FINAL PROJECT - TI141501

DESIGNING BATTERY MANAGEMENT SYSTEM FOR AN ELECTRIC VEHICLE

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Surabaya, 2018

TUGAS AKHIR - TI141501

DESAIN TAMPILAN DINAMIS *BATTERY MANAGEMENT SYSTEM* PADA MOBIL LISTRIK

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Surabaya, 2018

APPROVAL SHEET

DESIGNING DYNAMIC VISUALIZATION OF BATTERY MANAGEMENT SYSTEM FOR AN ELECTRIC VEHICLE

FINAL PROJECT

Submitted to Acquire the Requirement of Bachelor Degree:
Industrial Engineering Department
Faculty of Industrial Technology
Institut Teknologi Sepuluh Nopember
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Surabaya, January 2018

DESIGNING DYNAMIC VISUALIZATION OF BATTERY MANAGEMENT SYSTEM FOR AN ELECTRIC VEHICLE

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ABSTRAK

Visualisasi dinamis harus memiliki *interface*. Penggunaan *interface* pada visualisasi dinamis dapat menimbulkan beban kognitif ekstra yang dapat mengalihkan perhatian seseorang dalam memahami dan mempelajari visualisasi dinamis. Oleh karena itu, perancangan visualisasi dinamis yang efektif harus dikaji melalui penelitian mengenai desain *interface*.

Salah satu teknologi yang menerapkan visualisasi dinamis adalah kendaraan listrik. Visualisasi dinamis ini diimplementasikan pada *Battery Management System* (BMS) yang terintegrasi pada panel *dashboard* kendaraan listrik. BMS menjaga performa baterai di dalam *Safe Operating Area* (SOA). Baterai yang tidak beroperasi di dalam SOA akan menyebabkan kerusakan fisik hingga memicu ledakan. Padahal, baterai menjadi salah satu komponen yang berperan penting bagi kendaraan listrik. Tugas akhir ini membahas tentang konsep *user interface* dan *user experience* untuk merancang visualisasi dinamis tampilan BMS yang terpasang pada panel *dashboard*. Studi literatur mengenai tampilan BMS pada berbagai merek kendaraan listrik dilakukan guna mengetahui preferensi tampilan BMS saat ini. Kemudian, kuesioner *pair-comparison* dibuat untuk mengetahui preferensi responden terhadap alternatif tampilan visualisasi dinamis parameter fungsi yang terdapat dalam BMS. *Expert's judgement* juga diterapkan untuk memberikan penilaian terhadap hasil skor preferensi *pair-comparison* responden.

Hasil kuesioner *pair-comparison* alternatif tampilan kapasitas baterai (*state of charge*) terbukti konsisten, dibuktikan dengan nilai konsistensi oleh Amman dan Greenberg. Sementara pada kuesioner *pair-comparison* alternatif tampilan tegangan baterai, terdapat data 1 (satu) responden yang dikeluarkan dari penelitian karena konsistensi yang rendah.

Hasil penelitian menunjukkan skor preferensi tertinggi responden jatuh pada digital dengan pembacaan cek (*check reading*) untuk visualisasi dinamis kapasitas baterai, dan analog-setengah lingkaran dengan *check reading* untuk visualisasi dinamis tegangan baterai. Di sisi lain, *Expert's Judgment* menyatakan bahwa tampilan analog-setengah lingkaran dengan *check reading* untuk kapasitas baterai dan tampilan digital dengan *check reading* untuk tegangan baterai merupakan tampilan yang diutamakan untuk mendesain visualisasi dinamis kedua fungsi tersebut. Faktor desain yang paling berpengaruh untuk tampilan dinamis BMS adalah ketersediaan *check reading* (dalam bentuk warna) dan gaya desain.

Kata kunci: visualisasi dinamis, *safety operating area, battery management system, pair comparison, interface*

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DESIGNING DYNAMIC VISUALIZATION OF BATTERY MANAGEMENT SYSTEM FOR AN ELECTRIC VEHICLE

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ABSTRACT

Dynamic visualization must have an interface. An interface with dynamic visualization can resulted in extraneous cognitive load that can take the viewer’s attention away from the task of understanding and learning from the dynamic visualization. The design of effective dynamic visualizations must be explained by the research on interface design.

One of technologies that implement dynamic visualization is electric vehicle (EV). The dynamic visualization is implemented on the integrated battery management system (BMS) interface. BMS keeps the battery performance within safe operating area (SOA). When it is not operated inside the SOA, it may lead to physical damage due to overheating, or even an explosion. The battery plays important role as the ‘life’ of an electric vehicle.

This final project discussed about the concept of user interface and user experience to design a dynamic display for BMS display installed in dashboard panel. A literature study of BMS display on various existing brands of EV was conducted to know BMS display preference. Expert’s judgement was also applied to give judgement towards respondent’s preference score result.

Research resulted that the pair-comparison questionnaire of dynamic display alternatives for battery state of charge were consistent, proven by the consistency level by Amman and Greenberg, while the pair-comparison questionnaire of dynamic display alternatives for battery voltage screened-out data from 1 (one) respondent due to low consistency.

