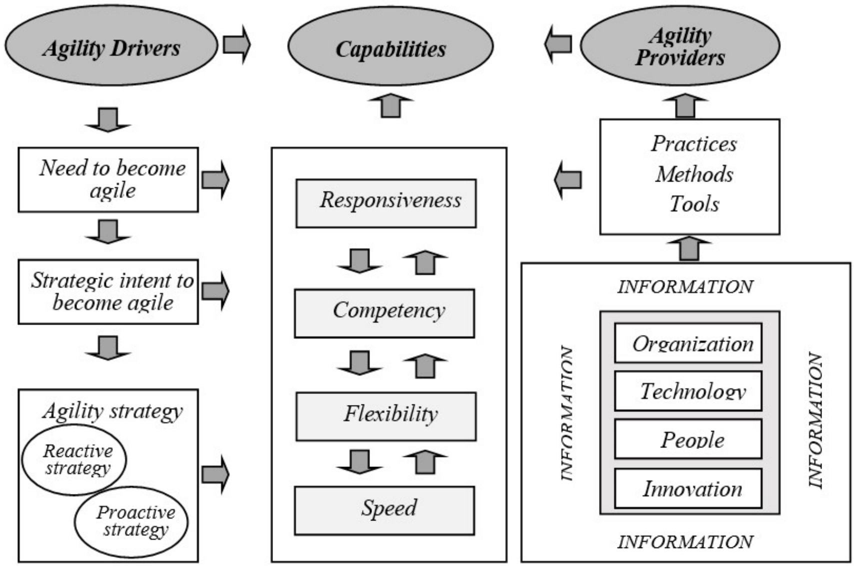
4.3 Review of the prominent AM model

Three prominent AM implementation models could be reviewed for developing a proposed AM model in the shipbuilding industry, as follows:

1. Zhang and Sharifi (2000) developed an agility implementation model in manufacturing companies described in 3 blocks, namely:
   - i Agility drivers, which encourage companies to make changes.
   - ii Agility capabilities, the main capabilities needed by the company to be able to respond to change.
   - iii Agility providers, capabilities to be achieved (see Figure 2). The AM model describes how to build agility capabilities, which agility drivers and agility providers encourage and support. Nonetheless, the model does not show the impact of agility achievement on the organisation's performance. However, the proposed AM model for the shipbuilding industry will adopt some elements of agility provider and capabilities, including organisational culture, technologies, empowerment, and core competence. Meanwhile, innovation and responsiveness will be indicators of the customer focus dimension.
2. Vazquez-Bustelo et al. (2007) developed an AM implementation model by describing the relationship between drivers, enablers, and outcomes, as shown in Figure 3. The AM model is close to the objective of our research. Therefore, the conceptual AM model for the shipbuilding industry is developed by adapting the existing AM model, which shows the correlation between drivers, AM, and output. However, the constructs in the model are adjusted to follow the specific characteristics of the shipbuilding industry. The adjustments of constructs and indicators include the characteristics of fluctuating demand in the shipbuilding business, the proper shipyard performance indicators, and appropriate AM variables and indicators.
3. Goswami and Kumar (2018) developed an AM implementation model in the automotive industry in India using structural equation modelling (SEM) with 5 AM attributes, namely: management responsiveness agility (MRA), MSA, workforce agility (WFA), technology agility (TCA), and manufacturing management agility (MMA). The AM model was developed, as shown in Figure 4. Some attributes from this model are adapted in the proposed AM model, such as manufacturing systems, technologies, and empowerment of workforces.

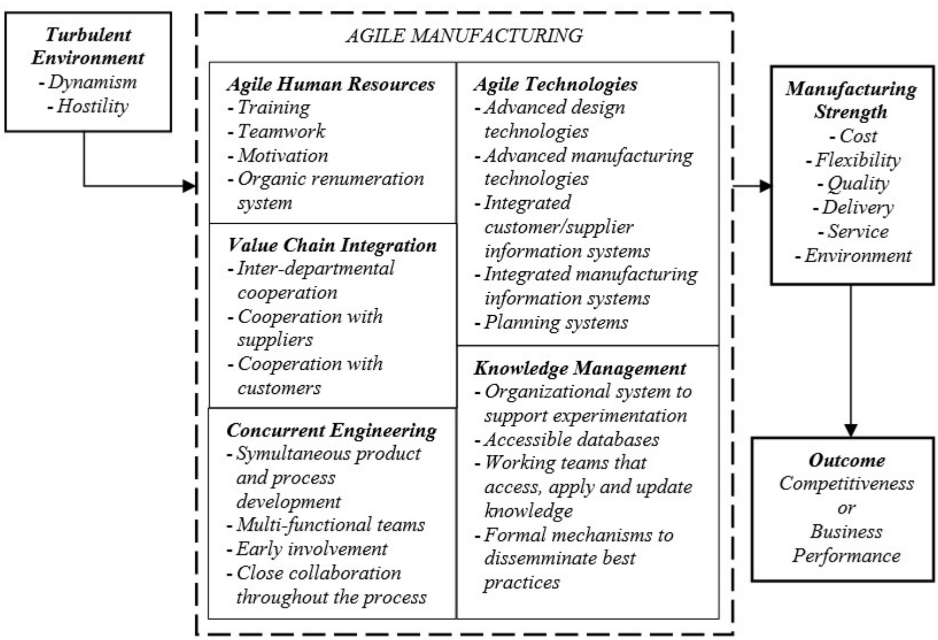
To describe more clearly the derivation of the proposed AM model in the shipbuilding industry, Table 2 shows the summary of major features or constructs that can be used in the new model and the missing features or constructs that must be added to the new model.

