

INCORPORATING THE CONCEPTS OF QUALITY FUNCTION DEPLOYMENT FOR IDENTIFYING NEEDS OF POWERED PROSTHETIC KNEE

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Abstract

This paper proposes a Quality Function Deployment (QFD) based framework to identify the needs of stakeholders and define the engineering characteristics of a powered prosthetic knee. QFD is extensively used as an effective design method for investigating customer needs and translating them into specific design characteristics to generate products/services to meet the needs. Results demonstrate that the proposed framework provides a better understanding of user needs and engineering characteristics in the House of Quality (HOQ), the primary tool of QFD. It is also found that QFD is a useful design tool for designing powered prosthetic knee because QFD can identify correlations between needs (performance, feature, and appearance) and engineering characteristics (Mechanics, Actuator, Sensors, Recognition, Control, Mass, Dimension, Operating Time, and Capability).

Keywords: Quality function deployment, Customer needs, Engineering characteristics, Powered prosthetic knee

Introduction

The transfemoral (TF), also well known as an above-knee (AK) amputation, can happen because of trauma, disease, or congenital conditions (Gailey *et al.*, 2010). The advance in modern-day knowledge provides a better understanding of residual limb preserving, especially the knee joint, decreasing in the number of TF amputations. However, there are still many TF disarticulated people.

The prosthetic knee is the most crucial component of the TF prosthesis because it substitutes amputees' knee function. The traditional prosthetic knees are the energetically passive components that store and release energy by the

passive mechanism without the powered actuation components. Passive prosthetic knees typically have limitations, including unstable gait, higher energy consumption, more restrictions when ambulating on various terrains and activities, and more prone to fall (Lawson *et al.*, 2014).

To overcome the limitations of passive prostheses and provide knee movement more realistic, devices with energy supplied are introduced. The powered prosthetic knees utilize the powered actuator to produce, store, and dissipation the prosthesis's power. However, most of the powered prosthetic knees researches focus on the

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excellence of technical features to serve the biomechanical demands and engineering perspectives, in which the needs of users are often not critically addressed (Beckerle *et al.*, 2017).

Quality Function Deployment (QFD) is one of the systematic approaches of product development principles that provide the design solution focusing on the optimization of users' satisfaction and the engineering aspect. In general, QFD benefits all stakeholders, including users, designers, and manufacturers (Hauser and Clausing, 1988). Until the present day, QFD is widely used to generate product development frameworks for various industries, both in product and service sectors (Mao *et al.*, 2019).

This paper presents the implementation of the QFD framework on identifying the needs of stakeholders for the powered prosthetic knee development. The case study employs the QFD on the voluntarily Thai amputee's participants and multidisciplinary experts. The pilot investigation of this research is presented in (Yodpijit *et al.*, 2018b). The outcomes of the case study are presented in the discussions and conclusions section. Limitations and future works are also presented in the paper.

Background of QFD in Rehabilitation Engineering

The QFD is a set of processes for transforming stakeholders' needs into design solutions to increase stakeholder satisfaction (Han *et al.*, 2001). The QFD is introduced in the 1970s in the Japanese heavy industry. Later, the substantial Japanese automobile manufacturer and affiliates developed QFD in several. The QFD is established on the idea that products should be designed to reflect stakeholders' aspirations and feelings. Therefore, the multidisciplinary staff teams need to work closely together since they conceived the product (Hauser and Clausing, 1988).

The HOQ is a voice of customer analysis tool of the QFD approach. Researchers have reported that QFD and HOQ often misunderstand that HOQ is all there is to QFD (Logan and Radcliffe, 1997). The HOQ could be the most critical part of QFD, consisting of a matrix in the center and various components in its surrounding that explain the crucial relationships and variables include, the relationship of needs factor technical factors, the correlation between technical factors, the importance weight of factors, the difficulty of implementation, and other essential parameters (Mao *et al.*, 2019).

