Electrical, Electronics and communications, and Computer Engineering

Agile manufacturing assessment model using multi-grade evaluation

Huthaifa Al-Khazraji *
Ph. D (Lecturer)
Control and System Engineering
Department, University of Technology
Baghdad, Iraq
60141@uotechnology.edu.iq

Sohaib Khlil
M. Sc. (Assist Lecturer)
Technical College-Baghdad,
Middle Technical University
Baghdad, Iraq
sohaib-khlil@mtu.edu.iq

Zina Alabacy
M. Sc. (Lecturer)
Control and System Engineering
Department, University of
Technology
Baghdad, Iraq
11510@uotechnology.edu.iq

ABSTRACT

In unpredicted industrial environment, being able to adapt quickly and effectively to the changing is key in gaining a competitive advantage in the global market. Agile manufacturing evolves new ways of running factories to react quickly and effectively to changing markets, driven by customized requirement. Agility in manufacturing can be successfully achieved via integration of information system, people, technologies, and business processes. This article presents the conceptual model of agility in three dimensions named: driving factor, enabling technologies and evaluation of agility in manufacturing system. The conceptual model was developed based on a review of the literature. Then, the paper demonstrates the agility evaluation by developing a multi-grade assessment model. This model can be used by decision maker to evaluate their current degree of agility. Lastly, the paper examined the conceptual model of evaluation in the State Company for Vegetable Oils Industry in Iraq. The calculation show that the State Company for Vegetable Oils Industry is very agile.

Keywords: Agile enterprise, Agility evaluation, Manufacturing

<div dir="rtl">

نموذج لقياس التصنيع الفعال باستخدام تقيم متعدد المستويات

* حذيفة الخزرجي
دكتوراه (مدرس)
هندسة السيطرة والنظم
الجامعة التكنولوجية

صهيب خليل
ماجستير (مدرس مساعد)
الكلية التقنية – بغداد
الجامعة التقنية الوسطى

زينة العباسي
ماجستير (مدرس)
هندسة السيطرة والنظم
الجامعة التكنولوجية

الخلاصة

ان التغير المستمر في البيئة الصناعية والانتاجية تتطلب من الشركات ان تمتلك القدرة على التكيف بشكل سريع وفعال للاستجابة لهذه التغيرات والحصول على ميزة تنافسية في السوق العلمية. ضمن هذا الاطار، يعتبر التصنيع الفعال هو احد الطرق المتبعة من اجل الاستجابة السريعة لمتطلبات السوق المتغيرة. التصنيع الفعال يمكن تنفيذه بشكل ناجح من خلال دمع نظام المعلومات والافراد والتقنيات الحديثة والعمليات التجارية. تقدم هذه الدراسة الاطار النظري لتصنيع الفعال من خلال ثلاث ابعاد هي: الدوافع

</div>

لتحويل لنظام التصنيع الفعال، التقنيات التي يجب توفرها وطريقة تقيم التصنيع. النموذج النظري تم تصميمه من خلال ادبيات التصنيع الفعال. بعد ذلك، تقدم الدراسة شرح تفصيلي عن كيفية تقيم الشركة من خلال نموذج تقيم متكون من عدة مستويات. بمكن استخدام هذا المودين من قبل صانعي القرار في الشركة لمعرفة مستوى الشركة ضمن اطار التصنيع الفعال. واخيرا، يقدم البحث تطبيق عملي لتقيم الشركة العامة لصناعة الزيوت النباتية. تمخضت الدراسة عن ان مستوى الشركة هو جيد جدا.

الكلمات الرئيسية: التصنيع الفعال، تقيم التصنيع الفعال، انتاج.

1. INTRODUCTION

Industrial companies adopt modern manufacturing strategies to gain a competitive advantage in the global industrial market. The principle of economies of scale or mass production was ruled the manufacturing world during the past, resulted an inflexible manufacturing system (**Sanchez and Nagi, 2001**). However, uncertainty in the industrial environment have been recognized as the main reason of most failures in manufacturing industry (**Small and Downey, 1996**). Therefore, there was a need for a flexible manufacturing that can successfully deal with unpredictable and continuous change in the operational environment in order to remain competitive. In this way, agile manufacturing was developed as a new manufacturing paradigm beyond the conventional manufacturing systems. Agility in manufacturing can be successfully achieved via the integration of different practices to enable the company to respond quickly to changes (**Sharifi and Zhang, 2001**). If agile manufacturing implemented properly, speed in the industrial market allowed manufactures to be a head over their competitors. Being the first in the market result some benefits. Among these benefits are creating a time gap with your competitor in the market and winning both the brand and customer loyalty (**Youssef, 1992**).