Figure 2 Agility implementation model



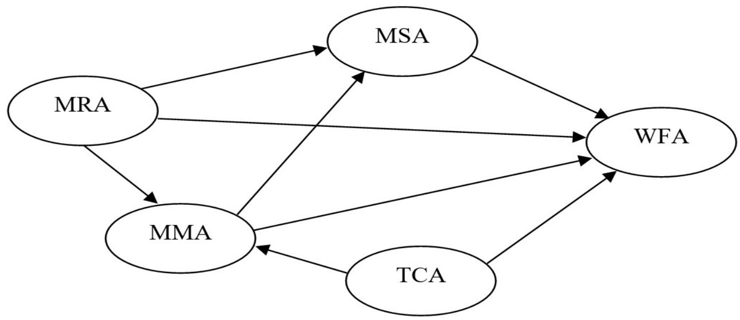
Source: Zhang and Sharifi (2000)

Figure 3 Model of AM implementation



Source: Vazquez-Bustelo et al. (2007)

Figure 4 AM implementation model



Source: Goswami and Kumar (2018)

Table 2 Summary of major features or constructs in the derivation of the proposed AM model

Prominent AM Model	Major features or constructs in the prominent AM model that can be used in the new model	Missing features or constructs that must be added to the new model
Agility implementation model (see Figure 2)	*Constructs*: technologies, empowerment, organisational culture, core competence *Major features*: customer response, customer-driven innovation	*Constructs*: customer focus *Major features*: ERP, e-commerce, delegation of authority, manpower utilisation, status of productivity, product quality, customer satisfaction, product life cycle management, outsourcing, cost-effectiveness, volume flexibility, design improvement, production methodology, organisational structure, top management support, the nature of management, multi-skilled and flexible people, new product development, virtual enterprise formation tools, change in business and technical processes, sales
Model of AM implementation (see Figure 3)	*Constructs*: fluctuating demand, technologies, empowerment, supplier relationship, manufacturing system, manufacturing strength/organisation performance *Major features*: IT technology, advanced design technologies, advanced manufacturing technologies, teamwork, training and education, long-term relationship, close relationship with suppliers, concurrent engineering, system integration and database management, production planning and control system, cooperation (internal and external), knowledge management, quality, cost, delivery	
AM implementation model (see Figure 4)	*Constructs*: technologies, empowerment, manufacturing systems	

5 Proposed AM model for the shipbuilding industry

The proposed AM model was developed by considering the gap findings in the critical review, including a review of the prominent AM model (Figures 2–4) and crucial aspects of developing the AM model in shipbuilding, as explained in the previous section.

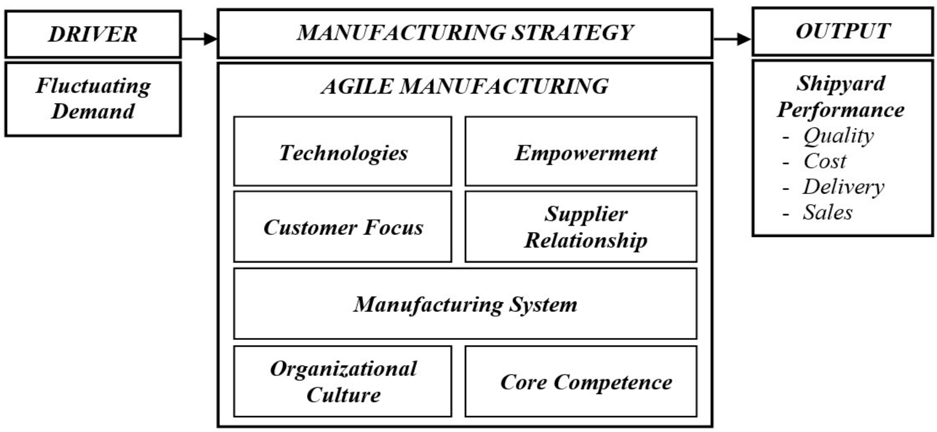
Therefore, the conceptual model of AM in the shipbuilding industry consists of 3 blocks, namely:

1 fluctuating demand as a driver

2 agile manufacturing as a MSA consisting of 7 vital AM variables, namely technologies, empowerment, customer focus, supplier relationship, manufacturing system, organisational culture, and core competence

3 shipyard performance as output (see Figure 5).

Figure 5 Proposed conceptual AM model for the shipbuilding industry



Fluctuating demand is a condition of the order that increases and decreases sharply in response to changes in economic conditions and consumer consumption patterns. The main factors influencing the shipbuilding market are the price of a used vessel worth operating, buyers' financial liquidity, credit availability, and buyer expectations (Gourdon, 2019).

Agile manufacturing has seven dimensions: technologies, organisational culture, empowerment, manufacturing system, supplier relationship, customer focus, and core competence (Sutrisno et al., 2022). Each dimension contains the measurement items shown in Table 3.

Shipyard performance is the achievement of targets set due to investing in human resources and other assets. The primary criteria for evaluating shipyard performance from the competitiveness point of view are production cost, building time, and quality (Pires et al., 2009). In addition, the main goal of implementing AM is to win the competition in fluctuating market conditions, so sales revenue indicators need to be measured as part of shipyard performance.

5.1 Validation of the proposed AM model

An empirical study was done to test the validity and reliability of the proposed AM model. Data were collected using a questionnaire survey, and 155 valid data were obtained from 27 shipyards representing the shipyard's population in Indonesia. Using the SEM method, the measurement model and structural model test were carried out using SmartPLS 4 software. Concerning models using second-order constructs, measurement model tests are carried out in two stages with an embedded two-stage approach.

Table 3 AM dimensions and measurement items

AM dimensions and description	*Measurement items and label*
Technologies (TE) are the application of knowledge to achieve practical goals in a way that can be determined and reproduced.	IT technology (TE1) ERP (TE2) AGV systems (TE3) Advanced design technologies (TE4) Advanced manufacturing technologies (TE5) e-commerce (TE6)
Empowerment (EP) is practical management related to rewarding, informing, and, most importantly, authorising employees to take the initiative and make decisions to solve problems and improve performance and service.	Delegation of authority (EP1) Manpower utilisation (EP2) Teamwork (EP3) Training and education (EP4) Status of productivity (EP5)
Customer focus (CF) is a business philosophy that puts the customer at the center of all business development and management decision-making	Product quality (CF1) Customer response (CF2) Customer satisfaction (CF3) Product life cycle management (CF4) Long-term relationship (CF5) Customer-driven innovation (CF6)
Supplier relationship (SR) is an affiliation with suppliers of goods and services in the company's business	Close relationship with suppliers (SR1) Outsourcing (SR2)
Manufacturing system (MS) is the combination of actions and processes used to produce goods	Concurrent engineering (MS1) Cost-effectiveness (MS2) System integration and database management (MS3) Volume flexibility (MS4) Design improvement (MS5) Production planning and control system (MS6) Production methodology (MS7)
Organisational culture (OC) is a collection of values, expectations, and practices that are guided and carried out by all organisation members	Organisational structure (OC1) Cooperation (internal and external) (OC2) Top management support (OC3) The nature of management (OC4)
Core competence (CC) is the ability to explore and access a broad spectrum of markets by increasing customer value for products and making competitors difficult to replicate	Multi-skilled and flexible people (CC1) Knowledge management (CC2) New product development (CC3) Virtual enterprise formation tools (CC4) Change in business and technical processes (CC5)

The stage 1 measurement model test includes the loading factor, internal consistency reliability (composite reliability, Cronbach's alpha), and convergent validity (AVE), as shown in Table 4. As a note, the AGV system (TE3) was deleted as an indicator due to the loading factor of 0.390. Meanwhile, the HTMT value is below 0.9, indicating that all constructs' discriminant validity is valid.

