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Developing Taiichi Ohno's Mental Model for Waste Identification in Nontraditional Applications

The growth of technology in the manufacturing domain is compelling industry to digitally transform with little to no guidance on what constitutes value-added and nonvalue-added data and information. However, the Toyota production system (TPS) approach, which has proven successful for decades in identifying wastes in physical manufacturing processes, can provide some insights. Extensive research has been conducted on the history of Toyota and the concepts and tools of the TPS, but there is no documentation of how Taiichi Ohno approached problems and developed the classification of wastes (the 7 Wastes) which led to the concepts and tools for continuous improvement that are collectively called the TPS. This article deconstructs literature on Ohno and the Toyota story to reconstruct the mental model that Ohno used to identify and categorize physical production waste in Toyota's manufacturing operations. The mental model attributed to Ohno proposed in this work is then generalized into a framework for identifying and eliminating both physical and nonphysical wastes in systems. Manufacturing companies and researchers can utilize the framework to foster the same thinking that Ohno used to identify nonvalue-added activities in production processes. Applying the described framework to data and information flows will allow for the discovery of wastes that were once hidden and will lead to the development of tools for improving the data and information needed to support manufacturing in a Smart Manufacturing environment. [DOI: 10.1115/1.4054037]

Keywords: Toyota production system, Lean manufacturing, waste categorization, mental models, Taiichi Ohno, continuous improvement, manufacturing, manufacturing systems

1 Introduction

The advancement of digital technologies is motivating manufacturers to transform the systems that support manufacturing processes. Manufacturers that wish to maintain a competitive advantage will need to digitize their processes by converting paper-based data to a digital form and digitalize data by using advanced technologies to continuously improve the flow of data and information [1–4]. This endeavor will require the ability to distinguish between value-added and nonvalue-added data and information. Due to a traditional focus of improvement efforts on production processes, manufacturers are ill-equipped to identify improvement opportunities in the data and information domain. Manufacturers need a structured framework to assist in waste identification that can then lead to the development of tools for waste elimination. Nonvalue-added activities must be identified before deploying tools to eliminate wastes. This article presents how manufacturing companies and researchers can learn from Toyota's waste identification techniques.

The Toyota Motor Company (TMC) has a history of continuous improvement that is envied by most manufacturers [5]. TMC credits its success to adhering to the philosophy and principles of the Toyota production system (TPS) [6,7]. Many manufacturers have attempted to replicate the tools used in the TPS, but they fail to grasp the underlying principles that make the TPS successful [7–12]. The philosophy behind the creation of the TPS principles is one of the most significant gaps in TPS literature [6]. Understanding what led Taiichi Ohno to define the 7 Wastes of a manufacturing system, a central analysis tool in the TPS, has not been documented. This article provides insights to discover the mental model behind the development of the classification of waste or nonvalue-added activity. By understanding Ohno's mental model, it is possible to determine and comprehend the manner in which Ohno turned observations of his environment into actions. The derivation of this mental model is used to create a generalized framework for identifying and classifying waste in a system. Ohno's categorization of the 7 Wastes is a means used to identify physical waste in a manufacturing system. The creation of a generalized framework for identifying and categorizing waste in any system, whether physical and/or nonphysical components, would be beneficial to the development of tools and capabilities to enhance system effectiveness.

A mental model is defined as a representation of how one understands their surrounding environment [13–15]. Mental models provide visibility into the decision-making process and reasoning [16]. The derivation of one's mental model opens the door to discovering how to reach a conclusion. The application of a mental model provides a structure for processing new information in other domains. Without uncovering Ohno's mental model, the Lean community cannot fully grasp how Ohno developed and deployed the concept of the 7 wastes at TMC, and thus successfully replicate the outcomes in other domains [17].

Smart Manufacturing places the focus directly on data and information flows. Most manufacturers spend copious amounts of employee time on performing data and information tasks (analyzing, reporting, manipulating, transferring, correcting, and waiting for data) without ever considering why. These costs are hidden in overhead and never really analyzed and/or reduced through the same level of continuous improvement efforts that are applied to physical processes. The generalized framework presented in this work will help manufacturers to analyze their data and information processes in the way Ohno did for physical processes and begin the search for improvement opportunities in their data and information tasks, reducing costs, and increasing efficiency.

The contributions of this article are: (1) the deconstruction and analysis of Ohno's mental model, (2) the utilization of psychology tools for a novel approach to evaluating a manufacturing process improvement model, and (3) the creation of a generalized framework for identifying and eliminating physical and nonphysical wastes in a system.

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The paper is structured as follows. Section 2 provides the context that created Ohno's mental model. Section 3 explains the methodology and development of Ohno's mental model. Section 4 presents Ohno's mental model. Section 5 introduces a generalized framework developed from Ohno's mental model for identifying and classifying waste. The article closes with conclusions and reasoning of how this generalized framework can be used in the context of Smart Manufacturing in Sec. 6.

2 Background

It is important to understand how Ohno's life experiences resulted in the development of the classification of 7 Wastes in the production of vehicles, leading to the TPS. Issues preventing the efficient operation of a system can be classified into subcategories. Classification is a form of knowledge organization that combines entities with similar attributes, and it is used to systematically investigate topics, develop ideas, and reduce complex issues into manageable parts. Decomposing a complex system into smaller categories assists in reducing complexity and making sense of the system and underlying performance issues. When classifying concepts, the resulting classifications are known as categories [18].

