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Assessment of Phase of Industry 4.0 Adoption: A Pilot Study in Automotive Industry in Thailand

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ABSTRACT

The fourth industrial revolution, often known as Industry 4.0, integrates many practices of technologies in digital transformation. Technology adoption in Industry 4.0 enables mass customization, as well as self-monitoring for production, and expanding information collaboration of machine-to-machine communication (M2M) for the virtualized analysis of new responses and real-time diagnosis of problems. Entering Industry 4.0 has several stages. Therefore, determining which stage the company is in will affect its preparation in various fields, such as investments in technology and personnel. In addition, the government can also prepare support for this transformation. Thus, the purpose of this research is to develop a model to classify the phases of Industry 4.0 adoption for companies. The research methodologies begin with a literature review of related studies to determine the current phase of Industry 4.0 adoption. The purposed model classifies Industry 4.0 into 5 phases: phase 0 beginner; phase 1 sensor; phase 2 automation; phase 3 integration; and phase 4 intelligence. Twelve aspects are considered: (1) the company's implementation of the Industry 4.0 strategy (2) the company's investment in the implementation of Industry 4.0 (3) the company's information technology (IT) equipment infrastructure through the collecting, storage, and processing of data (4) the company's operations via IT systems in its supply chain (5) the company's usage of cloud technology (6) the company's status of IT security (7) the company's autonomous processes for production (8) the company's status of information sharing (9) the company's products equipped with information communication technology (ICT) components (10) the company's data-driven services (11) the company's data analytics services of its products in the usage phase (12) the company's requirements for workforce qualifications of Industry 4.0. A questionnaire development and a questionnaire content validity test were conducted. The purposed model was then used to classify 31 companies in the automotive industry in Thailand, which has been dramatically affected by Industry 4.0 adoption, into different phases of Industry 4.0. It was found that most of the sample automotive companies are in phase 2 automation.

Keywords: Industry 4.0 phase; Automotive industry

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1. INTRODUCTION

The industrial revolution first began with the development of the steam engine, after which electric power enabled machines for mass production, followed by the digital revolution where computer control, the internet, and ICT created massive incoming data. The fourth revolution represents an integration of industrial systems where technologies blur the lines between the physical and digital worlds, using massive data to create new business models as well as other significant values such as productivity, flexibility, effectiveness, and interoperability [1]–[2].

The adoption of Industry 4.0 creates the conditions for companies to replace traditional industrial processes, which are based on centralized decision-making mechanisms, with flexible and reconfigurable processes in which they offer mass customization of interactive data from customers and collaborative industrial systems with decentralized decision-making mechanisms [1]. Therefore, a key transformation to digitization of industrial systems is the realization of the company's current actions of Industry 4.0 adoption [2]. This challenge urged the researchers to study relevant actions in the context of Industry 4.0 adoption. One of them is to identify the stage of Industry 4.0 the company is in. This allows the company, as well as the government, to prepare for future developments.

Automotive industry in Thailand uses 35 percent of industrial robots [3]. According to the proportion of robot density per 10,000 human workers, Thailand was at 45, while the world's average ratio was 74 robot density per 10,000 human workers [3]. So, there are many government policies for maintaining the competitiveness and attractiveness of the automotive industry in Thailand in the new working environment of Industry 4.0, which includes enhancing digital transformation by developing advanced database supporting systems and expanding infrastructure for logistics [4], as well as reducing excise tax to increase investment and demand [5]. This research aims at purposing a model to classify the Industry 4.0 adoption phase for companies. The purposed model was subsequently used in a pilot study of 31 automotive manufacturers in Thailand.

2. RESEARCH METHODOLOGIES AND RESULTS

The research methodologies are shown in Figure 1, which begins with a literature review of related studies to determine the current phase of Industry 4.0 adoption by the company. Then the model to classify the phase was purposed. Next, a questionnaire development and a questionnaire content validity test were conducted. Lastly, a web-based questionnaire was sent via email to 100 automotive manufacturers in Thailand to assess the company's phase of Industry 4.0 adoption and the results were discussed. Details are as follows.

