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Framework to assess technology readiness of lithium-ion battery to fulfill the safety standard: IEC 62660-3:2016 (case study: smart lithium battery of UNS product)

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Abstract. Electric vehicles are one of the ways to solve the problem of air. Electric vehicles have a very vital component which is the battery as a source of power for other components. The type of battery that has bes performance for electric vehicles is lithium-ion battery. Reliability and safety present significant challenges in lithium-ion batteries. Thus, lithium product standards are important to guarantee the quality of lithium battery products. The International Electrotechnical Commission (IEC) published a lithium battery standard product regulation in document IEC 62660-3:2016, that provide a basic level of safety test methodology and criteria with general versatility, serves a function in common primary testing of lithium-ion cells to be used in variety of battery systems. This paper aims to identify the technological readiness of Universitas Sebelas Maret (UNS) lithium-ion enterprise to fulfill the lithium battery product standards by modifying the Quality Functional Deployment (QFD). Several production processes in technoware and humanware are not compatible with lithium battery standard, but all production processes in infoware and orgaware are compatible with lithium battery standard.

1. Introduction

The source of air pollution in the world is motorized vehicles [1]. One of the ways to overcome the problem of air pollution is to present an electric vehicle. The battery is a vital component of electric vehicles, because the battery is a source of power from the components of the electric vehicles [2]. The various types of batteries used in electric vehicles, and lithium batteries have the highest performance compared to other types of batteries [3]. Battery safety is a rather complex and sophisticated problem, and the safety of lithium-ion battery in vehicle is apriority of automotive industry [4]. The availability of international standards regarding secondary lithium-ion cell safety requirements have been developed by world organizations, the one of them is International Electrotechnical Commission (IEC) published IEC 62660-3:2016 standard. The standard is concerning in secondary lithium-ion cells for electric vehicles on safety requirements. Nevertheless, achieving a good level of safety and reliability is now a goal for global large-scale distributed energy management systems [5].

In addition to meet the standard criterias for the battery production process, the readiness of technological readiness in the production process must also be considered. Many people avoid technology because they are uncomfortable, not ready to use technology [6][7]. Technology readiness refers to the human tendency to use new technology to achieve goals both at work and in everyday life

[8]. In accordance with the systematic approach to technology, the components of technological system include technoware, humanware, infoware, and orgaware must be kept out of date.

This study purpose to identify each stage of the production in Universitas Sebelas Maret (UNS) lithium battery plant against the standard lithium battery product. furthermore, to provide recommendations for improvement component technologies to fulfill the quality requirements of IEC 62660-3:2016. This study was conducted in the production process at Universitas Sebelas Maret (UNS) battery plant. The UNS lithium plant sells lithium battery using make-to-order production system. The name of lithium battery product commercialized by UNS is SMART UNS-Lithium Battery. The specifications of SMART UNS-Lithium Battery are presented in **Table 1**.

Table 1. SMART UNS-Lithium Battery product specification

Cathode material	LFP	NCA	NMC
Material	$LiFePO_4$	$LiNiCoAlO_2$	$LiNiMnCoO_2$
Electrical conductivity (V)	3.4	3.6	3.6
Current capacity (Ah/Kg)	160	180	180
Energy density/weight (Wh/Kg)	544	648	648
Energy density/volume (Wh/L)	1,953	3,110	3,110