To analyze what Ohno did requires knowledge of the environment and conditions at that time, the situation at TMC that caused him to develop the classifications, and how Ohno's personality and life experiences formed a mental model that led to the development of the TPS. By understanding his personality and experiences, Ohno's motivations and underlying decisions can be understood, which leads to a framework that can be applied to other domains.

2.1 Classification of the 7 Wastes of a Manufacturing System. Value creation was the focus of TMC to sell more cars and make more profit. For TMC to achieve this goal, the customer must be pleased with the product they purchased. Any action that does not change the form or function of materials into a product that the customer is willing to pay for is classified as waste. The TPS is built on the idea of reducing and eliminating all forms of nonvalue-added activities or wastes that impede the flow of value from raw material to finished goods [6]. Through many years of experience with continuous improvement by observing processes, Ohno categorized each of the identified wastes into seven categories, shown in Table 1 [6,19].

The 7 Wastes are used by many organizations, not just manufacturers, in an attempt to improve their systems and reduce costs [20]. However, many fail to grasp the underlying logic that makes the 7 Wastes a successful approach [7–12]. Understanding what went into the creation of the 7 Wastes aids in the identification and elimination of wastes in other domains. Fully comprehending the underlying logic behind waste identification is necessary for success in creating waste categories for data and information flows.

Table 1 Definitions of Ohno's 7 Wastes

Waste category	Definition
Overproduction	Producing a greater quantity of parts than required by the customer
Time on hand (waiting)	People or parts delayed until a specific action occurs
Transportation	The unnecessary movement of people or parts between processes
Processing itself (over-processing)	Processing beyond the standard required by the customer
Stock on hand (inventory)	Excess of raw materials, work in progress, or finished goods
Movement (motion)	The movement of people, parts, or machines within a process or work cell
Defective products (defects)	The result of incorrectly producing the product to customer expectations the first time

2.2 Background on Toyota. Until now, how Ohno developed the 7 Wastes has not been investigated and documented. To determine how the categories of waste were developed, it is important to identify the values and beliefs that drove Ohno to strive for success in a unique and unconventional manner. The historical events that shaped Ohno's perspective are shown in Fig. 1.

Taiichi Ohno worked at TMC from 1943 to 1978. A review of the situation in Japan from the 1940s to 1970s provides context to the circumstances of TMC and helps further understand Ohno's perception of need and the desire for change and constant improvement.

In August of 1945, two years after Ohno started with TMC, Japan surrendered to the Allies to end World War II (WWII). WWII was mostly responsible for the weakening of Japan's economy in the late 1940s. With a devastated infrastructure, few raw materials, and little to no domestic demand, TMC had to find a way to become a profitable enterprise. In hindsight, Ohno believed the war's end marked a new beginning for TMC [6,21].

BRIEF TIMELINE HISTORY

TOYOTA MOTOR COMPANY (TMC)		TAIICHI OHNO
	1932	Graduated from Nagoya Technical High School & Began Work at Toyota Spinning & Weaving (TS&W)
Beginning of WWII	1939	
Kiichiro Toyoda Becomes President of TMC	1941	
	1943	Began Work at TMC
End of WWII	1945	
The Union of Japanese Science and Engineering (JUSE) is Established	1946	
Kiichiro Toyoda Resigns from TMC, Japan Reaches Negative Net Worth, & Korean War Begins	1950	
Korean War Ends	1953	
	1954	Director at TMC
	1956	Visits General Motors and Ford
Rapid Economic Growth Begins	1959	
	1964	Managing Director at TMC
	1970	Senior Managing Director at TMC
Oil Crisis & Recession	1973	
Rapid Economic Growth Ends, State of Zero Growth	1974	
	1975	Executive Vice President at TMC
	1978	Retires from TMC

Fig. 1 Timeline of relevant events

Following WWII, Kiichiro Toyoda, the President of TMC from 1941 to 1950, conveyed the goal to "catch up with America in three years" [6,22]. This became a rallying cry and mantra for TMC. However, in 1950, seven years after Ohno began working at TMC, Japan was still in a devastating economic state and lacked essential natural resources. This situation led to a labor dispute in 1950 with a layoff of a quarter of the total workforce and the resignation of President Toyoda. This state of turmoil left TMC with no choice but to find a different way to achieve its goals [2,6,23].

To survive in the early 1950s, TMC had to turn the production of cars into cash quickly [24]. Ohno firmly believed that every improvement originates from a need. The economic crisis created a widespread sense of need. Instead of being viewed as a crutch, the economy of Japan was considered an open door to widespread improvement opportunities, which would be crucial to economic turnaround [6].

In June of 1950, the Korean War slowly initiated economic growth and helped expand the Japanese automobile industry [6]. In support of South Korea, the U.S. Army Procurement Agency became a significant customer for TMC with a requirement for quick production with high quality. Ramping up production without the financial ability needed for this effort was a challenge that forced new and creative ways of thinking. Between 1945 and 1955 TMC increased annual production from 3275 total units to 22,786 total units, a 595% increase [25]. With the new demand and financial support of the U.S. Army contracts, Ohno and TMC focused on continuous improvement in operations and created the culture behind the TPS.