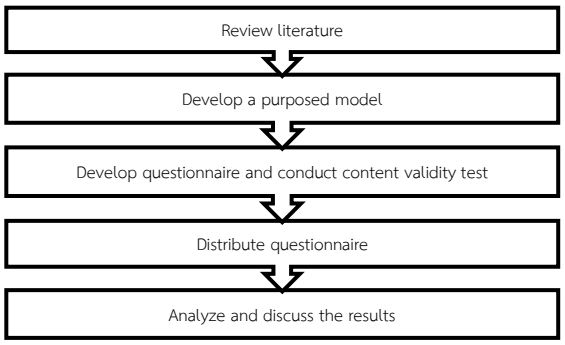

Figure 1 Research Methodologies

2.1 Literature review and purposed Industry 4.0 phase classification model

The model development in this study used past research studies as a guideline. It was found that many researchers studied specific applications of each key technology to classify a certain level of Industry 4.0 adoption. For example, a study [6] provided 5 levels of value creation for implementing Cyber-Physical Systems (CPS) by utilizing advanced information analytics and other required technologies. A study [7] presented 5 layers for policy formulation to support smart manufacturing by implementing Internet-of-Things (IoT) and other 18 advocated technologies. Moreover, studies [8] and [9] assessed the level of general readiness for Industry 4.0, which is differentiated by 6 levels of implementing 7 digital technologies.

Whereas, a study [10] explored Industry 4.0 readiness assessment for digital transformation for any industry in any size of companies using a questionnaire to assess 6 dimensions, which were compiled by the IMPULS model of (1) Strategy and Organization (2) Smart factory (3) Smart operations (4) Smart products (5) Data-driven services (6) Employees. Moreover, the study [11] also adopted these 6 dimensions from the IMPULS model as a guideline to classify the levels of Industry 4.0 adoption to guide the company in achieving a higher level.

The IMPULS model, which is widely cited, provides a comprehensive evaluation of all technological applications related to 6 dimensions, with weight assigned to each dimension with a total score of 100 scores as follows: strategy and organization – 25; smart factory – 14; smart products – 19; data-driven services – 14; smart operations – 10; employees – 18 [2]. As the fusion of physical and virtual environments demonstrates, there is a key understanding that 2 dimensions of smart factory and smart products are related to the physical world, while the other 2 dimensions of smart operations and data-driven services relate to the virtual world [2]. Moreover, in the IMPULS model, there are 6 levels that represent the characteristics of each level of Industry 4.0 adoption, from level 0 outsider, level 1 beginner, level 2 intermediate, level 3 experienced, level 4 expert, and level 5 top performer [2].

Adapted from the IMPULS model [2] and studies [6]–[7], [10]–[11], to be more suitable for the industry in Thailand, in our purposed model, the names of each phase are given to reflect the main characteristics of each stage. The term “phase” was used instead of “level” to identify the state in which a company has accomplished a task [8]. As a result, 5 phases of Industry 4.0 adoption were used in this research: phase 0 beginner, phase 1 sensor, phase 2 automation, phase 3 integration, and phase 4 intelligence. Moreover, in this research, all 6 dimensions to assess the phases of Industry 4.0 adoption as purposed in the IMPULS model [2] were adapted and extended to include 12 aspects of technology applications [2], [6]-[7], [10]-[11]. Table 1 summarizes the 12 aspects corresponding to each of the 5 phases of Industry 4.0.