2. Methodology

Notation

j	: Index for production process	k	: Index for the lithium standard
HL	: Lithium's humanware sophistication for production process number k	HS	: Standard humanware sophistication for production process number k
TL	: Lithium's technoware sophistication for production process number k	TS	: Standard technoware sophistication for production process number k
IL	: Lithium's infoware sophistication for production process number k	IS	: Standard infoware sophistication for production process number k
OL	: Lithium's orgaware sophistication for production process number k	OS	: Standard orgaware sophistication for production process number k
AHL	: Lithium's aggregate humanware sophistication to fulfill lithium standard number j	AHS	: Standard aggregate humanware sophistication to fulfill lithium standard number j
ATL	: Lithium's aggregate technoware sophistication to fulfill lithium standard number j	ATS	: Standard aggregate technoware sophistication to fulfill lithium standard number j
AIL	: Lithium's aggregate infoware sophistication to fulfill lithium standard number j	AIS	: Standard aggregate infoware sophistication to fulfill lithium standard number j
AOL	: Lithium's aggregate orgaware sophistication to fulfill lithium standard number j	AOS	: Standard aggregate orgaware sophistication to fulfill lithium standard number j
W_j	: Weight importance of production process number k	C_{jk}	: Correlation value between production process number k with lithium standard number j
NW	: The normalized matrix on planning	W_k	: Weight importance of standard number j

According to Noor, Quality Function Deployment (QFD) is a methodology that translates the needs and desires of consumers into a product/service design that has certain technical requirements and quality characeristics [9]. This method is identify the Voice of Customer (VOC) [10]. QFD consists of six main parts, namely the Voice of Customer (VOC), relationship matrix, technical response, technical correlation matrix, technical matrix, and planning matrix [11]. Then QFD is modified to fit the research conducted, Voice of Customer (VOC) is represented by lithium battery product standard, relationship matrix, technical response is represented by production process, technical matrix is represented by technological readiness, and planning matrix is represented by technological component standard benchmark. The technical correlation matrix is not include in this study because the production process is assumed to be independent of each other. The original QFD is presented in **Figure 1** and modificated QFD is presented in **Figure 2**.