In the 1960s, TMC's largest Japanese competitor was Nissan [26]. After Nissan received the Deming Prize in 1960, the highest honor for quality in Japan, TMC responded by implementing Deming's total quality control (TQC) approach in 1961 and received the Deming Prize in 1965 [27,28]. TMC's efforts to compete on both the local and the global scales demonstrate the organization's desire to become the world's most profitable automotive manufacturer.

Aside from economic factors, Japan's culture also influenced Ohno and enabled his success. Japan is historically a hierarchical society that creates many followers and few leaders. In Japanese culture, employees are team players that are hired as fixed assets and typically remain loyal to one company for their lifetime [29]. The Japanese culture allowed Ohno to form a learning and teaching culture at TMC. This learning culture is often noted as the reason TMC became so successful, and the lack of this learning culture is one of the reasons other companies do not successfully implement TMC's philosophy [7].

2.3 Background on Ohno. In addition to the environmental factors that impacted Ohno, his personal motivations and background shaped his teachings and leadership style. An examination of the personality and values that led him to become successful can provide insights into his mental model. This examination is conducted by the application of personality psychology in which a person's motivations and traits are studied [30]. Ohno's background shows who he was as a person, his motivations, and trends in his behavior. Thus, emphasis was placed on identifying consistent behaviors, thought processes, and important statements, as documented in his writings and those from other authors. Ohno's actions and thoughts reveal the mental model he used to understand the world.

Ohno graduated from Nagoya Technical High School's mechanical technology program in the spring of 1932. It can be assumed that Ohno's mechanical technology education can be reflective of today's mechanical engineering focus at a high school or technical college level. Ohno did not pursue higher education by attending a college or university [6]. With the range of Ohno's knowledge, it is evident that Ohno found other venues to self-educate throughout his career.

After high school, he began work at Toyoda Spinning and Weaving (TS&W). Ohno leveraged the knowledge gained at TS&W to identify shortcomings at TMC [6,22]. While at TS&W, Ohno taught himself standard work. Ohno said his experience with standard work at TS&W laid the foundation for 35 years of work on the TPS [6]. TS&W is also where Ohno learned about autonomous systems and quality. TS&W was his primary source of industry experience and served as a pivotal point in his career at TMC [6].

When Ohno compared the TS&W system to automobile production, he used critical thinking skills. He noted that his work began by challenging the old system [6]. To make drastic improvements, Ohno had to think of new and creative approaches. Ohno lived by the mindset of "there is *always* another way," which will make TMC a more profitable company [31]. He strived to "avoid being entrapped by a single way of thinking" [6,32]. He looked at every system with an eye for improvement and believed observation was the key to gaining insight into what is happening [6,22].

From Ohno's experience with standard work, he learned the best way to improve a job is to be at the process. The importance of learning by seeing developed his "plant-first principle," in which the focus was on helping the operators do their jobs better through observation [6,22]. Ohno viewed his employees as a set of eyes to identify ways to improve and reduce waste [8,32]. According to Ohno, "people don't go to Toyota to "work"; they go there to think" [33]. He did not simply provide solutions; he guided his employees by asking questions that would enhance their critical thinking skills. He wanted the operators to see the value of their work and show them they could improve their work. Ohno was known to show great support to plant floor employees but could be extremely hard on management. He made management responsible for encouraging employees to learn. He would scold his managers if they were not out on the floor, helping improve the operators' jobs [22].

Ohno had a drive to make improvements, and he did not give up. A quote from Ohno himself best describes the work ethic he fostered: "People got so tired of hearing me rant that they gave me a machining shop to try out my ideas" [22]. Ohno was eager to make changes to see if they resulted in cost reduction and improved productivity. He was a supporter of the scientific method, trial-and-error, and not waiting for a perfect solution. Ohno referred to this as "the mood to get things done." He urged others to match his work ethic [22].

Ohno's improvement ideas did not only come from his own thinking. Ohno often borrowed ideas from other influential leaders of his time. The Union of Japanese Science and Engineering (JUSE) brought quality experts, Dr. W. Edwards Deming and Dr. Joseph M. Juran, to Japan in 1950 and 1954, respectively. It is highly likely that Ohno was influenced by their teachings through the JUSE emphasis on quality and productivity improvement [24,34]. Many parallels can be drawn between Ohno and Deming's works. Ohno and Deming shared the quality first idea of "doing it right the first time" [24]. Like Deming, Ohno made improvement efforts everyone's responsibility. They also shared the concept that the employees on the plant floor are more important than management because they are the individuals making the product. It is also possible that Ohno's idea to eliminate waste came from Deming because Deming often mentions the word "waste" in his works. They also shared the idea that anything the consumer is not willing to pay for should be considered waste [6,24,31,32].