2.2 Questionnaire development

A questionnaire to assess the phase of Industry 4.0 adoption for the automotive manufacturers in Thailand was created and was divided into 2 parts:

Table 1 Twelve aspects and details corresponding to each phase of Industry 4.0 adoption in the purposed model

		Phase of Industry 4.0 adoption				
Dimension	**Aspects**	**0 beginner**	**1 sensor**	**2 automation**	**3 integration**	**4 intelligence**
Strategy and organization	**The company's implementation of the Industry 4.0 strategy**	There are pilot projects in various departments. But there is no integration of them into the organization's strategy [2,10,11].	Integrated Industry 4.0 into the organization's strategy, however, the Industry 4.0 strategy is not clearly defined [2].	Determined as an Industry 4.0 strategy, but no follow-up action [2,7,10,11].	Defined and implemented Industry 4.0 strategies and, in some departments, followed up their actions with appropriate indicators [2,7,10,11].	Implemented Industry 4.0 strategies and regularly monitors their operational status with appropriate indicators across the whole organization [2,10,11].
	The company's investment in the implementation of Industry 4.0	Invested related to Industry 4.0 at least one department [2,10,11].	Invested related to Industry 4.0 in at least 2 departments [2,10,11].	Invested related to Industry 4.0 in more than two departments and promoted the adoption of Industry 4.0 technology through innovation management focused within the department [2,10,11].	Invested in almost all relevant departments, supported by inter-departmental innovation management [2,10,11].	Invested in company-wide and innovation management is established throughout the organization [2,10,11].
Smart factory	**The company's IT equipment infrastructure through the collecting, storage, and processing of data**	No equipment infrastructure capable of meeting future changing needs [2,10].	Existing equipment infrastructure does not meet all requirements for expansion on demand for changes in the future because the software cannot be upgraded [2,7,10,11].	Existing equipment infrastructure can be software upgraded to support the expansion of demand that can change in the future [2,7,10,11].	Existing equipment infrastructure can be software upgraded. Moreover, there are additional investments in equipment infrastructure to support the expansion if needed [2,7,10,11].	Existing equipment infrastructure meets all requirements for further expansion [2,7,10,11].
	The company's operations via IT systems	Partial production data is collected when required, but no IT system has been used [2,6,7,10,11].	Some production data is collected and supported by IT systems and can be used to a limited extent [2,6,7,10,11].	There is an IT system to help connect and support the production process through collected production data, and for specific critical areas, this data is automatically collected [2,6,7,10,11].	Existing IT systems support large amounts of automatically collected data that is used to optimize production processes [2,6,7,10,11].	Existing IT systems cover all processes and support large amounts of data that are automatically collected that data is used to support every process in the supply chain [2,6,7,10,11].

Table 1 (Cont.) Twelve aspects and details corresponding to each phase of Industry 4.0 adoption in the purposed model

		Phase of Industry 4.0 adoption				
Dimension	**Aspects**	**0 beginner**	**1 sensor**	**2 automation**	**3 integration**	**4 intelligence**
Smart operation	**The company's usage of cloud technology**	No cloud technology is being used [2,10].	There is a plan to further expand cloud technology [2].	Used cloud technology for data storage [2,11].	Used cloud technology for data analysis [2,11].	Cloud technology is flexibly being used for storage, analysis, and access to information [2,11].
	The company's status of IT security	Still in the planning for implementing of IT security [2].	In the process of developing IT security [2,11].	Use third-party IT security services for certain departments. And there is a plan to establish a department of IT security in the organization in the necessary departments [2,10,11].	Use third-party IT security services for certain departments. And there is an IT security department of the organization in only the necessary departments [2,10,11].	There are experts in the IT security department of the organization that cover all departments throughout the organization [2,6,10,11].
	The company's autonomous processes for production	There are no plans to implement automated production processes [2,10].	Plan to implement a production system with automated processes and/or self-reacting processes [2].	Experiment with automated production processes or self-reacting processes for certain areas of production [2,6].	Implement automated production processes and self-reacting processes for all production areas [2,6,11].	Implement a production system with automated work processes and self-reacting processes at the cross-organizational level [2,6,11].
	The company's status of information sharing	No data sharing [2,10].	Information sharing is limited to certain departments within the organization [2,11].	There is information sharing within the organization with IT systems and a plan to share information across organizations with business partners [2,6,11].	Information is shared within the organization and across the organization with business partners only with specific departments via IT systems [2.6,11].	Information is shared within the organization and across the organization with all business partners in the supply chain via the same IT systems [2,6,11].
Smart product	**The company's products equipped with ICT components**	No additional functions of ICT [2,10].	Plan to add IT-based functions [2,11].	There is 1 function based on IT, such as object information or localization [2,10,11].	There is 1 function based on ICT that allows products to be connected to manufacturers or service centers, such as self-reporting or assistance systems [2,6,10,11].	A comprehensive ICT functions for service analysis, such as after-sales maintenance service [2,6,10,11].