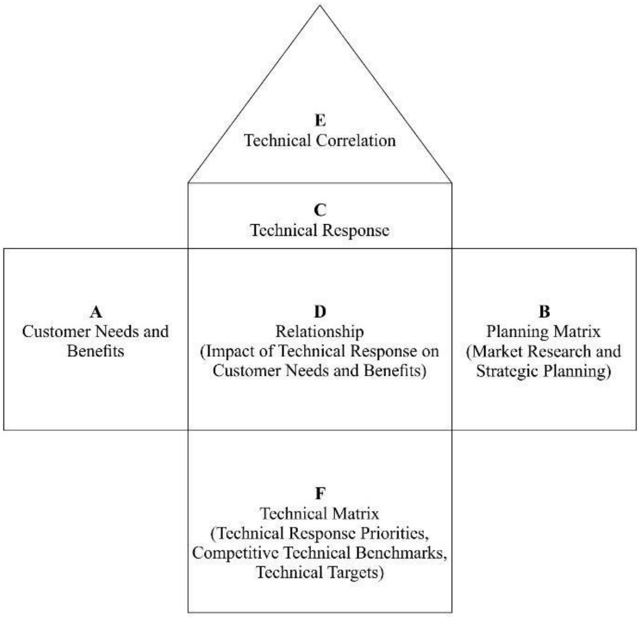

Figure 1. Original QFD

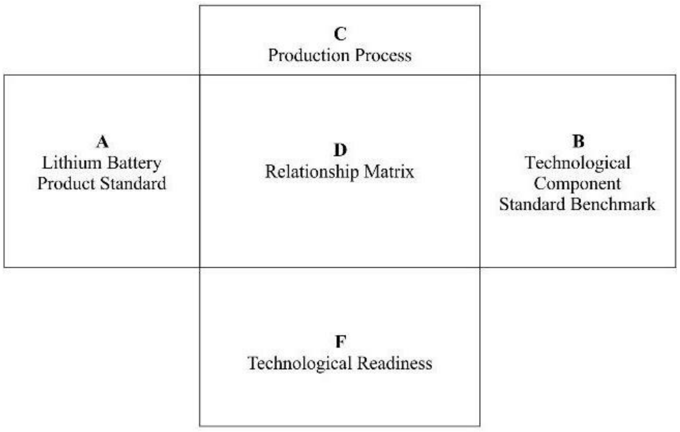

Figure 2. Modified QFD

The steps of methodology is presented in Figure 3. First step is identify lithium product standard. After that, lithium battery production processes are identified. Third, the existing sophistication of technology component (technoware, humanware, infoware, and orgaware) in every process is measured to get TL, HL, IL, and OL. Fourth, experts are asked to give TS, HS, IS, and OS value. TS, HS, IS, and OS value is minimum sophistication level of IEC’s quality requirement that needs to be fulfilled. Fifth, the relationship between every production process with the quality requirement in IEC 62660-3:2016 is evaluated. Sixth, the importance between production production processes is evaluated by using paiwise comparison technique. Seventh, ATL, AHL, AIL, AOL, ATS, AHS, AIS, and AOS are calculated based on relationship matrix, importance weighting TL, HL, IL, OL, TS, HS, IS, and OS. Thus, the gap between ATL with ATS, AHL with AHS, AIL with AIS, and AOL with AOS.

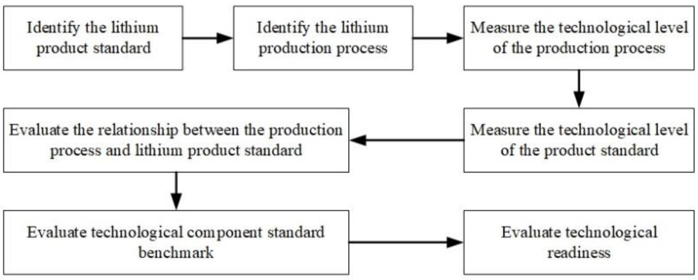

Figure 3. Methodology steps

3. Results

The process of producing lithium batteries is based on survey results can be identified are (1) mixing, (2) coating, (3) pressing, (4) slitting, (5) nickel tab welding, (6) winding, (7) welding into sleeves, (8) grooving, (9) cap welding, (10) electrolyte filling, (11) punching, (12) grading, (13) sorting, and (14) delivery.

To get TL, HL, IL, and OL score, a degree sophistication degree from UNESCAP (1989). The model has range score from 1 to 9, which the basic technological component has score 1 and the most advanced technological components has a score 9 with field survey and interview was taken to get TL, HL, IL, and OL score. Furthermore, two experts from electric vehicle technical committee and lithium battery researcher was asked to give TS, HS, IS, and OS to every production process. ATL, AHL, AIL, AOL, ATS, AHS, AIS, and AOS score is recapitulated in **Tabel 2**.

To find correlation between lithium battery standard *k* and production process *j,* a correlation matrix is used. A correlation value of 0, 1, 3 and 9 shows that the correlation between lithium battery standard *k* and production process *j* have no, weak, medium, and high correlation respectively. Two experts was asked to give the correlation value (C_{kj}) in relationship matrix. The correlation value is recapitulated in **Tabel 3**.

Every production process has a different importance weighting to create overall lithium battery product. the importance weighting between production process *j* is estimated by pairwise comparison technique, with two experts make the comparison judgment. In **Table 4** is recapitulation of the pairwise comparison (W_j) technique.

Table 2. ATL, AHL, AIL, AOL, ATS, AHS, AIS, and AOS score

Production Process / Tech. Components	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
TL	4.5	5.5	4.0	4.0	2.0	5.5	2.5	3.0	2.5	4.5	3.0	5.5	6.0	1.5
HL	4.0	5.5	4.0	4.0	4.0	4.5	4.0	4.0	4.5	5.0	4.0	4.0	5.0	4.5
IL	4.5	4.5	4.5	4.0	4.5	4.5	4.0	4.5	4.0	5.0	4.0	5.0	4.5	4.0
OL	5.0	5.0	4.0	3.5	4.5	5.5	3.5	4.0	3.0	5.0	3.5	4.0	3.5	3.5
TS	4.0	4.5	4.0	3.5	3.0	4.5	3.0	3.0	3.0	3.5	3.5	5.0	4.0	1.5
HS	3.0	3.5	3.0	3.0	4.5	3.5	3.5	3.0	3.5	4.5	3.0	5.0	3.5	2.5
IS	4.0	4.5	4.0	4.0	4.0	4.5	4.0	4.0	4.0	4.5	4.0	4.5	4.0	3.0
OS	3.0	3.5	3.0	3.0	3.0	3.5	3.0	3.0	3.0	3.5	3.0	3.0	3.0	2.5