When searching for improvement ideas, Ohno looked into the American automotive industry. Ohno first visited Ford, General Motors, and American supermarkets in 1956. He wanted to understand Ford's strategies and determine what was applicable for TMC, and what was not useful [6,21]. It is also likely that Ohno found value in General Motors' focus to produce money, not cars [10], since TMC faced the requirement of turning products into cash quickly. However, he took General Motors' aim further by focusing on quality and cost reduction as a means to make money [6,32,35]. Ohno not only drew his ideas from the automobile industry but also

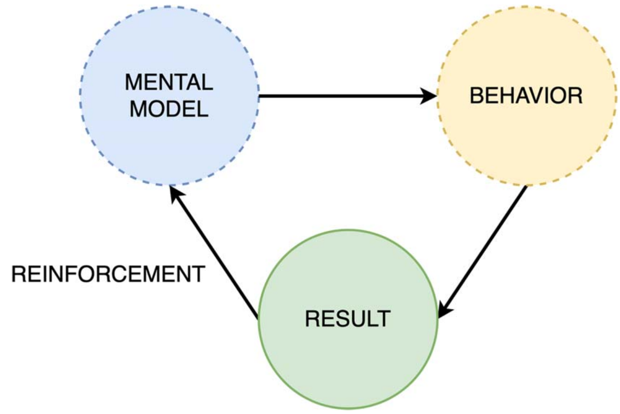

Fig. 2 Relationships between mental model, behavior, and result [37]

from how American supermarkets operated [36]. The supermarket method caught Ohno's attention in a 1954 report on how a Lockheed aircraft plant used the supermarket method to produce to customer demand. Ohno planned to investigate the approach when visiting America in 1956. The supermarket method established Ohno's concepts of inventory management and overproduction, which are 2 of the 7 Wastes [6].

It would not be possible to recreate Ohno's mental model without a thorough evaluation of his environment and personal motivations. The information about Ohno's life presented in this section was analyzed to derive his mental model so that it can be recreated for other domains, such as data and information processes in manufacturing systems. Section 3 explains the analysis method.

3 Methodology

The problem this research addresses is that the mental model behind the creation of the 7 Wastes of the TPS is unknown and cannot be replicated in other domains. According to Senge [14], ""mental models" determine not only how we make sense of the world, but how we take action." One contribution of this research is the uncovering of Ohno's core values and the discovery of how his actions aligned with his vision. The relationships between a mental model, one's behavior, and the result are shown in Fig. 2 [37].

Until now, Ohno's mental model and his behavior were not well understood or documented. To recreate Ohno's mental model, it was important to identify and analyze Ohno's behavior and actions. For this analysis, researchers thoroughly studied the TPS, Lean literature, and Ohno's personal writings, presented in Sec. 2. The focus was on evaluating primary sources such as content written by Ohno and those that knew Ohno in a work environment.

Kurt Lewin's equation for human behavior, Eq. (1), which represents a person's psychological situation, provided validity by which inferences could be made about Ohno's behavior based on his environment and personal experiences. Lewin proposes that human behavior is a function of the person and their environment. Lewin stated that "One can hope to understand the forces that govern behavior only if one includes in the representation the whole psychological situation" [38]. By collecting events from Ohno's life, researchers were able to accurately observe the correlation between Ohno's actions and behavior.

$$B = f(P, E) \tag{1}$$

where B represents human behavior, P person, and E environment.

In Eq. (1), variables such as attitude, personality, and skills are attributes of the person (P). A person's environmental variables (E) include workplace environment, culture, and economic state. Environmental variables tend to fluctuate often, impacting one's behavior. Lewin believed the relationships between personal and environmental variables affect the resulting human behavior [38]. Examples of personal and environmental variables specific to Ohno and his life experiences that were presented earlier are shown in Table 2. Lewin's equation for human behavior provides an understanding of how Ohno behaved and made decisions, which is related to his mental model as shown in Fig. 2.

While studying Ohno's life, researchers considered multiple psychology perspectives to ensure a complete analysis. Personality psychology was considered in determining the motivations and personality traits that made Ohno unique [30]. Social psychology placed attention on how Ohno behaved in a group setting, how his attitudes and beliefs were formed, and how he perceived his social environment [39]. An industrial-organizational (I-O) psychology perspective sought to understand Ohno's behavior in a

Table 2 Personal and environmental variables that formed Ohno's behavior

Person	Environment
(*a*) *Education*—graduated from the Mechanical Technology Department of Nagoya Technical High School [6]	(*j*) *World War II*—weakened Japan's economic state, devastated infrastructure, few raw materials, little to no domestic demand [6,21]
(*b*) *Work at TS&W*—taught himself standardization, learned about autonomous systems and quality, later compared TMC to his work at TS&W [6]	(*k*) *Goal*—TMC President conveyed the goal to "catch up with America in three years" [6,22]
(*c*) *Mindset*—challenged the old system [6], always believed there was a better method [31]	(*l*) *1950 Labor dispute*—layoff of a quarter of the workforce, state of turmoil, no money, fewer people, high expectations [6,22,23]
(*d*) *Thinking*—utilized critical thinking and "logic escape" [6,22,32]	(*m*) *Sense of need* [6,24,32]
(*e*) *Learned by observation* [6,22]	(*n*) *Korean War*—sparked economic growth, ramped up production without the ability to purchase new equipment or hire new employees [6,25]
(*f*) *Comparison of systems*—compared seemingly unrelated systems to automobile production to derive improvement ideas (e.g., American supermarkets, the human body, baseball games) [6,22,36]	(*o*) *Competition*—TMC's largest competitor was Nissan. Nissan won the Deming Prize in 1960. TMC implemented Deming's TQC approach in 1961 and received the Deming Prize in 1965 [27,28]
(*g*) *Likely influenced by the teachings of others*—shared Deming's ideas of "doing it right the first time," eliminating waste (or anything the consumer is not willing to pay for) [24]	(*p*) *Japanese Culture*—hierarchical society in which employees are hired as fixed assets [29]
(*h*) *Treatment of others*—treated plant floor employees with high regard [6,22], but was known to be harsh on managers [22]	
(*i*) *Personality*—self-driven, strong work ethic, always in "the mood to get things done" [22]	