Table 1 (Cont.) Twelve aspects and details corresponding to each phase of Industry 4.0 adoption in the purposed model

		Phase of Industry 4.0 adoption				
Dimension	**Aspects**	**0 beginner**	**1 sensor**	**2 automation**	**3 integration**	**4 intelligence**
Data-driven services	**The company's data-driven services**	No data-driven service [2,10].	Plan for data-driven service [2,11].	The product offers data-driven services, which the company plans to integrate with its services for its customers [2, 11].	The customer must give consent to the collection of data during the usage phase for data analysis in which the company is able to integrate between the customer and the company [2, 6, 11].	Use the information collected with the customer's consent to produce data for the data analysis. Offering the service as one with the product. The provided services, such as notifying users when it is time for maintenance or when the product is recently developed or other sales support [2, 6, 11].
	The company's data analytics services of its products in the usage phase	No data in the usage phase to analyze [2, 10].	Plan for the analysis of usage data to generate revenue share [2].	Analysis of usage data results in a revenue share < 7.5% [2, 7, 11].	Analysis of usage data results in a revenue share of ≥ 7.5% but less than 10% [2, 7, 11].	Analysis of usage data results in a revenue share of ≥ 10% [2, 7, 11].
Employees	**The company's requirements of workforce qualifications of Industry 4.0**	No basic requirements for its employees in relation to Industry 4.0 [2, 10].	The organization needs employees to have knowledge and understanding and basic skills to work towards Industry 4.0 in some departments [2, 10, 11].	The organization needs employees to have knowledge and understanding and basic skills for working towards Industry 4.0 in all departments. There is a plan for the assessment of those knowledge and skills necessary to operate in Industry 4.0 across all departments [2, 11].	The organization needs employees to have knowledge and understanding and basic skills for operating under Industry 4.0 in all departments. Employees of all departments are regularly assessed for their knowledge and skills in operating towards Industry 4.0 [2, 11].	The organization needs employees with their expertise required to operate for Industry 4.0, so, proficiency levels are being assessed and incentives are being provided for employees who meets the proficiency level [2, 6, 11].

Part 1 consists of 5 questions about the respondent and the company, including: job position of the respondent; years of experience in the current position of the respondent; area of expertise of the respondent; years of experience in the automotive industry of the respondent; and the organization category in the automotive industry, i.e., automobiles, other parts and accessories for automobiles, and bodies for automobiles, including trailers and semitrailers. A descriptive statistic was used to analyze the answers for each question.

Part 2 consists of 12 questions about the company's current actions regarding Industry 4.0 adoption according to the purposed model

previously described in the previous section. The questions in this part are used to classify the phase of Industry 4.0 adoption, which can be divided into 5 phases.

The 6 dimensions include strategy and organization, smart factory, smart operations, smart product, data-driven services, and employees [2]. These dimensions were extended to cover 12 aspects. As shown in Table 1, questions 1 and 2 ask about the company's **strategy and organization**, are: (1) the company's implementation of the Industry 4.0 strategy and (2) the company's investment in the implementation of Industry 4.0. Questions 3 and 4, asking about the company's **smart factory**, are: (3) the company's IT equipment infrastructure through the collection, storage, and processing of data and (4) the company's operations via IT systems in its supply chain. Questions 5 to 8, asking about the company's **smart operations**, are: (5) the company's usage of cloud technology; (6) the company's status of IT security; (7) the company's autonomous processes for production; and (8) the company's status of information sharing. Question 9, the company's products equipped with ICT components, asks about the company's **smart product**. Questions 10 and 11, asking about the company's **data-driven services**, are: (10) the company's data-driven services and (11) the company's data analytics services of its products in the usage phase. Question 12, the company's requirements for workforce qualifications of Industry 4.0, asks about the company's **employees**. Respondents were asked to select the answer most relevant to their company's actions from a total of 5 options representing each phase of Industry 4.0 adoption (as shown in Table 1).