Table 3. Correlation value in realtionship matrix

No. *j* / No. *k*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
1	9.0	9.0	3.0	1.0	9.0	9.0	5.2	1.0	3.0	9.0	1.0	0	0	3.0
2	9.0	9.0	3.0	1.0	9.0	9.0	5.2	3.0	3.0	9.0	1.0	0	0	3.0
3	9.0	9.0	3.0	1.0	9.0	9.0	5.2	3.0	3.0	9.0	1.0	0	0	3.0
4	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	1.0	0	0	1.0
5	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	1.0	0	0	1.0
6	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	0	3.0	0	1.0
7	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	0	3.0	0	1.0
8	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	0	3.0	0	1.0
9	9.0	9.0	1.7	1.0	9.0	9.0	9.0	1.0	3.0	9.0	0	30	0	1.0

Table 4. Importance weighting of the production process

No. j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Importance (%)	15.84	16.48	10.41	4.47	6.09	11.21	5.30	4.73	4.68	8.89	3.32	3.97	2.81	1.71

Lithium's technoware, humanware, infoware, and orgaware gap is defined as when raw technoware lithium is lower than raw technoware standard, raw humanware lithium is lower than raw humanware standard, raw infoware lithium is lower than raw infoware standard, and raw orgaware lithium is lower than raw orgaware standard respectively. Before determining the gap, we need to calculate ATL, AHL, AIL, AOL, ATS, AHS, AIS, and AOS by Equations (1)-(8). Technoware, humanware, infoware, and orgaware gap is identified when the value between raw lithium and raw standard is negatif. If the value between raw lithium and raw standard is positive, the production process meets lithium standard. Raw technoware lithium, raw humanware lithium, raw infoware lithium, raw orgaware lithium, raw technoware standard, raw humanware standard, raw infoware standard, and raw orgaware standard can be calculated by Equations (9)-(16). But before calculated the gap, we need to estimate the importance weighting between lithium standard by using pairwise comparison based on two experts. The result of importance weighting between lithium standard is showed in **Table 5** and the result of calculation by Equation (9)-(16) is showed in **Table 6, Table 7, Table 8, and Table 9**.

$$ATL_j = \sum_k W_k \, x \, TL_{k,j} \quad (1)$$
$$AHL_j = \sum_k W_k \, x \, HL_{k,j} \quad (2)$$
$$AIL_j = \sum_k W_k \, x \, IL_{k,j} \quad (3)$$
$$AOL_j = \sum_k W_k \, x \, OL_{k,j} \quad (4)$$
$$ATS_j = \sum_k W_k \, x \, TS_{k,j} \quad (5)$$
$$AHS_j = \sum_k W_k \, x \, HS_{k,j} \quad (6)$$
$$AIS_j = \sum_k W_k \, x \, IS_{k,j} \quad (7)$$
$$AOS_j = \sum_k W_k \, x \, OS_{k,j} \quad (8)$$
$$Raw\ Technoware\ Standard = \sum_k C_{k,j} \, x \, W_k \, x \, TS_{k,j} \, x \, NW_j \quad (9)$$
$$Raw\ Humanware\ Standard = \sum_k C_{k,j} \, x \, W_k \, x \, HS_{k,j} \, x \, NW_j \quad (10)$$
$$Raw\ Infoware\ Standard = \sum_k C_{k,j} \, x \, W_k \, x \, IS_{k,j} \, x \, NW_j \quad (11)$$
$$Raw\ Orgaware\ Standard = \sum_k C_{k,j} \, x \, W_k x \, OS_{k,j} \, x \, NW_j \quad (12)$$
$$Raw\ Technoware\ Lithium = \sum_k C_{k,j} \, x \, W_k \, x \, TL_{k,j} \, x \, NW_j \quad (13)$$
$$Raw\ Humanware\ Lithium = \sum_k C_{k,j} \, x \, W_k x \, HL_{k,j} \, x \, NW_j \quad (14)$$
$$Raw\ Infoware\ Lithium = \sum_k C_{k,j} \, x \, W_k \, x \, IL_{k,j} \, x \, NW_j \quad (15)$$
$$Raw\ Orgaware\ Lithium = \sum_k C_{k,j} \, x \, W_k x \, OL_{k,j} \, x \, NW_j \quad (16)$$