Behavior
(1) Reducing and eliminating nonvalue-added activities or wastes [6]
(2) Categorized wastes into seven categories [6,19]
(3) Formed a learning and teaching culture [7]

workplace environment [40]. Each of these psychology perspectives provided insight into Ohno and helped in understanding his reasoning for identifying and classifying waste in a process.

A timeline of nearly 100 events was created to capture any event that may have influenced Ohno's life and his work. The timeline included historical events for TMC (36 events), historical events for Japan (11 major events), milestones in Ohno's life (13 events), and events in the lives of people that potentially influenced Ohno (21 events). An illustration of this timeline was presented in Fig. 1 in Sec. 2.2. Events from the timeline and personal and environmental variables from Table 2 were used to form a complex diagram of potential influences on Ohno, shown in Fig. 3. Figures 1 and 3 are reduced in complexity to emphasize important content. Figure 3 resembles a neural network and a process diagram. The connectivity between the circular elements represents the relationships between the influential factors in Ohno's life. The outputs are the characteristics of Ohno's work and the 7 Wastes of the TPS (the variable of interest).

To obtain the characteristics of Ohno's work, researchers collected 15 primary sources that were written by Ohno, those who knew Ohno, and those who could have potentially influenced Ohno. In the analysis, researchers documented characteristics of Ohno's work that have influenced the identification of waste. A total of 118 characteristics of Ohno's life were collected and grouped based on their similarities, resulting in 16 major influential elements and 20 characteristics of Ohno's work, shown in Fig. 3. Connections were drawn between the influential factors and characteristics of Ohno's work. Connections were identified and documented between the characteristics of Ohno's work and the resulting output—the 7 Wastes. The characteristics that enabled Ohno to create the 7 Wastes were combined into eight elements that are used to establish Ohno's mental model. These eight elements are described in detail in Sec. 4.

Key elements of Ohno's personality and situation were determined by evaluating the common themes found in the literature. These themes were analyzed by asking two questions: (1) "Could this have enabled Ohno to identify and eliminate waste?" and (2) "If so, how?" This recursive analysis resulted in the discovery of eight specific elements of the mental model that led Ohno to strive for improving the Toyota system that resulted in the creation of the TPS. The eight elements of Ohno's mental model are presented removing references that are specific to TMC to form a generalized framework for identifying and eliminating waste in systems.

4 Results

This section presents the eight elements of Ohno's mental model: (1) know the goals, (2) understand the system, (3) focus on value-creating, (4) assume a better way, (5) identify nonvalue, (6) apply critical thinking, (7) try and try again, and (8) foster a thinking culture. The eight elements are the result of a deep dive into TPS literature, Ohno's personal writings, expert judgment, and the