Each question has a different weight assigned, i.e., 0.125 for questions 1 and 2; 0.07 for questions 3, 4, 10, and 11; 0.025 for questions 5-8; 0.19 for question 9; and 0.18 for question 12. These assigned weights were adapted from the IMPULS model [2] in accordance with the content of each question of the purposed model. In analyzing the result, the total score is obtained by the sum of multiplying the score of each answer by the assigned weight of each question. The total score range for each Industry 4.0 adoption classification is as follows: 1.00 represents phase 0 beginner; 1.01 – 2.00 represents phase 1 sensor; 2.01 – 3.00 represents phase 2 automation; 3.01 – 4.00 represents phase 3 integration; and 4.01 – 5.00 represents phase 4 intelligence.

2.3 Questionnaire content validity test

Before distributing the developed questionnaire, the index of Item- Objective Congruence (IOC) was used to test the content validity. Three experts in the fields of Industry 4.0, the automotive industry, and questionnaire development were asked to rate each question on a scale of 1 for clearly measure the objective, -1 for not clearly measure, or 0 for somewhat measure the objective or it is unclear whether it measures the objective [12]. Then, the index of IOC for each question can be calculated using (1) [12].

$$IOC = \frac{\sum_{i=1}^{N} R_i}{N} \quad (1)$$

Where

R_i is the score of the expert i

N is the number of experts

If the question had an IOC value below 0.5, the researchers needed to review or change that question according to the experts' advice [13 cited in 12]. If the question had an IOC value of between 0.5 and 1, that question was considered acceptable [13 cited in 12]. The results of the analysis are as follows:

In Part 1, all the questions had IOC values below 0.5. Therefore, the researchers improved the writing and explanation of the answers to be more comprehensive and clearer, then discussed with the experts again until the IOC of all questions passed the criteria.

In Part 2, most of the questions had IOC values that passed the criteria, with the exception of two questions, namely, the company's implementation of Industry 4.0 strategies and the company's share revenue of the data analytics services of its products in the usage phase. Therefore, the researchers revised these questions according to the experts' advice by providing clearer definitions for these two questions. In addition, the descriptive definitions of all 12 working activities of Industry 4.0 were provided. The questionnaire is in Thai so that respondents can fully understand it.

2.4 Results of the pilot study to classify phase of Industry 4.0 adoption in the automotive industry in Thailand

The web-based questionnaire was e-mailed to 100 companies having a registered capital of at least 100 million baht in the automotive industry in Thailand, listed in the 2019 Thailand automobiles, trailers, and semitrailers manufacturers list, including the manufacture of automobiles for the carriage of passengers or freight, the manufacture of other parts and accessories for automobiles, and the manufacture of bodies for automobiles, including trailers and semitrailers. The respondents had to have experience and understanding of the company and Industry 4.0 in the automotive industry. There were 31 companies that responded, with a response rate of 31 percent. All of the respondents had the aforementioned qualifications.

2.4.1 Demographics of respondents

Figure 2 shows that most of the respondents are engineers (46%), followed by managers (35%), and other positions (19%), i.e., business owner, director, instructor, and specialist, respectively.