Table 5. Importance weighting of the lithium standard

No. k	1	2	3	4	5	6	7	8	9
Importance (%)	5.77	5.53	5.95	17.50	9.86	17.88	11.27	5.20	21.04

Table 6. Technoware gap

Production Process	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Raw Technoware Standard	4.00	4.50	0.87	0.39	3.00	4.50	2.78	0.41	1.00	3.50	0.17	0.92	0	0.22
Raw Technoware Lithium	4.50	5.50	0.87	0.44	2.00	5.50	2.32	0.41	0.00	4.50	0.15	1.02	0	0.22
Gap	0.50	1.00	0	0.06	-1.00	1	-0.46	0	-0.17	1.00	-0.02	0.09	0	0

Table 7. Humanware gap

Production Process	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Raw Humanware Standard	3.00	3.50	0.65	0.33	4.50	3.50	3.24	0.41	1.17	4.50	0.15	0.92	0	0.37
Raw Humanware Lithium	4.00	5.50	0.87	0.44	4.00	4.50	3.71	0.55	1.50	5.00	0.20	0.74	0	0.67
Gap	1.00	2.00	0.22	0.11	-0.50	1.00	0.46	0.14	0.33	0.50	0.05	-0.18	0	0.30

Table 8. Infoware gap

Production Process	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Raw Infoware Standard	4.00	4.50	0.87	0.44	4.00	4.50	3.71	0.55	1.33	4.50	0.20	0.83	0	0.45
Raw Infoware Lithium	4.5	4.5	0.98	0.44	4.50	4.50	3.71	0.61	1.33	5.00	0.20	0.92	0	0.60
Gap	0.50	0	0.11	0	0.50	0	0	0.07	0	0.50	0	0.09	0	0.15

Table 9. Orgaware gap

Production Process	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Raw Orgaware Standard	3.00	3.50	0.65	0.33	3.00	3.50	2.78	0.41	1.00	3.50	0.15	0.55	0	0.37
Raw Orgaware Lithium	5.00	5.00	0.87	039	4.50	5.50	3.24	0.55	1.00	5.00	0.17	0.74	0	0.52
Gap	2.00	1.50	0.22	0.06	1.50	2.00	0.46	0.14	0	1.50	0.02	0.18	0	0.15

From the result of gap calculation, in the technoware gap there are four production processes are not sophisticated enough to fulfill the lithium battery standard, there are nickel tab welding process, welding into sleeves process, cap welding process, and punching process. In the humanware gap there are two production processes are not sophisticated enough to fulfill the lihtium battery standard, there are nickel tab welding process and grading process. In the infoware and orgaware gap that compatible to fulfill all lithium battery standard.

4. Analysis

The result show that all technological components in production process are partially compatible with lithium battery standard. In another hand, several production processes in technoware and humanware are not compatible with battery lithium standard, but the production processes in infoware and orgaware are compatible with battery lithium standard. There are several reasons why lithium battery technoware and humanware do not sophisticate enough to fulfill the standard. The first reason is standards that are still considered less important for their business. The second is because the business is relatively new, so it still needs to be adjusted to existing standards. The last is lack of knowledge and financial to conduct training and improve the sophistication of machines and tools. Those three reasons are main problems for lithium battery plant to improve their compatibility with standard.

Production process No. 1, 2, 5, 6, 7, and 10 has high correlation value with lithium battery standard. Thus, improvement of production process No. 1, 2, 5, 6, 7, and 10 have high impact to fulfill lihtium battery standard requirement.

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