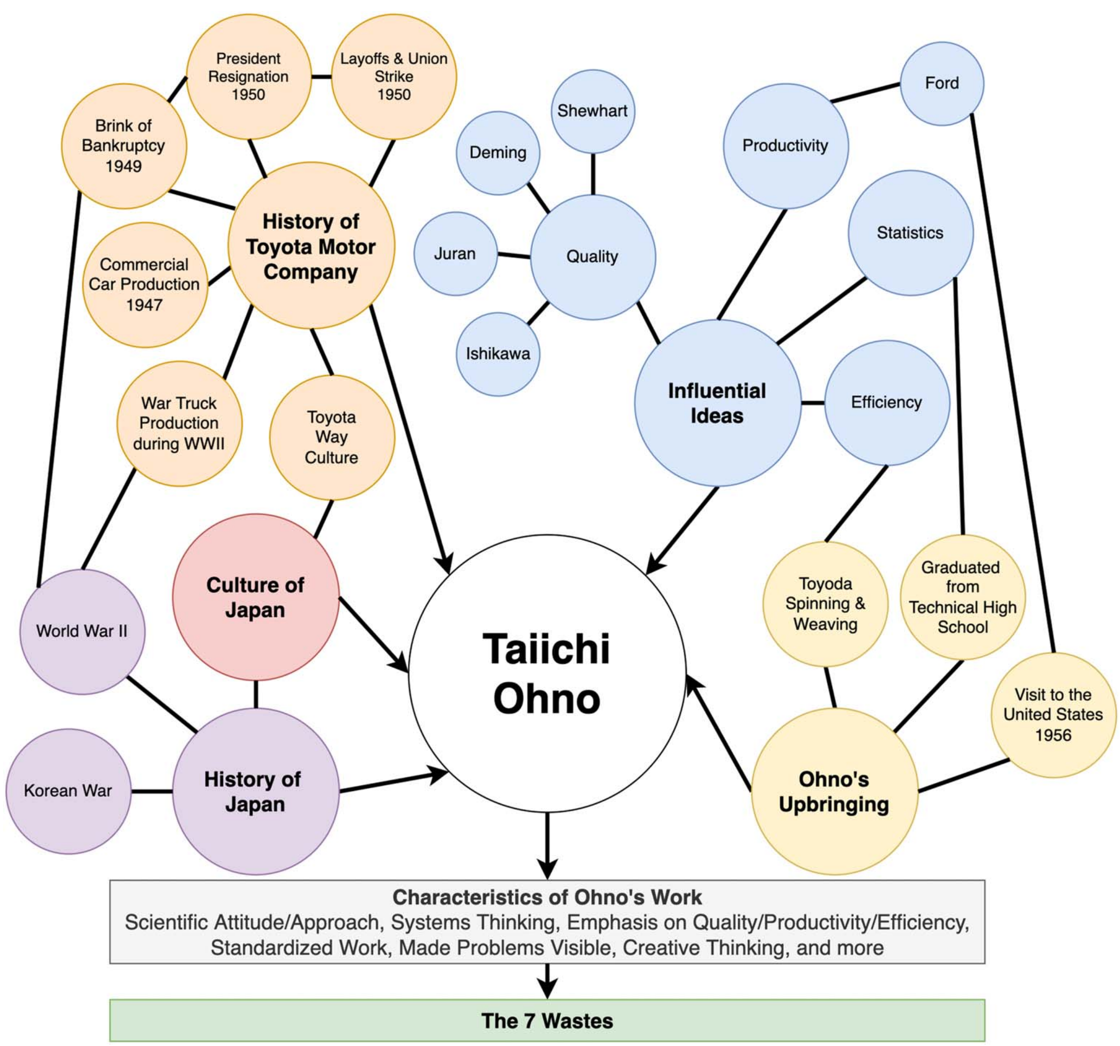

Fig. 3 Influential factors on Ohno's life and work

consideration of multiple psychology perspectives. This creation of Ohno's mental model serves as the basis of the framework presented in this research for identifying nonvalue-added activities in any domain. Without Ohno's mental model, we would not be able to fully grasp the philosophy behind the TPS and determine the principles that made Ohno's efforts successful.

4.1 Know the Goals. Knowing the goals is most directly related to the goal and sense of need environmental variables (variables *k* and *m* from Table 2). Ohno's actions came from a clear understanding of the goals from both the TMC and customer perspectives. In 1945, two years after Ohno began working for TMC, Toyoda aimed to "catch up with America in three years" [6,22]. Toyoda was able to motivate the organization toward improvement which provided the opportunity for Ohno to develop his continuous improvement mindset. Ohno stated that "cost reduction is the goal," and "all we are doing is looking at the timeline, from the moment the customer gives us an order to the point when we collect the cash. And we are reducing that timeline by removing the nonvalue-added wastes" [5]. These statements describe the tactics used to achieve the goal. The actual goal was to make money by turning products into cash quickly while maintaining high quality. This goal was also a subset of their broader aim to become the most profitable automobile manufacturer in the world. These goals were rather lofty for a company faced with a devastated economy and limited resources following WWII. Ohno understood the need to create a successful approach for TMC [6].

4.2 Understand the System. Understanding the system is most directly related to Ohno's personal variable of learning by observation (variable *e* from Table 2). Ohno understood the system of manufacturing automobiles from spending time observing what was happening. Ohno believed the most valuable place to learn was the "gemba," which is Japanese for the real place in which the work happens. He knew this was the plant floor with the operators, and he is known for telling managers and engineers to go to the gemba to learn. Before making changes to a system, he stressed that you must first understand every detail of how the system works, including each of its components, their interactions, and where the value is created. Ohno expected managers to be able to answer all questions about the plant floor operations. If they were unable to answer a

Fig. 4 Generalized framework for identifying and eliminating waste

question, Ohno sent them back to the plant floor to find the answer. They were not supposed to return to him until they fully understood the purpose of each component of the system [22,32].

4.3 Focus on Value-Creating Resources. Focusing on value-creating resources is most directly related to the personal variables of thorough observation and the possible influence of Deming's teachings (variables *e* and *g* from Table 2). One of the fundamental motivations of the TPS is identifying and creating value. Value is defined by the customer [41]. Value-added activities are those that transform the product and add value from the customer's perspective. Activities that do not add value but are necessary should be minimized. Activities that are nonvalue-added and not necessary are wastes and should be eliminated. Emphasis should be placed on activities and resources that create value [42]. Ohno knew that the operators were the primary value-creating resource because they knew the system the best from performing the tasks. This knowledge enabled employees to also see their value and understand their role as a part of the system, which created an increase in the number of people searching for improvement opportunities.