The implementation of QFD on rehabilitation engineering works is found since the 1990s. The researchers employ a QFD to improve myoelectric upper limb prosthesis design for children (Jacques *et al.*, 1994). The study intends to present the

implementation of HOQ on the low production volume product, including prosthetics and orthotics products (P&O). The customized P&O products do not allow mass volume production to absorb the enormous initial design costs, production, analysis, and improvement processes. In sum, the QFD can help define the efficiently and accurately design solutions to meet the user's requirements at the lowest possible cost.

The next related study is the customization of wheelchair seats for amputees using QFD (Logan and Radcliffe, 1997). The researchers employ the HOQ presented in (Jacques *et al.*, 1994) in real clinical works. The study uses the case-by-case post-analysis of recorded video by a multidisciplinary expert team. The conclusion reveals the ability of QFD to match the engineering characteristics with the critical user needs to achieve the user's satisfaction. The accuracy of the interpreter and evaluation in each step of QFD is essential and results in achieving the mission objective. However, QFD has the challenge of performing real-time clinical works because it consumes much time to complete all processes.

The QFD is used to develop passive prosthetic knees for children (Andrysek *et al.*, 2004). In the 2000s, multi-axis knee prostheses have been more popular and achieved better performance than single-axis knee prostheses, especially the stability concern. However, for children amputees, the multi-axis knee prosthesis has more weight and size than the single-axis knee. Therefore, the study aims at developing the optimal knee prosthesis solution for children's users using the HOQ. The researcher asks five children participant and their parents to evaluate the importance of needs factors. Then, experts establish the relationship between needs factors and technical factors and develop the optimal solution. The outcome exhibits that the suitable selected single-axis knee may satisfy and better work with the children's user.

In the 2010s, there have been many emerging powered prosthetic knees due to the advancements in fundamental technologies, such as the high-density lithium batteries, low-power and high-performance systems on chip (SOC), and accuracy small form factors inertial measurement units (IMUs) (Lawson *et al.*, 2014). One of the few studies of the development of powered knee prosthesis with the consideration of user requirement is found in (Beckerle *et al.*, 2017). The researchers apply the human-machine centered concept to develop the power lower-limb prosthesis based on the data from the literature review, users, and experts. The study employs the HOQ is a part of the work to evaluate the relationship and priority of technical factors. The conclusion reveals that

considering both human factors and technical factors results in different design outcomes, compared to the considering only technical factors.

A review of relevant research indicates the possibility of QFD implementation in the powered knee prosthesis development application. It further has been found that there is almost no work of this kind in Thailand. This paper, therefore, presents the QFD framework's implementation of the powered prosthetic knee development by applying the framework from (Hauser and Clausing, 1998; Beckerle *et al.*, 2017; Mao *et al.*, 2019) in the case study of the voluntarily Thai amputee's participants and multidisciplinary experts.

Methods

The HOQ is selected to transform stakeholders' needs into technical characteristics and prioritize them to facilitate decision-making on design solutions (Hauser and Clausing, 1988). The proposed method is illustrated in Figure 1. The geometric layout of the HOQ is applied from previous findings (Mao *et al.*, 2019; Kim *et al.*, 2020), as illustrated in Figure 2.

Identification of needs factors

The needs factor represents the desirable characteristics of the powered prosthetic knee from various stakeholders' perspectives, as illustrated in section A of Figure 2. Ulrich's tools are proper methods for this task, including focus groups, interviews, and product observations (Ulrich and Eppinger, 2017). Griffin and Hauser (1993) suggest that 1-h interview can identify almost the same quantity of needs as the 2-h focus group. Unobtrusive tools can be alternative approaches, including document review and audio-visual analysis (Leavy, 2017).

Identification of technical factors

The technical factor represents the system-level engineering characteristics associated with needs factors, as illustrated in section B of Figure 2. Unobtrusive tools are standard tools for this task, and Ulrich's tools can be applied.