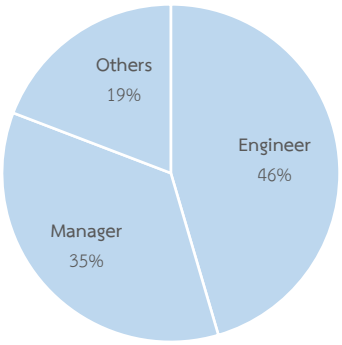

Figure 2 Job position of respondents

Figure 3 shows that most of the respondents' expertise is in production (41%), followed by research and development (28%), supply chain management and logistics (17%), and quality control (14%), respectively.

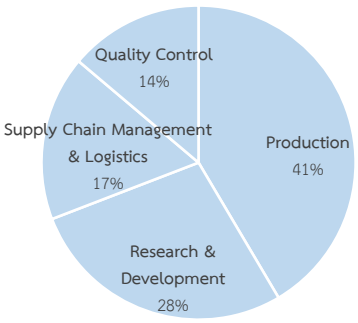

Figure 3 Area of expertise of respondents

It was found that the average years of experience of respondents in the automotive industry was 10 years (S.D. = 7.2, with the longest 27 years and the shortest 2 years of experience) while the average years in the position of respondents was 7.8 years (S.D. = 8.5, with the longest 46 years and the shortest half a year in the position). Most of the respondents were engineers, whose areas of expertise were in production.

When analyzing the companies of the respondents, it was found that most of them are companies in manufacture of automobiles group (45%) and other parts and accessories for automobiles group (45%). Only 10% are in manufacture of bodies for automobiles, including trailers and semitrailers group, as shown in Figure 4. For a clearer understanding, the automobile category means manufacturing of personal cars, pickup trucks, motors, and other motors used for passenger or freight. Other parts and accessories for automobiles category means manufacturing of seats, electrical equipment, and other parts and accessories. Bodies for automobiles, including trailers and semitrailers category means manufacturing of trailers, semi-trailers, and cargo containers.

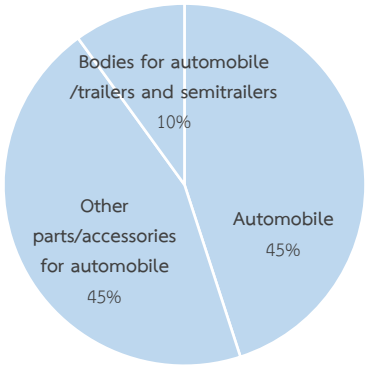

Figure 4 Category of automotive industry of organizations of respondents

2.4.2 Results of the survey study

From the pilot study of 31 companies, the results of total scores used to classify phase of Industry 4.0 adoption for each company are shown in Table 2. The results found that there is no company in the sample group considered to be in phase 0 beginner (a total score of 1.00). Most of the manufacturers in the pilot study (16 companies, or 52%) have scores between 2.01 – 3.00 and are classified as in phase 2 automation. This is followed by phase 3 integration (7 companies or 23%, with total scores between 3.01 – 4.00), phase 1 sensor (5 companies or 15%, with total scores between 1.01 – 2.00), and phase 4 intelligence (3 companies or 10%, with total scores between 4.01 – 5.00), respectively.

In addition from Table 3, when considered by industry categories of automotive industry, it was found that for the automobile group, most of them are in phase 2 automation (7 companies out of a total of 14 companies, or 50%). For other parts and accessories for automobile group, most of them are in phase 2 automation (9 companies out of a total of 14 companies, or 64.29%). Whereas, bodies for automobiles including trailers and semitrailers group, most of them are in phase 3 integration (2 companies out of a total of 3 companies, or 67.77%).

Furthermore, when considering the individual question represents each aspect, the results are summarized as shown in Table 4.

The first dimension, **strategy and organization**, consists of 2 questions. The first question asking about the company's implementation of the Industry 4.0 strategy. It was found that most of the companies (35%) indicated

that there are pilot projects in various departments. But there is no integration of them into the organization's strategy. The second question asking about the company' s investment in the implementation of Industry 4.0. It was found that most of the companies (48%) indicated that the investment related to Industry 4.0 is at least in one department.