The experiment showed respondent’s highest preference scores of dynamic visualizations for battery state of charge is digital with check reading and analog-semicircular with check reading for dynamic visualization of battery voltage. Expert's judgment stated that analogue semi-circular with check reading is the most preferred display for battery state of charge and digital display with check reading for battery voltage. The most influential design factors for BMS dynamic display are the check reading availability (in form of color) and design style.

Key words: *dynamic visualization, battery management system, pair comparison, safe operating area, interface*

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PREFACE

All praises to Allah God Almighty that has been giving His blessing to the author. By His mercy and His blessing, author could finish the final project report entitled "**Designing Dynamic Visualization of Battery Management System for an Electric Vehicle**" on time that this book had been published. This final project was made as a completion of the undergraduate education in Industrial Engineering Department at Institut Teknologi Sepuluh Nopember, Surabaya.

Grateful acknowledgement is here made to some parties who have assisted author in this research. Those parties are as follow:

1. Ratna Sari Dewi, S.T., M.T., Ph.D. as the supervisor of this research. Her knowledge, advise and generous affection helped the author.
2. Stefanus Eko Wiranto, S.T., M.T. (Financial Manager of PUI SKO ITS), Indra Sidharta S.T., M.Sc. (Director of R&D PUI SKO ITS), and Agus Mukhlisin S.T., M.T. (Engineer of Battery Pack BMS and Controller of PUI SKO ITS), and other respondents as the interviewee who helped giving a valuable data for this research.
3. Dr. Adithya Sudiarno, S.T., M.T. and Anny Maryani., S.T., M.T. as the reviewer of this research. Their critical point of view and constructive comments complemented to this research.
4. Nurhadi Siswanto, S.T., MSIE., Ph.D. as the Head of Industrial Engineering Department, Yudha Andrian Saputra, ST., MBA as the Secretary of Industrial Engineering Department, and Dr. Adithya Sudiarno, S.T., M.T. as the Coordinator of Final Project in Industrial Engineering Department.
5. Author's beloved family and friends who never stop giving support, motivation, facilities, and inspiration to the author.

Surabaya, January 20th, 2018

Ninda Lastri Yulia

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CHAPTER 1
INTRODUCTION

This chapter will be described some points that are fundamental for this research. Research background, objectives, benefits, assumptions and limitations are described.

1.1 Research Background

According to Reunanen (2013), dynamic visualization is simply defined as those representations that go beyond traditional static forms, such as printed media. It can be characterized by either animation, interaction, or real-time circumstances. Powerful visualizations of scientific phenomena and more abstract information can be produced by using current advanced information technology and graphics (Card, et al., 1999). It makes perception that there should be a benefit of dynamic over static media (Hegarty, 2004). Lowe (1999) stated that dynamic media allow us to show processes explicitly. There are several strengths possessed by dynamic visualization (Reunanen, 2013). The greatest strength of dynamic visualization is its ability to create different views to the same data. Besides, the real-time nature become another strength of dynamic visualization. In addition to become a tool for communication, dynamic visualization plays role as a tool for exploration which are grouping and regrouping of variables, highlighting and filtering support decision-making.

However, Hegarty revealed that the first phase of research examining differences between dynamic and static displays failed to show a clear advantage for dynamic displays. From over 20 studies that compared static and animated graphics, most of them indicated that there was no advantage of animations over static graphics (Tversky, et al., 2002). A small number of studies showed such an advantage, but in these studies, more information was presented in the animated graphics than in the static graphics, i.e., they were not informational equivalent. This leads us to the much more interesting and challenging issues of understanding what conditions must be in place for dynamic visualizations to be effective.

1.2 Problem Identification

Problems to be discussed in this research is the preferred display of battery management system for EV drivers in the future and what dynamic factors affecting it, and generating a design alternative for Integrated BMS display.

1.3 Research Objectives

The research objectives of final project are:

1. Identifying dominant function parameters of BMS that must appear in a BMS interface of an EV.
2. Identifying dynamic display of BMS function parameters for an EV.
3. Getting expert's judgement regarding display alternative for BMS function parameters.

1.4 Research Benefits

The research benefits of final project are:

1. Provide data of BMS interface preferences in an EV.
2. Help EV manufacturers in the near future to determine functions/indicators that must be included in BMS interface.
3. Help EV manufacturers in the near future to design BMS interface considering the concept of user interface and user experience.

1.5 Research Scope

This subchapter discusses the limitations and assumptions used in final project.

1.5.1 Limitations

Limitations of this final project are:

1. This research only focuses on the design process of dynamic display alternatives of two function parameters of an integrated BMS, without installing and integrating it to both the whole integrated BMS display and to EV dashboard.
2. The usability of Integrated BMS dynamic display alternatives are not

measured.

1.5.2 Assumptions

Assumptions used in this final project are:

1. According to voting theory in Pacuit (2016), the voters' opinions are described by linear rankings of the set of candidates.
2. The result for alternatives of dynamic display of both battery state of charge and voltage is ranked linearly.
3. The circular triad (inconsistency) of respondent's preference score are randomly generated.