Evaluation of the relationships between needs factors and technical factors

The relationship matrix represents the connection between technical factors and needs factors, as illustrated in section C of Figure 2. This matrix depicts the kernel of transformation in HOQ by establishing the link of each different pair of technical factors and needs factors. Focus groups and questionnaires are common tools in the

relationship evaluation process. Complex tools, including data mining, can be applied when having adequate data. (Hauser and Clausing, 1988). The evaluation uses the 9-3-1-0 scale (9 = strong relationship, 3 = medium relationship, 1 = weak relationship, 0 = no relationship) (Beckerle *et al.*, 2017). The evolution directions of technical factors are evaluated (Marsot, 2005), including increased (↑), decreased (↓), or remained (O), as illustrated in section D of Figure 2.

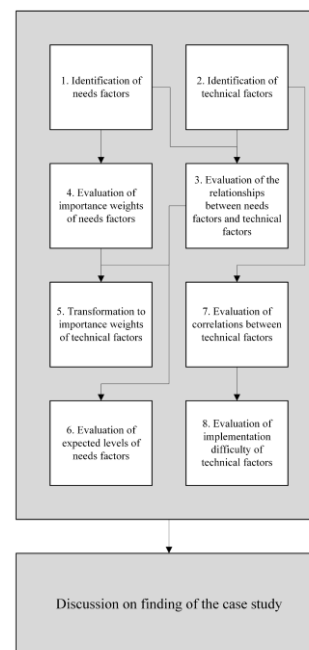


Figure 1. General process of the HOQ implementation of the proposed framework.

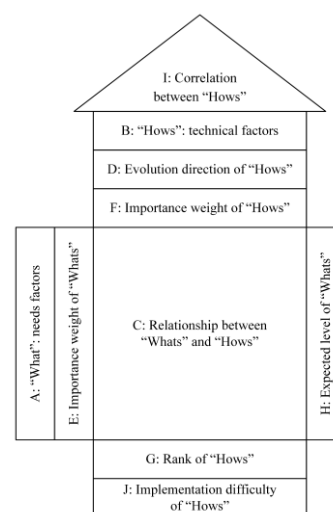


Figure 2. Geometric layout of the HOQ of the proposed framework.

Evaluation of importance weights of needs factors

The needs factor's importance weight represents the determined priorities of needs factors to be satisfied, as illustrated in section E of Figure 2. Since it is not possible to equally fulfill all of the needs factors due to the limit of resources, the proper determination of the importance weights is crucial. Ulrich's tools are standard tools for this task. The evaluation uses Likert's scale (5 = highest importance, 4 = high importance, 3 = medium importance, 2 = low importance, 1 = lowest importance) (Kuijt-Evers *et al.*, 2009; Päivinen and Heinimaa, 2009). The geometric mean is calculated (Kengpol, 2004), as illustrated in Equation (1), where n is the total number of experts, and x is the expert's response value. Lastly, the geometric means are normalized (Mao *et al.*, 2019).

$$\text{Geometric Mean} = \sqrt[n]{x_1 \times x_2 \times \cdots \times x_n} \quad (1)$$

Transformation to importance weights of technical factors

The importance weight of the technical factor represents the determined priorities of needs factors to be fulfilled, as illustrated in section F of Figure 2. These technical factors importance weights are transformed from the importance weights of needs factors, as presented in Equation (2) (Mao *et al.*, 2019), where Tw_j is the importance weights of technical factor j , Nw_i is the importance weights of needs factor i , and R_{ij} is the relationship between needs factor i and system factors j (Marsot, 2005). Lastly, the transformed weights are normalized (Mao *et al.*, 2019) and ranked (Beckerle *et al.*, 2017), as illustrated in section G of Figure 2.

$$Tw_j = \sum_{i=1}^n Nw_i R_{ij} \quad (2)$$

Evaluation of expected levels of needs factors

The expected level of needs factors represents the need factor's expectation level based on stakeholders' scientific surveys with specific segments, as illustrated in section H of Figure 2. Therefore, the evaluating method depends on the case (Mao *et al.*, 2019). This section of the HOQ can also imply the tangible bond from the product's concept-level to a strategic vision-level of the organization (Hauser and Clausing, 1988).