Table 2 Results of the pilot study indicating phase of Industry 4.0 adoption for each company

Company	Category of automotive industry	Total score	Phase of Industry 4.0 adoption
1	automobiles	2.61	phase 2
2	other parts and accessories for automobiles	4.09	phase 4
3	automobiles	3.77	phase 3
4	other parts and accessories for automobiles	2.68	phase 2
5	other parts and accessories for automobiles	2.14	phase 2
6	automobiles	1.28	phase 1
7	bodies for automobiles including trailers and semitrailers	3.90	phase 3
8	other parts and accessories for automobiles	2.10	phase 2
9	other parts and accessories for automobiles	4.21	phase 4
10	other parts and accessories for automobiles	2.12	phase 2
11	other parts and accessories for automobiles	2.40	phase 2
12	other parts and accessories for automobiles	1.73	phase 1
13	other parts and accessories for automobiles	2.07	phase 2
14	other parts and accessories for automobiles	1.31	phase 1
15	automobiles	1.54	phase 1
16	automobiles	3.19	phase 3
17	automobiles	2.73	phase 2
18	other parts and accessories for automobiles	2.87	phase 2
19	other parts and accessories for automobiles	3.71	phase 3
20	automobiles	2.93	phase 2
21	bodies for automobiles including trailers and semitrailers	4.36	phase 4
22	automobiles	3.73	phase 3
23	automobiles	2.89	phase 2
24	automobiles	3.82	phase 3
25	automobiles	1.56	phase 1
26	bodies for automobiles including trailers and semitrailers	3.83	phase 3
27	other parts and accessories for automobiles	2.55	phase 2
28	automobiles	2.44	phase 2
29	automobiles	2.84	phase 2
30	automobiles	2.08	phase 2
31	other parts and accessories for automobiles	2.08	phase 2

Table 3 Percentage of number of companies in each industry category and in each phase of Industry 4.0 adoption

	Category of automotive industry			
Phase of Industry 4.0 adoption	Auto-mobile	Other parts/acces-sories for automobiles	Bodies for automobiles including trailers and semitrailers	Total
phase 0 beginner	0	0	0	0
phase 1 sensor	9	6	0	15
phase 2 automation	23	29	0	52
phase 3 integration	13	3	7	23
phase 4 intelligence	0	7	3	10
Total	45	45	10	100

The second dimension, **smart factory**, consists of 2 questions that ask about the company's IT equipment infrastructure and the company's operations via IT systems in its supply chain. For the first question, it was found that most of the companies (26%) indicated that the existing equipment infrastructure can be software upgraded to support the expansion of demand that can change in the future. For the second question, it was found that most of the companies (32%) indicated that there is partial production data being collected when required. But no IT system has been used.

The third dimension, **smart operations**, consists of 4 questions. Firstly, asking about the company's usage of cloud technology. It was found that most of the companies (32%) indicated that there was no cloud technology being used. Secondly, asking about the company's status of IT security. It was found that most of the companies (26%) indicated that there are experts in the IT security department of the organization that covers all departments throughout the organization. Thirdly, asking about the company's autonomous processes for production. It was found that most of the companies (32%) indicated that there is a plan to implement a production system with automated processes and/ or self- reacting processes. And lastly, asking about the company's status of information sharing. It was found that most of the companies (39%) indicated that there is information sharing within the organization with IT systems and a plan to share information across organizations with business partners.

The fourth dimension, **smart products**, where the question asked about products equipped with ICT components, and it was found that most of the companies (42%) indicated that there is a plan to add IT-based functions.

The fifth dimension, **data- driven services**, consisted of 2 questions. The first question asked about providing data-driven services to customers. It was found that most of the companies (39%) indicated that there is a plan for data- driven service. The second question asked about the company's data analytics services of its products in use. It was found that most of the companies (39%) indicated that there is a plan for the analysis of usage data to generate revenue share. Based on these findings, it can be concluded that most companies agreed on the benefits of incoming data from customers for enabling mass customization by planning to offer some data-driven services in order to generate revenue share.