1.6 Writing Systematics

The writing systematic that is used in this final project consists of:

CHAPTER 1: INTRODUCTION

This chapter explains the research background, problem identification, research objectives, research benefits, research scopes and writing systematic of final project.

CHAPTER 2: LITERATURE REVIEW

This chapter discusses the theoretical and conceptual literatures used as the framework of thinking in final project.

CHAPTER 3: RESEARCH METHODOLOGY

This chapter contains overview and description of systematic processes to compose this final project.

CHAPTER 4: DATA COLLECTION AND PROCESSING

This chapter explains how data are collected and how it is processed to gather certain information. Data processing used approaches to obtain the research objectives. The result of data processing will be analyzed in the next chapter.

CHAPTER 5: DATA ANALYSIS AND INTERPRETATION

This chapter contains the analysis and interpretation of data that has been processed in chapter 4.

CHAPTER 6: CONCLUSION AND SUGGESTION

This chapter contains the result of research that refers to data process and analysis so that the research objectives can be obtained. In addition, this chapter contains suggestions to improve the further research.

CHAPTER 2
LITERATURE REVIEW

This chapter explains about the theories that are related and used in supporting this research.

2.1 Electric Vehicle (EV) and Battery Management System

This subchapter will explain about electric vehicle, battery management system, user experience design, user interface design, pair comparison basic, and dynamic display.

2.1.1 Electric Vehicle (EV)

Electric vehicle has the basic meaning of all vehicles driven by electrical energy source. Aside from the other definitions available, in this research electric vehicle is a system with the power source of battery which is charged by activating one or more of the automobile's electric motors (Udaeta, et al., 2015)

According to Volkswagen Group of America, Inc. (2013), the electric drive system generally consists of:

- High-voltage battery with control unit for battery regulation and charger
- Electric motor/generator with electronic control (power electronics) and cooling system
- Transmission including the differential
- Brake system
- High-voltage air conditioning for vehicle interior climate control

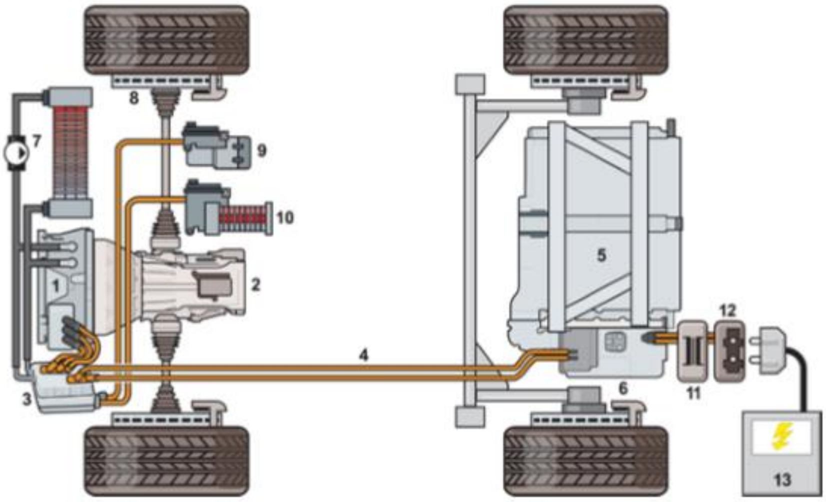

Figure 2.1 Electric Vehicle Components

Notes:

1 Electric motor/generator

2 Transmission with differential

3 Power electronics

4 High-voltage lines

5 High-voltage battery

6 Electronics box with control unit for battery regulation

7 Cooling system

8 Brake system

9 High-voltage air conditioner compressor

10 High-voltage heating

11 Battery charger

12 Charging contact for external charging

13 External charging source

2.1.2 Battery Management System

Battery management system (BMS), which is installed on an EV dashboard, plays as the connector between the battery and the vehicle. It portrays a vital role, such as improving battery performance and optimizing vehicle operation in a safe and reliable means. It is crucial to develop a comprehensive and mature BMS, as it is with an engine management system in a gasoline car. The battery's state of the safety, usage, performance, and longevity should be presented in BMS indicators (Xing, 2011). The battery is risky to ignite when overcharged due to its volatility, flammability and entropy changes. In additional, over-discharge leads the cell capacity to reduce because of irreversible chemical reactions. It becomes a serious problem, since an explosion could cause a fatal accident (Stuart, et al., 2002 at (Xing, 2011).

Xing (2011) also stated the importance of monitoring and controlling the safety circuitry within the battery packs of BMS. When over-voltage, overheating, or any other abnormal conditions are detected, the BMS shall alert the user and perform the preset correction procedure. To accommodate a better power consumption scheme, and communicates with individual components and operators, BMS also needs to monitor the system temperature. In other words, a comprehensive BMS integrated in the dashboard system should include the following functions:

1. Data acquisition
2. Safety protection
3. Ability to determine and predict the state of the battery
4. Ability to control battery charging and discharging
5. Cell balancing
6. Thermal management
7. Delivery of battery status and authentication to a user interface
8. Communication with all battery components
9. Prolonged battery life

A good BMS installed on the dashboard should be designed to facilitate safe steering experiences. The whole interface should be user-friendly and functional rich. When smart and safe vehicle concept is put into consideration, a good dashboard shows its importance in integration to give intelligent guidance to the EV driver (Hu & Yeh, 2015).