Evaluation of correlations between technical factors

The correlation between technical factors represents the relationship between a pair of technical factors, as illustrated in section I of

Figure 2. These correlations are useful in avoiding conflicting factors and enhancing the advantages of synergetic factors. Ulrich's tools are standard tools for this task. This evaluation uses -2 to 2 scale (2 = strong synergy 1 = weak synergy, 0 = no correlation, -1 = weak conflict, -2 = strong conflict) (Mao *et al.*, 2019).

Evaluation of implementation difficulty of technical factors

The technical factor's implementation difficulty represents the difficulty in developing each technical factor regarding all related aspects, as illustrated in section J of Figure 2. Due to the limit of resources, this step can regulate the optimal design solutions (Mao *et al.*, 2019). Ulrich's tools are standard tools for this task. This evaluation uses Likert's scale (5 = highest difficulty, 4 = high difficulty, 3 = medium difficulty, 2 = low difficulty, 1 = lowest difficulty) (Kuijt-Evers *et al.*, 2009; Päivinen and Heinimaa, 2009).

Results and Discussions

Case study

This section aims at demonstrating the proposed method to identify stakeholders' needs of the powered prosthetic knee as a case study in Thailand. The stakeholders of this case study are classified into two groups, including amputees (A) and experts (B).

(A) The amputees are volunteers who have experienced using TF prosthesis and participate in the study from January to June 2018. Amputees' inclusion criteria are the following: TF amputation, experience with TF prosthesis, cognitive ability to read and write in Thai or English, can speak the Thai or English language fluently. The participants with age under 18 years old on the first day of participating are excluded from the study. The Characteristics of amputees are illustrated in Table 1.

Table 1. Characteristics of amputees.

Characteristics	Amputees (n = 34)
Age, years	
Mean (SD)	50.94 (13.32)
95% CI	46.47-55.42
Gender, no. (%)	
Female	11 (32%)
Male	23 (68%)
Weight, kg	
Mean (SD)	71.12 (13.28)
95% CI	66.65-75.78
Experience with TF prosthesis, years	
Mean (SD)	15.47 (8.99)
95% CI	12.45-18.49

(B) The experts are volunteers who have a qualification or competency in related fields, including prosthesis & orthotics, engineering, design, healthcare. Experts' inclusion criteria are the following: occupational or licensed or graduated in a related field, the cognitive ability to read and write in Thai or English, and the ability to speak the Thai or English language fluently. This research follows previous directions (Dror, 2019; Mao *et al.*, 2019) where three experts evaluate QFD parameters. It is mentioned that three experts are the smallest number to neutralize outliers (Dror, 2019). The experts in this study consist of a prosthetist, a human factors engineer, and a production engineer.

After the stakeholders are defined, the first House Quality is used to identify the needs and technical factors and establish the relation and essential parameters. The detail of the results is described as follows.

Identification of needs factors

This step begins with learning the interested stakeholder's needs and communicating them to the researcher team. An interview is a proper tool for this investigation (Marsot, 2005). Thirty-four TF amputees participate in this study as stakeholders. One of the authors is an interviewer, while another one takes part as a notetaker. The individual interview took on approximately 60 minutes in an enclosed room. The interviewer asks the topics about the needs and perspective of Thailand's prosthesis development circumstances.

All participants show great interest in the concept of powered prosthetic knee development with principles that focus on users' needs. This step also considers the questionnaire survey results for TF prosthesis' user needs assessment presented in (Yodpijit *et al.*, 2019). Finally, collected needs will

be arranged using the affinity diagram concept, as illustrated in Table 2.

Identification of technical factors

The set of technical factors of a powered prosthetic knee in this research are applied from (Beckerle *et al.*, 2017) and expert discussion results. The primary source of technical information reveals from the systematic review of twenty-two publications on powered lower-limb prostheses. The expert discussion is applied to arrange the various technical information, solutions, and criteria into nine technical factors and determine their definitions, as illustrated in Table 3.