4.4 Assume a Better Way. Assuming a better way is most directly related to the personal variable of constantly challenging systems, comparing systems, and Ohno's personality of being in "the mood to get things done" (variables *c*, *f*, and *i* from Table 2). Ohno believed there was always another way that would result in more profit for TMC. He looked at existing resources and systems as if they were unacceptable in their current state and thus had the opportunity for improvement [22]. Productivity improvements were not achieved by hiring more people or purchasing new equipment; he did not have the capital to do so. Instead, he focused on better utilizing the employees he already had through the elimination of wastes. He searched for successful methods and then sought to make them more profitable [6].

4.5 Identify Nonvalue. Identifying nonvalue is most directly related to the personal variable of being influenced by other teachings and the behavior of identifying wastes (variable *g* and behavior 1 from Table 2). There are three categories of activities. There are value-added, nonvalue-added, and nonvalue-added but necessary activities [42]. Ohno focused on eliminating waste or "muda," which is Japanese for unnecessary or nonvalue-added activity. With an understanding that the customer determines value, Ohno identified actions that did not create the value the customer desired. Ohno sought to eliminate or reduce costs and increase profit. He looked for activities that did not occur in the right place, at the right time, in the right amount, or in the right form. He then categorized these unnecessary activities into seven categories, known as the 7 Wastes (Table 1) [6].

4.6 Apply Critical Thinking. Applying critical thinking is most directly related to Ohno's personal variables of his education and methods of thinking (variables *a* and *d* from Table 2). Ohno was "fond of thinking about a problem over and over" to create a new and more profitable solution. Using his past experiences, Ohno sought out unique ways to improve systems. For example, he used his experience from TS&W to adapt standard work and the concept of autonomous systems to the TPS. He also analyzed unrelated systems to gather improvement ideas, such as applying American supermarket methods to the principle of producing automobiles to the rate of the customer pull. Ohno would not have been as successful without using ideas from systems outside of the automobile manufacturing industry [6].

4.7 Try and Try Again. Trying and trying again is most directly related to Ohno's self-driven personality (variable *i* from Table 2). As an advocate of trial-and-error methods, Ohno did not wait for the perfect solution. He motivated everyone to be in "the mood to get things done" by taking action and analyzing the outcomes quickly. He made sure to be quick to admit when he was wrong and fixed his mistakes promptly. His enthusiasm for improvement eventually gave him the opportunity to run a machine shop to try to prove that his ideas would be successful [22].

4.8 Foster a Thinking Culture. Fostering a thinking culture is most directly related to the way in which Ohno treated others and the Japanese culture, which Ohno utilized to create a teaching culture (variables h and p and behavior 3 from Table 2). The ability to learn and teach was instrumental in Ohno's success. He trained the workforce to view their jobs as roles to think, not simply to work. He refined his critical thinking skills while also developing those of his employees. By teaching the operators, Ohno was able to create a large number of problem solvers on a mission to eliminate nonvalue-added activities. The development of an inquisitive mindset helped employees find value in their work. This overarching element of Ohno's mental model is something he did throughout each of the previous steps. He fostered a thinking culture by encouraging others to view systems as an opportunity for improvement. Ohno thought of himself as a co-worker that helped the operators rather than a leader who enforced his ideas. He valued the employees and their contribution to the system, and he encouraged them to be engaged, fostering a mental model that included the principles of continuous improvement and respect for people [6,22].

5 Discussion

The elements of the generalized framework that will be presented in this section are organized in the same manner as the analysis of Ohno's approach to continuous improvement presented in Sec. 4. This organizational approach is intended to assist the reader in easily matching the elements of Ohno's mental model to the corresponding steps in the generalized framework.

Ohno's mental model described in Sec. 4 serves as the basis for the identification and classification of physical wastes in a manufacturing system. The first four steps and the overarching thinking culture create a foundation for the identification of wastes in the system. The effort to eliminate waste begins in Step 5 by identifying nonvalue-added activities in the system. Understanding the goals of TMC and the customer, Ohno was able to recognize what actions support the goals of the organization. Understanding the system allowed him to determine which processes were essential because he understood the purpose that each activity served. By going to the gemba, he was able to perceive which activities added value.

Ohno recognized that nonvalue-added activities have a ripple effect. This ripple effect can cause one waste to be hidden within another, which creates difficulty in identifying root causes. A clear step-by-step mindset is essential to determine the underlying issues that create wastes and the resulting inefficiencies. Ohno utilized a systematic mental model that allowed him to identify and classify the wastes of a manufacturing system successfully.

5.1 Creation of the Generalized Framework. Successfully eliminating waste in any system can be a difficult task. The 7 Waste classifications were created by Ohno for a manufacturing system, which is a physical system where waste can be observed. The 7 Wastes have been applied in many other domains besides manufacturing. However, not all 7 Wastes will be applicable, especially in a system that is not solely physical, and thus challenging to observe. For example, a digital system that involves the transfer of data and information does not have wastes that can be seen by the human eye. Waiting for data and information might be easy to find, but what about inventory, motion, or transportation? The 7 Wastes, as identified by Ohno and documented in the TPS, do not equally apply to all domains. Because the 7 Wastes do not apply to all systems, understanding how Ohno came up with the 7 Wastes of TPS is important so others can successfully define wastes in their systems.