However, important issue and questions need to be addressed properly to implement agile manufacturing. For example, how an industrial company clearly identifies the requirements to be agile, what are the capabilities that company need to acquire in order to be agile and how agility of any company could be measured and evaluated. **Nabass and Abdallah (2019)** examine the impact of agile manufacturing on the business performance. The experimental design was performed by analyzing data collected from 282 industrial companies in Jordan. The hypotheses of the study was construct as whether agile manufacturing is positively impact the business performance in terms of cost, quality, delivery and flexibility. The outcomes was confirm that agile manufacturing is positively impacted on business performance.

The present paper develops a framework to address the driving factors, enabling technologies and evaluating criteria of agility manufacturing. Then, the paper demonstrates the agility evaluation by developing a multi-grade assessment model. This model can be used by decision maker to evaluate their current degree of agility. Lastly, the paper examined the conceptual model of evaluation in the State Company for Vegetable Oils Industry in Iraq.

2. LITERATURE REVIEW

Many industrial strategies such lean manufacturing, six sigma, and total predictive maintenance were adopted by industrial companies in order to improve production efficiency (**Ketan and Yasir, 2015**). These strategies focus on reducing the wastages and improve productivity as maximum as possible. However, none of these strategies focus on how industrial companies can cope with dynamic, unpredictable, and constantly changing in the industrial environments. In the face of that, the agile manufacturing paradigm was introduced in response to unexpected changes as a basis to provide sustainable competitive advantage (**Mohammed and Jasim, 2018**). The concept of agility was initially developed by a group of researchers at the Iacocca Institute, Lehigh University, in 1991 (**Ganguly et al., 2009**). During the last three decades, a large body of research

have been developed from both academics and industrial communities in this topic. Agility has been defined in different ways. For example, **Christopher and Towill (2000)** defined agility as a business process that is capable of integrating organizational structures, information systems, logistics processes. **Cho et al. (1996)** defined agility as a manufacturing system that able to rapidly respond to unpredictable changes in customers' demands with high productivity and quality. **Gunasekaran (1998)** added that agility is not just being able to face current demand, it also about being able to respond to future changes. It can summarized from above that agility definitions comprised both characteristics of adaptability and flexibility. Based on that, agile manufacturing is a demand-driven rather than forecast-driven (**Christopher et al., 2004**).

In terms of outcomes, **Goldman et al. (1995)** defined agility as the ability of industrial company to succeed and growth in a continuous and unanticipated changing market. **Youssef (1994)** point out that agility is not just speed of doing things, it is the proper way of using technology into manufacturing to take advantages of changes as the windows of opportunities. According to **Dove (1994)**, the concept of agility is divided into four dimensions: cost, time, quality, and scope, where the agility of an enterprise can be achieved by comprised these four dimensions in a perfect balance. Another conceptual model of agility was proposed by **Yusuf et al. (1999)** includes four core concepts named: core competence management, virtual enterprise, capability for re-configuration, and knowledge-driven enterprise.