The last dimension, **employees**, asked about the company's requirements for workforce

qualifications of Industry 4. 0. Most of the companies (45%) indicated that the company requires employees to have knowledge and understanding and basic skills for working towards Industry 4.0 only in some departments.

Table 4 Percentage of answer for each 12 aspect question

Phase of Industry 4.0 adoption	Dimension / Aspect											
	Strategy and organization		Smart factory		Smart operations				Smart products	Data-driven services		Employees
	1	2	3	4	5	6	7	8	9	10	11	12
phase 0 beginner	35*	48*	16	32*	32*	23	16	0	10	10	26	3
phase 1 sensor	13	3	23	13	13	19	32*	26	42*	39*	39*	45*
phase 2 automation	16	23	26*	29	29	19	26	39*	16	16	23	16
phase 3 integration	13	6	19	13	0	13	23	19	19	29	6	26
phase 4 intelligence	23	19	16	13	26	26*	3	16	13	6	6	10

*Most frequent answered

3. CONCLUSIONS AND DISCUSSIONS

The main purpose of this research is to develop a model to classify the phases of Industry 4.0 adoption for companies. The purposed model classifies Industry 4. 0 into 5 phases: phase 0 beginner, phase 1 sensor, phase 2 automation, phase 3 integration, and phase 4 intelligence. Six dimensions adapted from the IMPULS model [2] were considered and extended to cover 12 aspects of the company's current actions regarding Industry 4.0. In the pilot study, the purposed model was used to classify 31 companies in the automotive industry in Thailand. It was found that most of the responding companies are in phase 2 automation. This second phase, automation, focuses on information access via cloud technology, which exists throughout the company, and there is a scenario of IT systems across its value chain. There is also experimenting with new automated processes via IT-based devices that can facilitate virtual environment simulation as well as data-driven services. Employees in all departments were expected to have knowledge and understanding and basic skills for working towards Industry 4. 0 in this phase.

In addition, when analyzing by automotive industry category, it was found that for both automobiles and other parts and accessories for automobiles categories, most of the respondent companies are in phase 2 automation as well.

Although the results of this pilot study cannot be used to generalize the results for the entire country, they can provide a rough idea.

The definition of phases of Industry 4. 0 adoption purposed in this research also provides a roadmap for the automotive industry' s future development for Industry 4.0

For managerial implications, determining which certain stage of Industry 4.0 the company is in will affect the company's preparation in various fields, such as investments in technology and personnel. In addition, it also benefits the government sector when making policies and other support for investors in the automotive industry in Thailand.

4. LIMITATIONS AND FUTURE RESEARCH

Due to the COVID-19 situation, the researchers were unable to travel to interview the respondents directly. In addition, many companies could not be reached from their official addresses because they allowed employees to work from home. Communicating with respondents and following up required email and phone calls back and forth, making them time-consuming and low-response. Therefore, future research may collect additional data, which will increase the number of company respondents in each phase of Industry 4.0 adoption.

In addition, disregarding the criterion that the company respondents had to be manufacturers with a registered capital of at least 100 million baht might increase the number of company respondents in phase 0 of Industry 4.0 adoption in the automotive industry. Furthermore, future research should cover samples in all categories of the automotive industry equally.

Furthermore, in future research, the purposed model may be used to assess the phase of Industry 4.0 in different industries in order to compare the results of each industry. Comparative results of several industries will allow government agencies to determine policies to promote each industry.

In addition, studies comparing the results of classification in the automotive industry with those of other countries will also help to develop and determine the direction of the country.

Lastly, this research used the weight of each aspect adapted from the IMPULS model [2]. So in future research, it may be interesting to determine the weight of each aspect using other techniques, for example, the Analytic Hierarchy Process (AHP), Delphi Technique or Conjoint Analysis. In addition, by using these techniques, selecting assessors with Industry 4.0 knowledge and expertise will ensure that the assessment results reflect and are appropriate for the situation in Thailand.

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