Table 4 Measurement model test result – stage 1

Constructs and items		*Loadings (>0.60)*[a]	*VIF (<5)*[b]	*Cronbach's alpha (≥0.70)*[c]	*Composite reliability (≥0.70)*[c]	*AVE (≥0.50)*[c]
Fluctuating demand (FD)	FD1	0.744	1.488	0.750	0.837	0.562
	FD2	0.716	1.588			
	FD3	0.785	1.487			
	FD4	0.750	1.275			
Technologies (TE)	TE1	0.857	2.388	0.838	0.886	0.609
	TE2	0.813	2.053			
	TE4	0.778	2.670			
	TE5	0.725	2.599			
	TE6	0.720	2.534			
Empowerment (EP)	EP1	0.854	4.507	0.898	0.925	0.711
	EP2	0.786	3.876			
	EP3	0.889	2.953			
	EP4	0.816	2.206			
	EP5	0.868	2.656			
Customer focus (CF)	CF1	0.813	4.007	0.905	0.927	0.680
	CF2	0.899	4.003			
	CF3	0.846	2.752			
	CF4	0.711	1.674			
	CF5	0.856	2.991			
	CF6	0.813	2.452			
Supplier relationship (SR)	SR1	0.925	1.584	0.756	0.889	0.801
	SR2	0.863	1.584			
Manufacturing system (MS)	MS1	0.872	4.327	0.899	0.921	0.627
	MS2	0.741	2.691			
	MS3	0.805	2.713			
	MS4	0.721	3.370			
	MS5	0.882	3.907			
	MS6	0.790	3.648			
	MS7	0.715	2.805			

Table 4 Measurement model test result – stage 1 (continued)

Constructs and items		*Loadings (>0.60)[a]*	*VIF (<5)[b]*	*Cronbach's alpha (≥0.70)[c]*	*Composite reliability (≥0.70)[c]*	*AVE (≥0.50)[c]*
Organisational culture (OC)	OC1	0.812	4.744	0.844	0.896	0.683
	OC2	0.870	4.946			
	OC3	0.755	3.034			
	OC4	0.864	2.159			
Core competence (CC)	CC1	0.855	2.672	0.901	0.927	0.717
	CC2	0.889	3.206			
	CC3	0.756	1.824			
	CC4	0.850	4.305			
	CC5	0.876	3.978			
Shipyard performance (SP)	SP1	0.796	1.463	0.798	0.867	0.620
	SP2	0.780	1.715			
	SP3	0.859	2.370			
	SP4	0.707	1.524			

[a]Chin (1998); [b]Becker et al. (2015); [c]Henseler et al. (2016), Hair et al. (2019).

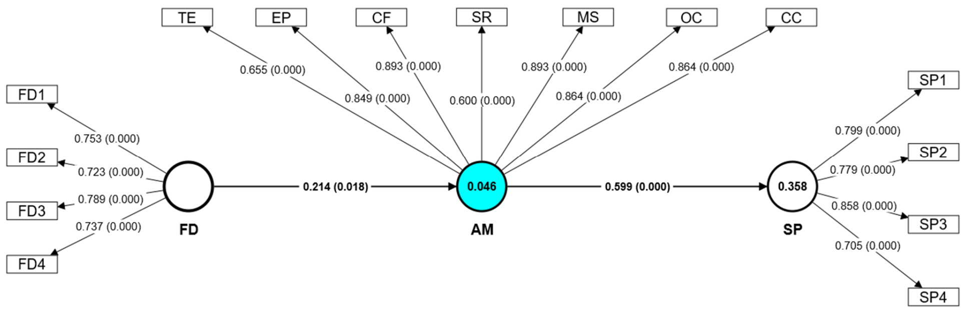
The stage 2 measurement model was tested using variable latent score data of the higher-order construct generated by SmartPLS 4 software. The result is shown in Table 5.

Table 5 Measurement model test result – stage 2

Constructs and items		*Loadings (>0.60)[a]*	*VIF (<5)[b]*	*Cronbach's alpha (≥0.70)[c]*	*Composite reliability (≥0.70)[c]*	*AVE (≥0.50)[c]*
Fluctuating demand (FD)	FD1	0.753	1.488	0.750	0.838	0.564
	FD2	0.723	1.588			
	FD3	0.789	1.487			
	FD4	0.737	1.275			
Agile manufacturing (AM)	TE	0.655	1.646	0.910	0.929	0.657
	EP	0.849	3.599			
	CF	0.893	4.061			
	SR	0.600	1.676			
	MS	0.893	4.287			
	OC	0.864	3.173			
	CC	0.864	4.461			
Shipyard performance (SP)	SP1	0.799	1.463	0.798	0.866	0.619
	SP2	0.779	1.715			
	SP3	0.858	2.370			
	SP4	0.705	1.524			

The final stage of model validation was carried out by structural model test, where the results show that the proposed AM model is valid, as seen in Figure 6.