Table 3. Identified technical factors

Technical Factor	Definition or explanation
Mechanics (MEC)	The crucial mechanical components of the prosthesis.
Actuator (ACT)	The powered components that control the movement of the prosthesis to support the user.
Sensors (SEN)	The components are used to measure situations or changes in their circumstances or the user and send it to associated systems.
Recognition (REC)	The high-level software or hardware recognizes the user's intention, the momentary condition of the movement, or circumstances and plans the movement strategies from this information.
Control (CON)	The low-level software or hardware controls the actuator of prosthesis based on the measured information and commands.
Mass (MAS)	The Mass of the prosthesis.
Dimension (DIM)	The Dimensions of the prosthesis.
Operating Time (TIM)	The operation time of prosthesis without connected to the source of power.
Capability (CAP)	The capability of the prosthesis in different movements and transitional and adaptational of the movements.

Table 2. Identified needs factors.

Groups of Needs	Needs
Performance	maintain movement stability
	response to the different movements
	do not hurt the stump
	able to walk on different level surface
	reduce energy expenditure for movements
Features	reduce the impact
	mimic the human knee
	durable structure
	low noise when operating
	can be used entire day
Appearance	lightweight
	weatherproof
	affordable price
	easy maintenance and configuration
	can use with cosmetic cover
	do not damage clothing
	compact size
	look like human knee

Evaluation of the relationships between needs factors and technical factors

The expert discussion is conducted to evaluate the relationship between needs factors and technical factors. All three experts participate in this discussion. The experts are asked to define the consensus value of the relationship of each pair of factors in scale (9-3-1-0) with four response options. The evolution direction of each technical factor also is defined by the consensus of experts in this step. The results are illustrated in the completed first HOQ table (Table 6).

Evaluation of importance weights of needs factors

Twelve TF amputee participants are randomized selected from thirty-four TF amputee participants to evaluate the importance weights of needs factors. The participants are asked to rate the needs factor. The geometric mean is calculated, and the results are normalized. The importance of the weight of needs factors is illustrated in Table 4.

Table 4. Identified technical factors

	Needs Factor	Importance score	Normalized weight
Performance	maintain movement stability	4.82	0.063
	response to the different movements	4.73	0.062
	do not hurt the stump	4.26	0.056
	able to walk on different level surface	4.24	0.055
	reduce energy expenditure for movements	4.22	0.055
	reduce the impact	4.14	0.054
	mimic the human knee	4.06	0.053
	durable structure	4.51	0.059
	low noise when operating	4.45	0.058
Features	can be used entire day	4.37	0.057
	lightweight	4.29	0.056
	weatherproof	4.21	0.055
	affordable price	4.13	0.054
	easy maintenance and configuration	4.03	0.053
Appearance	can use with cosmetic cover	4.37	0.057
	do not damage clothing	4.26	0.056
	compact size	4.01	0.052
	look like human knee	3.45	0.045

Transformation to importance weights of technical factors

The importance weights of technical factors are transformed based on data from the importance weights of needs factors and relationships between needs factors and technical factors and then normalized and ranked. Table 5 illustrates the importance of the weight of technical factors.

Evaluation of expected levels of needs factors

The expert discussion is conducted to evaluate the expected levels of needs factors. All three experts participate in this discussion. The experts are asked to define the consensus value of expected levels of needs factors. The development of powered prosthetic knee is established on the belief that the design should reflect the user's needs. Therefore, the experts are agreed to evaluate the expected levels of needs factors taking into account

the importance of weight given by the TF amputees participants. The results are illustrated in the completed first HOQ table (Table 6).

Table 5. Importance score and normalized weight of the technical factors.

Technical Factor	Importance score	Normalized weight	Rank
Mechanics (MEC)	0.089	2.478	6
Actuator (ACT)	0.238	6.65	1
Sensors (SEN)	0.066	1.844	8
Recognition (REC)	0.073	2.041	7
Control (CON)	0.099	2.759	5
Mass (MAS)	0.117	3.279	3
Dimension (DIM)	0.110	3.061	4
Operating Time (TIM)	0.061	1.695	9
Capability (CAP)	0.148	4.132	2

Evaluation of correlations between technical factors

The expert discussion is conducted to evaluate the correlations between technical factors. All three experts participate in this discussion. The experts are asked to define the consensus value of the correlations between technical factors in the integer range (-2 to 2). The results are illustrated in the completed first HOQ table (Table 6).