Hu & Yeh (2015) also stated that the statuses (e.g. speed, battery SOC, braking, and mileage) can be seen and monitored in all driving scenarios. Taking them into an example, when there is an overload problem, an electric vehicle would face the danger of self-ignition problem. These fatal conditions can be eliminated by a guard of smart interface. The presented system can assist the driver to keep the energy efficiency, steering stability, and others under a proper design. Additionally, a graphical view is utilized to present the safety related information for an easy and quick comprehension. Next, a simplified operation procedure can be used so the driver can concentrate more on steering. The smart system can perform customization, which cannot be found on commercial dashboard.

The smart system is an intelligent, multipurpose, and user-friendly information revealing system, which not only display the vehicle's status such as speed, temperature, mileage, and functions but also show the current safety evaluations of steering. For electric vehicle, the management of battery packs' state of charge (SOC) is also an urgent issue. Therefore, such monitoring system is necessary to overcome the safety issue.

2.1.3 Building Blocks of a Battery Management System

A typical battery management system consists of several functional blocks, such as cutoff cut-off field-effect transmitters (FETs), a fuel gauge monitor, cell voltage monitor, cell voltage balance, real time clock (RTC), and temperature monitors (Intersil Corporation, 2015). Below are the explanations of each building block:

a. **Cutoff FETs and FET Driver:** A FET driver functional block is functioned as the connection and isolation of the battery pack between the load and charger. The behavior of the FET driver is determined by the measurements from battery cell voltages, current measurements and real-time detection circuitry.
b. **Fuel Gauge / Current Measurements:** The fuel gauge functional block keeps track of the charge entering and exiting the battery pack. Charge is the product of current and time.
c. **Cell Voltage and Maximizing Battery Lifetime:** Monitoring the cell voltage of each cell within a battery pack is essential in determining its overall health. All cells have an operating voltage window that charging, and discharging should occur to ensure proper operation and battery life. If an application is using a battery

with a lithium chemistry, the operating voltage typically ranges between 2.5V-4.2V. The voltage range is chemistry dependent. Operating the battery outside the voltage range significantly reduces the lifetime of the cell and can render the cell useless.

d. **Temperature Monitoring:** Today's batteries deliver a lot of current while maintaining a constant voltage, which can lead to a runaway condition that causes the battery to catch fire. The chemicals used to construct a battery are highly volatile, and a battery impaled with the right object can result in the battery catching fire. Temperature measurements are not just used for safety conditions, they can also be used to determine if it's desirable to charge or discharge a battery. Temperature sensors monitor each cell for energy storage system (ESS) applications or a grouping of cells for smaller and more portable applications. Thermistors powered by an internal ADC voltage reference are commonly used to monitor each circuit's temperature. The internal voltage reference is used to reduce inaccuracies of the temperature reading versus environmental temperature changes.

2.2 User Experience Design

User experience covers all facets of the end-user's interaction with the company, its services, and its products (Norman & Nielsen, 2016). User experience design is a study from various fields, such as computer science, cognitive science, ergonomics, art and graphic design, psychology, communications, anthropology, and others (Manca, 2015).

Furthermore, Manca wrote that the basis of user experience design is based on a comprehension of the needs, values, abilities, and limitations of a user. A user-experience designer is required to manage the expectations of company while taking care the user's needs. This requires considering business and product goals, as well as the developers' objectives.

Peter Morville (2004) defines the factors influencing user experience in developing an interface by using User Experience Honeycomb.

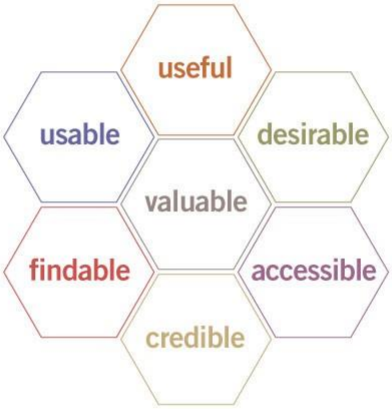

Figure 2.2 User Experience Honeycomb

Below is the elaboration of the user experience honeycomb:

1. **Useful:** A user experience designer must have the courage and creativity to ask whether a products and systems are beneficial, and to apply the knowledge of craft and medium to describe innovative solutions that are more effective.
2. **Usable:** Quality attribute that assesses the easiness to use a product by user. The term also refers to methods to improve ease-of-use during the design process (Nielsen, 2012).
3. **Desirable:** Encompasses all elements of emotional design that accompany the efficiency of product, such as image, identity, brand, and others.
4. **Findable:** The ability to design navigable interface and locatable objects in order for users to be able finding what they need.
5. **Accessible:** An interface should be accessible to disable people, considering its also ethical to implement it.
6. **Credible:** Concept which can defined as believability, trust, perceived reliability, and alike (Self 1996 in (Freeman & Spyridakis, 2004).
7. **Valuable:** Delivering value to sponsors. For non-profits, the user experience must master the mission. While for-profits, it has to contribute to the bottom line and improve customer satisfaction.