3. THE CONCEPTUAL MODEL OF AGILITY MANUFACTURING

Agility concept is not yet clearly defined and conceptualized. However, a general agility attributes could be defined in terms of responsiveness, flexibility, integration, customized products, speed and culture of change (**Osinga, 2019**). As industrial environment experiences increasing in uncertainties and unpredictability, industrial companies have to become agile in order to stay in the business. Based on the finding from the literature, this section identifies the concept of agility through three dimensions. These dimensions are drivers of becoming agile, key enablers of agility, and evaluating criteria of agility manufacturing as shown in **Fig.** 1.
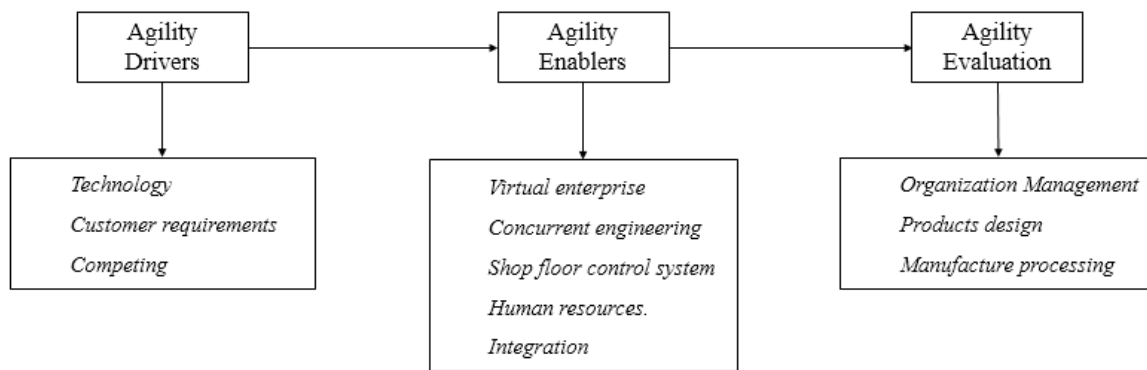
Figure 1. Concept of agility.

3.1 Agility drivers

Agility drivers is the changing in the industrial and business environment that drive a company to consider moving to agility manufacturing system as a basis to provide sustainable competitive advantage **(Lin et al., 2006)**. Agility drivers are further breakdowns as follows:

- *Technology.* The introduction of more efficient, faster and economic manufacturing system increase the ability of industrial companies to listen to their customers, and to try out new things **(Yusuf et al., 1999)**.
- *Customer requirements.* Instability in the market due to the widening customer choice and expectation was the most compelling drivers of agile manufacturing **(Yusuf et al., 1999)**.
- *Competing.* US industries were embarrassed with a recession which hit its in 1991 and 2008. This stressed the need to formulate a new manufacturing strategy for global competition **(Gunasekaran et al., 2018)**.

3.2 Agility enablers

An appropriate integration between different practices is required to enable a company to become an agile manufacturing. In this section, five enabling capabilities are discussed as follows:

- *Virtual enterprise.* According to **Sharp et al. (1999)**, virtual enterprise means that a company is capable of forming temporary alliances for development a specific product during specific time. Then the co-operation is dissolved when the company move to another product development. **Gunasekaran (1998)** defines virtual enterprise as the ability of a company to reengineering its manufacturing process quickly to meet the changing in the demand.
- *Concurrent engineering.* It is a systematic approach that is used by company to reduce product development costs and reduce product modifications after it is launched **(Cho et al., 1996)**. For example, during product development, it is important that all the product related information is well documented and illustrated **(Gunasekaran, 1998)**.
- *Shop floor control system.* It concerns with advance equipment such as material handling, machining, assembly, and inspection. In order to be agile, a full automatic control system in the shop floor must be established **(Cho et al., 1996)**.
- *Human resources.* Agility is a result of highly-skilled and motivated people that are able to work as a team in order to take the advantage of flexible and smart technology **(Vázquez-Bustelo et al., 2007)**.
- *Integration.* To achieve agility, it necessary to establish a system which is consist of three types of integration: human-human integration, human-technology integration and technology- technology integration **(Wong and Whitman, 1999)**.

3.3 Agility evaluation

Based on the core concept of agility, such as rapidly obtaining the information of the demand, and develop a product in responding to this information utilizing advance technologies. Therefore, agility evaluation is divided into organization management, product design and manufacturing process as follows **(Yang and Li, 2002)**:

- *Organization management.* This index involves three indices as follows: knowledge management, inter-organization management, and organization framework
- *Product design.* This index involves three indices as follows: customer demand information, speed of product design, product design flexibility
- *Manufacturing process.* This index involves three indices as follows: re-configurable, speed of manufacturing, and manufacture flexibility.

A more detailed description of agility evaluation is given in **Table 1**.

Table 1. Multi-grade assessment model agility evaluation.