Evaluation of implementation difficulty of technical factors

The expert discussion is conducted to evaluate the implementation difficulty of technical factors. All three experts participate in this discussion. The experts are asked to define the consensus value of technical factors' implementation difficulty in the Likert scale five response format. The results are illustrated in the complete House of Quality table (Table 6).

Discussions

This section describes the discussion on notable findings and implications of the case study. The identified needs factors are assigned in three groups by their characteristics, including performance group, feature group, and appearance group. The evaluation of importance weights of needs factors indicates performance group seems more crucial than other groups. This because the performance group contains needs related to the prosthesis user's primary purposes and stability considerations.

Table 6. First HOQ of the case study.

		1 -12 -2-21 -2-2-12 1-2-1-12 1-2-10-1-1 11200-1-1 2122-11 122-11										
Technical Factor		MEC	ACT	SEN	REC	CON	MAS	DIM	TIM	CAP	Expected Level	
		Evolution Direction	↑	↑	↑	↑	↓	↓	↑	↑		
		Normalized Importance weight	0.089	0.238	0.066	0.073	0.099	0.117	0.110	0.061	0.148	
Needs Factor												
Performance	maintain movement stability	0.063	3	9	3	3	9	3	0	0	3	100%
	response to the different movements	0.062	1	9	3	9	3	3	1	0	9	100%
	do not hurt the stump	0.056	1	3	3	0	0	3	1	0	1	90%
	able to walk on different level surface	0.055	1	9	3	3	3	3	1	0	9	90%
	reduce energy expenditure for movements	0.055	3	9	3	3	9	9	1	1	3	90%
	reduce the impact	0.054	1	3	3	3	9	9	1	0	3	90%
mimic the human knee		0.053	3	9	3	9	9	3	3	1	9	90%
Features	durable structure	0.059	9	9	1	0	0	3	3	1	3	100%
	low noise when operating	0.058	3	9	0	0	1	3	1	0	0	100%
	can be used entire day	0.057	1	9	1	1	1	3	1	9	9	90%
	lightweight	0.056	3	9	1	0	0	9	3	9	3	90%
	weatherproof	0.055	3	9	1	1	1	1	1	1	3	90%
	affordable price	0.054	3	9	3	1	1	3	3	3	9	90%
	easy maintenance and configuration	0.053	1	3	3	3	3	1	1	3	3	90%
Appearance	can use with cosmetic cover	0.057	3	3	1	0	0	0	9	0	3	90%
	do not damage clothing	0.056	1	1	0	0	0	0	9	0	1	90%
	compact size	0.052	3	3	0	0	0	0	9	0	0	90%
	look like human knee	0.045	1	3	1	0	0	3	9	3	3	80%
Rank		6	1	8	7	5	3	4	9	2		
Implementation difficulty		4	5	3	4	4	3	3	3	5		

A number of amputees pay more attention to the needs of performance group, such as maintain movement stability and response to the different movements over the top needs of feature group, such as durable structure or low noise when operating. It might have implications for the experience of amputees with the prostheses. Typically, any prosthesis is usually prescribed by licensed physicians or professionals. The selection and customization of prosthetic components are carefully decided based on the user's biological characteristics and ambulation performance. However, the limitations of budget and medical welfare coverage still affect the prosthesis selection. Therefore, many amputees are unable to choose the most desirable or suitable prosthetic components on them. The importance of affordable price in the performance group indicates the requirement of amputees on this issue. The results also show the importance of appearance group affecting prosthetic users' needs, reflecting the need for social acceptance (Beckerle *et al.*, 2017).