The diagram above explains about the designer's view of user interface. Peter Morville (2004) also developed design elements for user experience in the view of user.

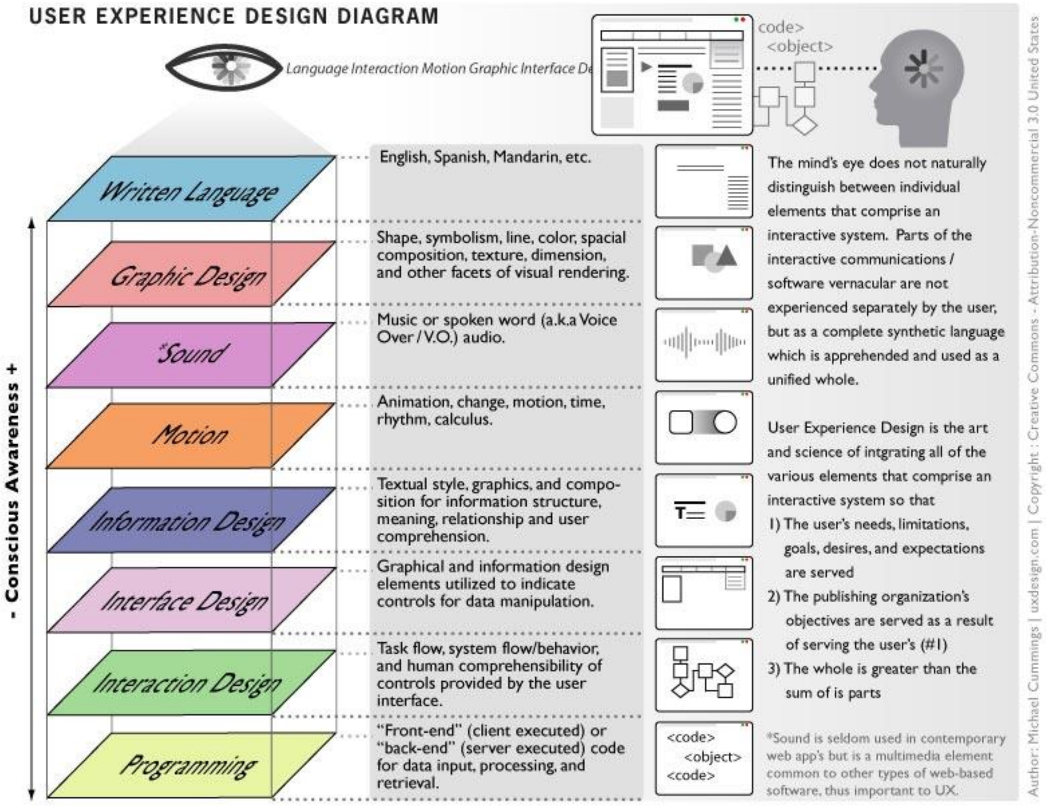

Figure 2.3 User Experience Design Diagram (http://uxdesign.com/about-user-experience-design/article/what-is-ux/4)

2.3 User Interface Design

User Interfaces (UIs) have already existed since the beginning invention of computers, even before Human-Computer Interaction (HCI) was coined (Jørgensen & Myers, 2008). It helps users to carry out information communication efficiently with computers to complete their tasks (Ping & Xing, 2008). Ping and Xing (2008) also added that since UI design is an essential component of HCI system, software designers hold great burden to develop interfaces that predict and interpret the operator's needs effectively besides allowing the user to carry out tasks in natural ways (Frankish, et al., 1996).

2.4 Paired Comparison Basic

A paired comparison is a binary choice which presenting all possible pairs of a set of stimuli, or items, for respondent to be judged. Thus, the respondent chooses for each pair the item that better satisfies the specified choice criterion (for example, more preferred, more serious, more beautiful). With paired comparisons, respondents choose the item in each pair with the greater magnitude on the choice dimension they were guided to use. The simplest approach is to present all possible pairs of the items to each respondent. With t items, there will be total t(t – 1)/2 pairs (Brown & Peterson, 2009).

Champ, et al., (2003) stated that a preference score, which is the number of times the respondent preferred the item to other items in the set, will be resulted from each respondent for each item in the full set of choices. Preference scores are the simplest form of scale values for the items. These scores are easily calculated by creating a t by t matrix and entering a 1 in each cell where the column item was preferred to the row item, or a 0 otherwise.

Column sums provide the preference scores. As can be seen on Table 2.4, there is a hypothetical matrix for a 10-item choice set. Preference scores, at the bottom of the matrix, indicate that, for example, item 5, with a preference score of 7, was selected seven of the nine times it came up among the choices. Mathematically stated, the preference score, or the column sum of an item is:

$$a_c = \sum_{r=1}^{t} a_{rc} \qquad (2.1)$$

Where a_{rc} is the cell score (either 0 or 1) for a given row (r) and column (c). The row sum is:

$$a_r = \sum_{c=1}^{t} a_{rc} = (t-1) - a_c \qquad (2.2)$$

As presented in equation 2, row sums are a mirror image of column sums. A respondent's vector of preference scores explains the individual's preference order among the items in the choice set, with larger integers indicating more preferred items. The number of items in the set determines the preference score range, which is always from 0 to t–1. So, for 10 items, the range is from 0 to 9.