The generalization of Ohno's mental model allows users to replicate the process of identifying, classifying, and eventually eliminating wastes in different domains. In this research, Ohno's thought processes were obtained and separated from any physical system ideology, creating a step-by-step, iterative process for identifying and classifying waste in both physical and nonphysical systems, shown in Fig. 4. The eight components of this framework are the following:

(1) *Know the goals* of the organization and the customer. The goals should be described so that all system participants easily understand them. A shared understanding of the goals ensures that everyone is working together toward the same purpose. The need should be felt, and the purpose should be clear. Do not neglect to consider the customer that receives the system's output. Strong emphasis should be placed on the customer's needs and wants. Consider that the customer may not always be a physical person, e.g., production data arriving at a scheduling system to form actionable information.
(2) *Understand the system* and how its components interact. These components include but are not limited to inputs, outputs, enablers, and constraints. Determine which processes and/or activities add value by transforming the inputs to the desired output.
(3) *Focus on value-creating* resources that produce the desired outcome. Emphasis should be placed on increasing the effectiveness of the resources that add value by transforming the inputs efficiently into the output. The primary purpose is to enhance and optimize the value-added components to increase value and make identification of nonvalue-added wastes possible.
(4) *Assume a better way* with an eye for improvement opportunities. This mindset is crucial to making continual improvements because it is where untapped improvement opportunities are identified.
(5) *Identify nonvalue* features that do not optimally attain the desired outcome. Identify components of the system that are not in the right place, at the right time, in the right amount, or in the right form to attain the desired outcome and apply tools to eliminate these wastes.
(6) *Apply critical thinking* to identify new and creative ideas. Do not limit opportunities by using conventional methods and problem-solving techniques, rather look at the activities from different perspectives. Think of new ways to eliminate the identified value inhibitors by creating new processes that most effectively utilize resources to attain the desired outcome.
(7) *Try and try again* without waiting until the perfect solution is uncovered. Seek many small improvements instead of delaying action to find one big win. Define success by the increased ability to attain the goals of the business and customer.

Foster a thinking culture. Facilitate a thinking and learning culture in which all members of the organization understand the value of their work. This critical component of the generalized framework creates the environment in which the previous seven steps are practiced, improved, and celebrated.

Utilizing a framework such as this can have many benefits that go beyond identifying waste in a system. This generalized framework can be used to create a continuous improvement mindset that provides a better approach to achieving organizational goals, determine who or what defines the success, and encourage new ways of achieving those goals. This generalized framework can be used to identify value-added and nonvalue-added activities by ensuring every component serves a purpose that supports the overarching goal(s). As Ohno would say, there is always a better way, and this generalized framework enables the finding of that better way.

6 Conclusions and Future Work

Ohno had a clear purpose of making TMC profitable and a desire to ensure that TMC outperformed its competition. Today, the purpose and desire remain the same for manufacturing companies everywhere—to make money and outperform competitors. Applying tools without comprehending the underlying mental model will not lead to the improvements that companies and organizations seek. By deploying a culture of continuous improvement utilizing the generalized framework, organizations can create a model for systematic improvements and waste elimination that is tailored to their particular system. The TPS's 7 Wastes cannot be effectively applied to domains that are not physical manufacturing production systems. However, the philosophy and mental model behind the creation of the 7 Wastes can be replicated for identifying categories of wastes in many other domains.

Future research should focus on the application and continued development of this generalized framework. Additional research is needed to develop performance metrics that can be employed to guide the implementation of the framework in domains other than discrete product manufacturing [4]. This research has raised the question of where else Ohno's mental model can be effective in analyzing and eliminating waste in systems. Additional research can apply the generalized framework developed here to other domains such as services, healthcare, financial, and government systems.

With today's Smart Manufacturing environment, a framework such as the one presented in this work will be crucial to manufacturing digitalization efforts. Currently, manufacturers have little to no guidance on how to digitally transform or decipher the difference between value-added and nonvalue-added data and information practices. The Generalized Framework for Identifying and Eliminating Waste can be leveraged for training and preparing an entire organization for a digital transformation. Doing so will form a culture that is equipped to identify inefficient and costly data and information flows, and in return, organizations can determine the right tools and software to eliminate these costly wastes.

The flow of manufacturing information that supports production is an improvement area that has already been identified by industry. The increasing complexity of production systems requires efficiency gains in nonphysical components of systems, such as data and information flows [4,43,44]. Previous efforts have been made to adapt the 7 Wastes to apply to information streams [44], but the mental model used by Ohno in the creation of the 7 Wastes was not considered. The generalized framework proposed here is the missing link that is needed to successfully identify, categorize, and eliminate waste in nonphysical systems.

An important use of the generalized framework is to develop waste categories focused on the flow of data and information in production systems. Doing so will show where to find the hidden costs of inaccurate and inefficient information in manufacturing systems. Being able to identify and eliminate nonphysical waste in information systems that support manufacturing production will open a new domain of improvement opportunities for manufacturing. These efforts will support the ongoing digital transformation initiatives that are taking place as a part of the Smart Manufacturing movement.

Conflict of Interest

There are no conflicts of interest. This article does not include research in which human participants were involved. Informed consent not applicable. This article does not include any research in which animal participants were involved.

Data Availability Statement

The authors attest that all data for this study are included in the paper. No data, models, or code were generated or used for this paper.

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