The study calculates the importance weights of technical factors based on the importance weights of

needs factors and relationships between needs factors and technical factors. The rank can be determined from the prioritization of the importance weights of technical factors. ACT (Actuator), the first in the ranking, is one of the most critical and complex components of the powered prosthesis. Without a powered actuator, the prosthesis cannot control the movement to support the user. There are several technologies of actuators, such as pneumatic, hydraulic, electromechanical, result in different pros and cons. The transmission systems and elastic energy storages (spring and damper) also consider in the actuator systems (Beckerle *et al.*, 2017). The capability (CAP) is the second in ranking because it is highly related to the critical needs of the performance group and the feature group. A third and the fourth is the mass (MAS) and the dimension (DIM), respectively, which influence the performance group and feature group, while only dimension (DIM) has a significant impact on the appearance group. The fifth is control (CON), highly relate to the performance group same as actuator (ACT) because these two components have to cooperate in operation. Mechanics (MEC) is

ranked in sixth and tends to relate to all needs groups since it comprises structural and supporting components and additional mechanical parts. Recognition (REC) is ranked seventh and strongly relates to response to the different movements and mimic the human knee. Previous study of powered TF prosthesis recognition systems development is presented on the application of artificial neural networks (Yodpijit *et al.*, 2018a). The eighth is Sensors (SEN); they are still crucial and sensitive devices, but advancing in MEMS technology makes high-performance sensors now smaller and easily affordable (Lawson *et al.*, 2014). The Operating Time (TIM) is ranked last, because today, the battery tends to improve both in capacity and performance, making the powered prosthesis more prolonged usage (Lawson *et al.*, 2014).

The expert discussion evaluates the implementation difficulty of technical factors based on the evolution direction, correlations and importance of technical factors. The actuator (ACT) and capability (CAP) are rated to have the highest (five points) difficulty level because both are highly complex systems, require advancement technology in implementation, and are expected for outstanding performance. The results are also consistent with their high ranking. Three factors are assessed at four points: mechanics (MEC), recognition (REC), and control (CON). These factors are essential and require high development resources. However, with today's advances in engineering knowledge, these can be achieved even though much effort is required. The remaining factors are sensors (SEN), mass (MAS), dimension (DIM), and operating time (TIM). These factors are assessed at a difficulty of 3 points because the equipment or materials required to fulfill these factors are available today at an affordable cost. Nevertheless, it is still crucial to select the appropriate equipment or materials with good performance and compact with other systems.

Conclusions

This paper illustrates the implementation of the first HOQ of the proposed QFD framework to identify stakeholders' needs of the powered prosthetic knee as a case study. The stakeholders of this case study consist of the TF amputees and the related-field experts. The TF amputees are the real end-users of the prosthesis and voluntarily participate in this study to provide the source of needs factors and the needs factors prioritization. Three experts in different fields contribute to evaluate parameters and refine outcomes of this study. Eighteen needs are discovered and categorized into three groups. In addition to this, the performance group has the

highest score, reflecting the expectation of prostheses' performance and stability. Based upon previous findings and expert discussions, nine engineering characteristics are recruited, where the Actuator (ACT) is in the highest rank and correlates with crucial needs. Experts determine thirty-six correlations of technical factors, where Mass (MAS) and Dimension (DIM) have conflict colorations with other technical factors indicating several trade-offs in the design process.

Limitations and Future Works

This research can be extended by determining technical factors' improvement requirements as the guideline presented in (Mao *et al.*, 2019). Validation of the needs factor can be possibly done in the future (Beckerle *et al.*, 2017). In generic of the product design and development process, iterations of improvement in any steps are possible and unlimited as long as the product is not released to the market (Ulrich and Eppinger, 2017). Furthermore, the methods presented in this research can be applied to developing other prostheses and orthosis design cases (Beckerle *et al.*, 2017). Nowadays, all of the powered TF prostheses in Thailand have to be oversea imported at an expensive cost. Making Thai TF amputees rarely have access to this kind of prosthesis. Further development of prosthesis products will bring significant benefits to people with disabilities.

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