- Raw choice matrix

item	1	2	3	4	5	6	7	8	9	10	sum
1	--	0	0	1	1	1	1	1	1	1	7
2	1	--	1	1	1	1	1	1	1	1	9
3	1	0	--	1	1	1	1	1	1	1	8
4	0	0	0	--	0	0	0	0	1	0	1
5	0	0	0	1	--	0	0	0	1	0	2
6	0	0	0	1	1	--	1	0	1	1	5
7	0	0	0	1	1	0	--	0	1	1	4
8	0	0	0	1	1	1	1	--	1	1	6
9	0	0	0	0	0	0	0	0	--	0	0
10	0	0	0	1	1	0	0	0	1	--	3
sum:	2	0	1	8	7	4	5	3	9	6	

Figure 2.4 A perfectly consistent individual choice matrix for 10 items (C = 0, g = 1.0)

The difference between the preference scores of items in a pair is the *preference score difference* (PSD) for each respondent. This integer can range from 0 to t–1. A *circular triad* is an intransitive preference order among three items. For example, three binary choices among items i, j, and k may produce the following order: k > j > i > k. Any of the three choices could be the cause of the circular triad. If an individual respondent is sampled only once, a lack of internal reliability can be discovered only if it causes one or more circular triads. In the case of a 10-item choice set, an individual's preference score vector with no circular triads contains all 10 integers from 0 through 9 (Figure 2.4). If the double-sort matrix contains no circular triad it will have a "1" in all the cells above (and thus to the right of) the principal diagonal and a "0" in all cells below the principal diagonal. Figure 2.5 shows a 10-item data set identical to that of figure Figure 2.6, except that the choice between items 3 and 7 has been reversed (item 3 was chosen instead of item 7, whereas in Figure 2.4, item 7 was chosen). This reversal produces three circular triads.

- Raw choice matrix

item	1	2	3	4	5	6	7	8	9	10	sum
1	--	0	0	1	1	1	1	1	1	1	7
2	1	--	1	1	1	1	1	1	1	1	9
3	1	0	--	1	1	1	0	1	1	1	7
4	0	0	0	--	0	0	0	0	1	0	1
5	0	0	0	1	--	0	0	0	1	0	2
6	0	0	0	1	1	--	1	0	1	1	5
7	0	0	1	1	1	0	--	0	1	1	5
8	0	0	0	1	1	1	1	--	1	1	6
9	0	0	0	0	0	0	0	0	--	0	0
10	0	0	0	1	1	0	0	0	1	--	3
sum:	2	0	2	8	7	4	4	3	9	6	

Figure 2.5 An individual choice matrix with three circular triads (C = 3, g = 0.93)

- Double sorted matrix

item	2	1	3	8	6	7	10	5	4	9	sum
2	--	1	1	1	1	1	1	1	1	1	9
1	0	--	0	1	1	1	1	1	1	1	7
3	0	1	--	1	1	0	1	1	1	1	7
8	0	0	0	--	1	1	1	1	1	1	6
6	0	0	0	0	--	1	1	1	1	1	5
7	0	0	1	0	0	--	1	1	1	1	5
10	0	0	0	0	0	0	--	1	1	1	3
5	0	0	0	0	0	0	0	--	1	1	2
4	0	0	0	0	0	0	0	0	--	1	1
9	0	0	0	0	0	0	0	0	0	--	0
sum:	0	2	2	3	4	4	6	7	8	9	

Figure 2.6 An individual choice matrix with three circular triads (C = 3, g = 0.93)

2.4.1 Reliability

The reliability of pair comparison (Brown & Peterson, 2009) can be defined in three concepts, which are consistency, internal reliability, and test-retest reliability. Consistency is a theoretical entity in that the expected values upon which this measure is based are non-observable. Internal reliability and test-retest reliability are empirical measures.

a. Consistency

Consistency measures the respondent's ability to make binary choices that are consistent with the expected values of the items in each pair.

b. Internal reliability

It questions whether a respondent's binary choices between items taken in pairs from a set of items are in agreement with each other, that is, whether they produce intransitivity as manifest by circular triads. Internal reliability refers to the level of agreement among a given respondent's choices and is thus a between-choice measure. A common measure of internal reliability is based on the number of circular triads among a respondent's choices. The causes of circular triads in a paired comparison experiment include:

1. Respondent inability to consistently discriminate between similar items
2. Dominance of different attributes in different pairs (for multi attribute pair-comparison only)
3. Order effect
4. Respondent carelessness (a mistake in indicating a choice), incompetence (lack of understanding of the task), or intentional misrepresentation of preferences.