A_i	A_{ij}	A_{ijk}
Organization management	Knowledge management	Degree information system
		Degree of network connection
		Information and network utilization rate
	Inter-organization cooperative	The degree of cooperating with other enterprises
		The degree of involving workers in the decision making
	Production organizing	Factory layout
		Delivery speed
	The agility framework	The form of institutional framework
		The speed of the team building
Products design	Customer demand information	The way of demand information got
		The adaptability of company with customer needs
		Add value for product
	Products design speed	The period products design
		The proportion of design period in products period
	Products design flexibility	The universalization degree of the part
		The similar degree of products structure
Processing manufacture	Re-configurable	The degree of which the company utilise scrap
		Displacement compatibility
	Manufacture speed	The period of manufacturing
		The proportion of production and technology preparing time in products period
	Manufacture flexibility	The universalization degree of the equipment
		The scalable degree of the equipment

4. MULTI-GRADE ASSESSMENT OF AGILE MANUFACTURING

This paper uses a multi-grade assessment model to evaluate agility. **Table 1** presents three grades of agility evaluation based on the characteristics of agility. Suppose A is the manufacturing agility index of each grade, R_i and W_i are the value and the weight of each agility evaluation index, the agility evaluation index system A is established as follow:

$$A = \sum_{i=1}^{N} R_i \times W_i \tag{1}$$

$$\text{where } \sum_{i=1}^{N} W_i = 1 \tag{2}$$

The value of the performance ratings and importance weights of different agility evaluation need to be assessed by experts. The steps to evaluate agility are:

- Determine the appropriate scale to assess the performance ratings and importance weights of the agility capabilities.
- Measure the performance and importance of agility capabilities.
- Compute manufacturing agility index of each grade.
- Aggregate assessment calculation.
- Match the agility evaluation with an appropriate level as given in **Table 2**.

The assessment model was examined by conducting a case study in an Iraqi manufacturing company.

Table 2. Linguistic levels to match agility index.

Linguistic variable	Score range
Extremely agile	10-8
Very agile	8-6
Agile	6-4
Fairly agile	4-2
Not agile	2-0

5. ASSESSING AGILITY: CASE STUDY

In this section, the procedure of applying the multi-grade assessment model to evaluate agility is given via a practical application in an industrial case study. The State Company for Vegetable Oils Industry in Iraq (SCVOI) is an Iraqi company that concerns on the development and production of a variety of edible fats and cosmetics, detergents, soaps, and oils. The questionnaire used in this study to evaluate agility was prepared on the basis of the existing literature. The questionnaire was checked by two experts in the field of industrial engineering (one practitioner and academics one). The practitioner expert check that the questions are cover all the aspect of agile manufacturing based on his accumulative of experience in this filed, while the academic expert check that the questions are written in accurate format to maximize the outcomes of the questionnaire. The questionnaire was given to plant manager, operations manager, and manufacturing manager. An explanation letter of the purpose of this questionnaire is also given to them. It was assume that respondents based on their position had full access to the information requested in the questionnaire. For convenient calculation, it was suggested that score levels of rating R_i in the range of (0-10). The assessment of each index by the plant manager, operations manager, and manufacturing manager is determined as shown in **Table 3**.

The assessment calculation is as follows:
As shown in Table (3), for the index A_{11}:
$$W_{11} = (0.3, 0.3, 0.4)$$

$$R_{11} = \begin{bmatrix} 8 & 8 & 7 \\ 9 & 9 & 8 \\ 8 & 8 & 9 \end{bmatrix}$$

$$A_{11} = W_{11} \circ R_{11} = (8.3, 8.3, 8.1)$$

Using the same principle, the following can obtained:

$A_{12} = W_{12} \circ R_{12} = (6.5, 7.5, 7.5)$, $A_{13} = W_{13} \circ R_{13} = (7, 7, 7.5)$

$A_{14} = W_{14} \circ R_{14} = (7, 8.4, 10)$, $A_{21} = W_{21} \circ R_{21} = (6.9, 8.1, 7.8)$

$A_{22} = W_{22} \circ R_{22} = (7, 6.5, 6.5)$, $A_{23} = W_{23} \circ R_{23} = (7.6, 7.4, 8)$

$A_{31} = W_{31} \circ R_{31} = (7, 6.5, 6.5)$, $A_{32} = W_{32} \circ R_{32} = (7.5, 8.5, 8)$

$A_{33} = W_{33} \circ R_{33} = (8.5, 8, 8.5)$,

Table 3. Single factor assessment vector and weights.