Figure 6 A validated model of AM in the shipbuilding industry (see online version for colours)



5.2 *Assessment of AM implementation*

To measure the level of AM implementation in the shipyard, the authors developed an assessment tool using the scoring approach with a maximum total score of 1000, in line with the Malcolm Baldridge National Quality Award (Vinodh et al., 2008; Raj and Vinodh, 2014). The score of 1000 was apportioned according to the loading factor of each element and item, as shown in Table 6.

Table 6 Scoring of AM element and item

Elements and items		*Maximum score*
1	**Technologies (TE)**	**75**
	1.1 Integrated information technology (TE1)	16
	1.2 Enterprise resource planning/ERP (TE2)	16
	1.3 Advanced design technologies (TE4)	15
	1.4 Advanced manufacturing technologies (TE5)	14
	1.5 Electronic commerce (TE6)	14
2	**Empowerment (EP)**	**97**
	2.1 Delegation of authority (EP1)	20
	2.2 Manpower utilisation (EP2)	18
	2.3 Team working (EP3)	20
	2.4 Training and education (EP4)	19
	2.5 Status of productivity (EP5)	20
3	**Customer focus (CF)**	**102**
	3.1 Product quality (CF1)	17
	3.2 Customer response adoption (CF2)	18
	3.3 Customer satisfaction (CF3)	17
	3.4 Product life cycle management (CF4)	15
	3.5 Long-term and trust-based relationship with customers (CF5)	18
	3.6 Customer-driven innovation (CF6)	17

Table 6 Scoring of AM element and item (continued)

	Elements and items	Maximum score
4	**Supplier relationship (SR)**	**68**
	4.1 Close relationship with suppliers (SR1)	35
	4.2 Outsourcing (SR2)	33
5	**Manufacturing system (MS)**	**102**
	5.1 Concurrent engineering (MS1)	16
	5.2 Cost-effectiveness (MS2)	14
	5.3 System integration and database management (MS3)	15
	5.4 Volume flexibility (MS4)	13
	5.5 Design improvement (MS5)	16
	5.6 Production planning and control system (MS6)	15
	5.7 Production methodology (MS7)	13
6	**Organisational culture (OC)**	**98**
	6.1 Organisational structure (OC1)	24
	6.2 Cooperation (internal and external) (OC2)	26
	6.3 Top management support (OC3)	22
	6.4 Nature of management (OC4)	26
7	**Core competence (CC)**	**99**
	7.1 Multi-skilled and flexible people (CC1)	20
	7.2 Knowledge management (CC2)	21
	7.3 New product development (CC3)	18
	7.4 Virtual enterprise formation tools (CC4)	20
	7.5 Change in business and technical processes (CC5)	20
8	**Shipyard performance (SP)**	**359**
	8.1 Quality (SP1)	91
	8.2 Production cost (SP2)	89
	8.3 Building time (SP3)	98
	8.4 Sales revenue (SP4)	81
TOTAL SCORE		**1.000**

The method of calculating the score refers to the score obtained against each response from the questionnaire of each element and item. Each element and item has a maximum score with a maximum total score of 1000, while the gap is the difference between the maximum and obtained scores. The AM index of the organisation is to be computed as follows:

$$AM\ index = \frac{Total\ score}{1000}$$

6 Conclusion and direction for future research

A new proposed AM model for the shipbuilding industry has been developed to improve shipyard performance. The AM model consists of three main blocks:

1. fluctuating demand as a driver
2. agile manufacturing as a MSA, which comprises seven essential variables: technologies, empowerment, customer focus, supplier relationship, manufacturing system, organisational culture, and core competence
3. shipyard performance as output.

The impact and effectiveness of the AM approach to improve shipyard performance depends on the level of implementation of each element and item in the organisation. It is necessary to assess all elements and items to determine the level of implementation of AM in the shipyard. After identifying the weaker element or item, a suitable proposal is developed to improve the organisation's agility. The continuous improvement program is recommended to increase the agility index to achieve better shipyard performance (quality, production cost, building time, and sales revenue).

This study contributes to science, particularly in developing the AM conceptual model in the shipbuilding industry, including the specific variables and indicators appropriate to shipyards' business practices. Empirically, this study provides new insights for shipyard practitioners where the AM model can be used as an alternative strategy to solve the crucial problem of improving shipyard performance amid fluctuating markets.

Finally, we recommend expanding this study with a case study in the selected shipyard, including an assessment of the implementation of the proposed AM model to measure the agility index and the influence on the shipyard performance improvement. The case study is expected to strengthen the result of this study.

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