For the purpose of this final project, it is assumed that all observed circular triads are randomly generated. Kendall and Smith (1940) in Brown and Peterson (2009), defined the way to find the coefficient of internal reliability, which are:

1. Calculate the number of circular triads in an individual's responses from the preference scores with formula:

$$C = \frac{t}{24}(t^2 - 1) - \frac{1}{2}\sum(a_i - b)^2$$

C : number of circular triads from an individual's responses

t : number of items in the set

a_i : preference score of item i

b : average preference score, $\frac{t-1}{2}$

2. Calculate maximum possible number of circular triads

$$C_{\max} = \frac{t(t^2 - 1)}{24}, \quad t\ odd,$$

$$C_{\max} = \frac{t(t^2 - 4)}{24}, \quad t\ even.$$

C_{max} : maximum number of possible circular triads

t : number of items in the set

3. Calculate the coefficient of individual's internal reliability.

$$\zeta = 1 - \frac{C}{C_{\max}}$$

ζ : coefficient of internal reliability

C : number of circular triads from an individual respondent

C_{max} : maximum number of possible circular triads

This measure requires that all possible pairs of items in the set have been judged and varies between 1 for no circular triads and 0 for the maximum possible number. The criterion of individual's reliability $\zeta < 0.6$ will be used to screen out unreliable participant (Parizet, 2002; Amman & Greenberg, 1999)

c. Test-retest reliability (the usual meaning of reliability):

Test-retest reliability asks about the degree of agreement between choices for identical pairs presented at different times.

2.5 Voting Method

Voting is an easy application that widely used widely to choose options (Burgman, et al., 2014). Different voting systems can come up with different outcomes, even under the same preferences. Yet, voting systems often are used unthinkingly and many people are unaware of the effect of choosing one voting system. Common voting system allocates one vote per participant, and the most voted option will be the chosen alternative.

Another property of voting systems is the probability to select the alternative that would defeat every other alternative in one-on-one (pairwise) comparisons. It may be important that all members of the group understand how the voting system works (Burgman, et al., 2014). Burgman also wrote the properties of voting systems as follows:

1. Homogeneity: The outcome of a vote depends on the proportions of the total number of votes assigned to each alternative, and not on their

absolute counts.

2. Monotonicity: A winning alternative cannot become a loser by increasing its number of votes for, and a losing alternative cannot become a winner when its number of votes decreases.
3. Anonymity: Voters are treated the same in the sense. If any 2 individuals trade their votes, the outcome would be the same.
4. Decisiveness: The voting system delivers an unambiguous winner or a winning set, if more than one alternative is desired.
5. Consistency: If a group is divided into subgroups and each subgroup selects the same alternative, then the entire group also selects that alternative.
6. Invulnerability to the no-show paradox: It is not possible for a group of voters to obtain their first-ranked choice by abstaining if voting would lead to the selection of some other option.

Below is the example of the application of voting method (Pacuit, 2016).

- There is a group of 21 people, or voters, who need to make a decision about which of four options, should be elected.
- Let A, B, C and D denote the four different candidates.
- Decide how to represent the voters' opinions about the set of candidates. Here the voting theory assume that the voters' opinions are described by linear rankings of the set of alternatives (describing the voters' ordinal preference orderings).
- For this example, assume that each of the voters has one of four possible rankings of the alternatives. The information about the rankings of each voter is given in the following table.

Table 2.1 Example of Voting Result (Pacuit, 2016)

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

- Each column represents a ranking in which candidates in lower rows are ranked lower.
- The numbers at the top of each column indicate the number of voters with that particular ranking.
- One alternative who, at first sight, seems to be a good choice to win the election is alternative A. Alternative A is ranked first in more of the voters' rankings than any other candidate. (A is ranked first by eight voters, B is ranked first by seven; C is ranked first by six; and D is not ranked first by any of the voters.) That is, more people think that A is better than any other candidate.
- 13 people rank A *last*, a much larger group of voters will be unsatisfied with the election of A. So, it seems clear that A should *not* be elected. None of the voters rank D first, which suggests that D is also not a good choice. The choice, then, boils down to B and C.
- Here, there are good arguments for each of B and C to be elected. This echoes an 18th-century debate between the two founding fathers of voting theory, Jean-Charles de Borda (1733–1799) and M.J.A.N. de Caritat, Marquis de Condorcet (1743–1794). For a precise history of voting theory as an academic discipline, including Condorcet's and Borda's writings. Below is the sketch of the intuitive arguments for the election of B and C.
- *Alternative C should win*. Initially, this might seem like an odd choice since C received the fewest number of first-place rankings. However, C is a strong choice because it beats every other candidate in a one-on-

one election. To see this, it is necessary to observe how the population would vote in the various two-way elections:

Table 2.2 Rank of Votes (Pacuit, 2016)

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

13 rank C above A; 8 rank A above C

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

11 rank C above B; 10 rank B above C

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

15 rank C above D; 7 rank D above C

- The idea is that C should be declared the winner since it beats every other alternative in one-on-one elections. An alternative with this property is called a **Condorcet winner**.
- *Alternative B should win*. Consider B's performance in head-to-head elections.