A_i	W_i	A_{ij}	W_{ij}	A_{ijk}	W_{ijk}	Expert1	Expert2	Expert3
A_1	0.4	A_{11}	0.3	A_{111}	0.3	8	8	7
				A_{112}	0.3	9	9	8
				A_{113}	0.4	8	8	9
		A_{12}	0.2	A_{121}	0.5	6	7	9
				A_{122}	0.5	7	8	6
		A_{13}	0.3	A_{131}	0.5	5	8	8
				A_{132}	0.5	9	6	7
		A_{14}	0.2	A_{141}	0.4	7	9	10
				A_{142}	0.6	7	8	10
A_2	0.3	A_{21}	0.4	A_{211}	0.4	6	9	9
				A_{212}	0.3	8	8	7
				A_{213}	0.3	7	7	7
		A_{22}	0.3	A_{221}	0.5	8	7	7
				A_{222}	0.5	6	6	6
		A_{23}	0.3	A_{231}	0.4	7	8	8
				A_{232}	0.6	8	7	8
A_3	0.3	A_{31}	0.3	A_{311}	0.6	7	9	10
				A_{312}	0.4	8	10	10
		A_{32}	0.35	A_{321}	0.5	8	8	9
				A_{322}	0.5	7	9	7
		A_{33}	0.35	A_{331}	0.5	8	7	9
				A_{332}	0.5	9	9	8

As the same above, for the index A_1:

$$W_1 = (0.3, 0.2, 0.3, 0.2)$$

$$R_1 = \begin{bmatrix} 8.3 & 8.3 & 8.1 \\ 6.5 & 7.5 & 7.5 \\ 7 & 7 & 7.5 \\ 7 & 8.4 & 10 \end{bmatrix}$$

Then:
$$A_1 = W_1 \circ R_1 = (7.29, 7.77, 8.18)$$

Using the same principle, the following can obtained:
$$A_2 = (7.14, 7.41, 7.47)$$
$$A_3 = (7.7, 7.73, 7.73)$$

Finally, for the index A:

$$W = (0.4, 0.3, 0.3)$$

$$R = \begin{bmatrix} 7.29 & 7.77 & 8.18 \\ 7.14 & 7.41 & 7.47 \\ 7.7 & 7.73 & 7.73 \end{bmatrix}$$

Then:

$$A = W \circ R = (7.37, 7.65, 7.84)$$
$$\bar{A} = \frac{7.37, 7.65, 7.84}{3} = 7.62 \in \{6,8\}$$

Based on Table (2), the manufacture is very agile.

Being very agile company is meant that this company is a leadership in attracting the customer by achieving excellence level of performance in terms of satisfy the customer requirements. Being able to expect customer requirement is the core of agility manufacturing strategy.

6. CONCLUSIONS

Competition between industrial companies nowadays is more than quality, delivery, price, and service of products, it is about how to response to changing in the markets at speed. Agile manufacturing is a production system that is developed in response to unexpected changes and dynamic demand as a basis to provide sustainable competitive advantage. This paper explain the concept of agility via three dimensions named: agility drivers, agility enablers and agility evaluation. For each one of these dimensions, a sub-dimension was developed. In general, agility strategy concept could be defined in terms of advance technology, responsiveness, flexibility, integration, customized products, speed and culture of change. The bottom line of this is to reinforce the knowledge of agility and to provide a general view of the current status in agile manufacturing research. With regard to agility evaluation, to ensure that the decision made of evaluation process is not biased, a multi-grade assessment model of agile manufacturing is developed. In this approach, the evaluation process expressed in terms of ranges of value. The potential contribution of this is to provide practitioners a practical procedure of agility evaluation. The model was examined to evaluate the State Company for Vegetable Oils Industry in Iraq. The calculation show that the State Company for Vegetable Oils Industry is very agile. Achieving high level of agility came by the accumulated effort that are represented by the administrative of the company and long experience in the field of designing and manufacturing products. As an example of that high confidence in suppliers, continues surveys of customer requirement, involving workers in making decisions. All of this creating a good atmosphere to be a creative that lead the company to be leadership in the market.

REFERNCES

- Cho, H., Jung, M. and Kim, M., 1996. Enabling technologies of agile manufacturing and its related activities in Korea. *Computers & Industrial Engineering*, *30*(3), pp.323-334.

- Christopher, M., Lowson, R. and Peck, H., 2004. Creating agile supply chains in the fashion industry. *International Journal of Retail & Distribution Management*, *32*(8), pp.367-376.

- Christopher, M. and Towill, D.R., 2000. Supply chain migration from lean and functional to agile and customised. *Supply Chain Management: An International Journal*, *5*(4), pp.206-213.

- Dove, R., 1994. Tools for analyzing and constructing agility. In *Proceedings of the Third Annual Agility Forum Conference/Workshop, Austin, TX*.

- Ganguly, A., Nilchiani, R. and Farr, J.V., 2009. Evaluating agility in corporate enterprises. *International Journal of Production Economics*, *118*(2), pp.410-423.

- Goldman, S.L., Nagel, R.N. and Preiss, K., 1995. *Agile competitors and virtual organizations: strategies for enriching the customer* (Vol. 8). New York: Van Nostrand Reinhold.

- Gunasekaran, A., 1998. Agile manufacturing: enablers and an implementation framework. *International journal of production research*, *36*(5), pp.1223-1247.

- Gunasekaran, A., Yusuf, Y.Y., Adeleye, E.O., Papadopoulos, T., Kovvuri, D. and Geyi, D.A.G., 2019. Agile manufacturing: an evolutionary review of practices. *International Journal of Production Research*, *57*(15-16), pp.5154-5174.

- Ketan, H.S. and Yasir, F.M., 2015. Reducing of Manufacturing Lead Time by Implementation of Lean Manufacturing Principles. *Journal of Engineering*, *21*(8), pp.83-99.

- Lin, C.T., Chiu, H. and Tseng, Y.H., 2006. Agility evaluation using fuzzy logic. *International Journal of Production Economics*, *101*(2), pp.353-368.

- Mohammed, S.R. and Jasim, A.J., 2018. Examining the Values and Principles of Agile Construction Management in Iraqi Construction Projects. *Journal of Engineering*, *24*(7), pp.114-133.

- Nabass, E.H. and Abdallah, A.B., 2019. Agile manufacturing and business performance. Business Process Management Journal.

- Osinga, T.H.M., 2019. *Virtualization Technologies for Enterprise Agility* (Master's thesis).

- Sanchez, L.M. and Nagi, R., 2001. A review of agile manufacturing systems. *International journal of production research*, *39*(16), pp.3561-3600.

- Sharifi, H. and Zhang, Z., 2001. Agile manufacturing in practice-Application of a methodology. *International Journal of Operations & Production Management*, *21*(5/6), pp.772-794.

- Sharp, J.M., Irani, Z. and Desai, S., 1999. Working towards agile manufacturing in the UK industry. *International Journal of production economics*, *62*(1-2), pp.155-169.

- Small, A.W. and Downey, E.A., 1996, August. Orchestrating multiple changes: a framework for managing concurrent changes of varied type and scope. In *IEMC 96 Proceedings. International Conference on Engineering and Technology Management. Managing Virtual Enterprises: A Convergence of Communications, Computing, and Energy Technologies* (pp. 627-634). IEEE.

- Vázquez-Bustelo, D., Avella, L. and Fernández, E., 2007. Agility drivers, enablers and outcomes: empirical test of an integrated agile manufacturing model. *International Journal of Operations & Production Management*, *27*(12), pp.1303-1332.
- Wong, S.P. and Whitman, L., 1999. Attaining agility at the enterprise level. In *Proceedings of The 4th Annual International Conference on Industrial Engineering Theory, Applications and Practice, San Antonio, TX*.
- Yang, S.L. and Li, T.F., 2002. Agility evaluation of mass customization product manufacturing. *Journal of Materials Processing Technology*, *129*(1-3), pp.640-644.
- Youssef, M.A., 1992. Agile manufacturing: a necessary condition for competing in global markets. *Industrial Engineering-New York Then Atlanta Norcross-American Institute of Industrial Engineers Incorporated-*, *24*, pp.18-18.
- Yusuf, Y.Y., Sarhadi, M. and Gunasekaran, A., 1999. Agile manufacturing: The drivers, concepts and attributes. *International Journal of production economics*, *62*(1-2), pp.33-43.