Table 2.3 Rank of Votes (Pacuit, 2016)

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

13 rank B above A; 8 rank A above B

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

10 rank B above C; 11 rank C above B

# Voters			
3	**5**	**7**	**6**
A	A	B	C
B	C	D	B
C	B	C	D
D	D	A	A

21 rank B above D; 0 rank D above B

- Alternative B came up with result the same as C in a head-to-head election with A, loses to C by only one vote and beats D in a landslide (everyone prefers B over D). Both Condorcet and Borda suggest comparing alternatives in one-on-one elections in order to determine the winner. While Condorcet tallies how many of the head-to-head races each alternative wins, Borda suggests that one should look at the margin of victory or loss. According to Borda, each alternative should be assigned a score representing how much support he or she has among the electorate. One way to calculate the score for each alternative is as follows:

- A receives 24 points (8 votes in each of the three head-to-head races)
- B receives 44 points (13 points in the competition against A, plus 10 in the competition against C plus 21 in the competition against D)
- C receives 38 points (13 points in the competition against A, plus 11 in the competition against B plus 14 in the competition against D)
- D receives 20 points (13 points in the competition against A, plus 0 in the competition against B plus 7 in the competition against C)
- The alternative with the highest score (in this case, B) is the one who should be elected.
- The conclusion is that in voting situations with more than two alternatives, there may not always be one obvious candidate that "best reflects the will of the people."

2.6 Dynamic Display

Dynamic visual environments have been gaining increasing importance to represent intricate ideas and communication (Plass, et al., 2009). Dynamic visualizations, or animations, are often seen as a natural alternative to tell concepts that alter over time (Hegarty, 2004). It is very important to go beyond making a simple distinction between static and dynamic displays, because there are in fact many different types of dynamic displays (Hegarty, 2004).

One of them is identified in three types of dynamic representations: transformations (physical properties of an object are altered, such as size, shape, colour, and texture), translations (objects are moved from one place to another), and transitions (objects appear or disappear, either fully or partly) (Lowe, 2003; Lowe, 2004). Another type of dynamic representations is expressed by Ainsworth and

VanLabeke (2004). They stated these types are time-persistent (explain the relation between at least one variable), time-implicit (present a range of values with no specific time frame), and time-singular (displaying one or more variables at a single point in time). These different categorizations all share the notion that dynamic visualizations display the process of change over time, whether time is explicitly expressed or not.

Hegarty (2004) wrote that a realistic animation of a visible phenomenon is one of dynamic display type. This dynamic display type is presenting processes visible in real world, such as world machine in motion animation. On top of that, dynamic display can ‘‘envision’’ invisible entities that are spatially distributed, for example changes in pressure or temperature on a weather map (Lowe, 2004). Dynamic displays are also able to portray abstract information, such as statistical concepts, changes in population over time, or computer algorithms.

2.6.1 Dynamic Display Basic Design

According to Sanders & McCormick (1992), the basic design of dynamic display consists of several designs described below.

a. Quantitative readings: The display is used to read a precise numeric value. For example, a quantitative reading would precede a response such as "The pressure is 125 psi."
b. Qualitative readings: The display is used to read an approximate value or to discern a trend, rate of change, or change in direction. For example, a qualitative reading would result in a response such as "The pressure is rising."
c. Check readings: The display is used to determine if parameters are within some "normal" bounds or that several parameters are equal. For example, check reading would elicit a response such as "All pressures are normal."
d. Situation awareness: The display (a representation of some physical space) is used to perceive and attach meaning to elements in a volume of time.

Green (1988) listed the recommendations for the design of automotive displays, in particular gauges to help designers develop displays that are easy to use.

- **Display Type**

Rule 1. The display that is easiest to use depends on the task for which it is intended. In general, when an exact number is required, a numeric display should be provided. When the primary task is-check reading, a moving pointer display is best.

a. Recommendation 1: For motor vehicles a numeric display is preferred for the speedometer.

b. Recommendation 2: The engine and fuel gauges should be moving pointer displays.

- **Display Format**

Rule 2. When a group of moving pointer displays are to be check read, they should be arranged so their pointers are aligned when they all show normal values.

a. Comment: There is considerable discussion in the literature as to which position is best. The key is consistency, with alignment at 9 or 12 o'clock being most common for circular displays. For arc meters and horizontal and vertical scales, alignment of pointers is straightforward.

b. Recommendation 3: When more than one engine gauge is on the instrument panel, they should be close to each other and arranged so their pointers are aligned when all show normal values. They should not be grouped with the fuel gauge.

Rule 3. For quantitative reading, the ranking of moving pointer displays from best to worst is: circular, arc, horizontal, vertical.

a. Comment: This rule is based on laboratory data in which visual search is not required. It assumes that reading time is strongly influenced by how far the pointer tip is from the fixation point.

Rule 4. For check reading, the differences between moving pointer displays are small with vertical displays tending to be more difficult to read.

a. Comment: Both quantitative and check reading performance are markedly affected by the compatibility of the pointer motion and the associated response. So, for example, a design that required users to move a switch up when the pointer moves down would be a poor.

- **Scale Marks**

Rule 5. Scale marking considerations are less important than the choice of the proper display and the alignment of pointers for check reading.

Rule 6. For zero-based numbers, scales should be marked with values greater than 1 and numbered in even multiples of 10 (0, 10, ... or 0, 100, ..., etc.) when an exact number is desired. Easy to use displays are ones which minimize the number of mental operations a viewer is required to complete to interpret them. Nondecimal schemes (0, 2.5,. .., or 0, 1.7, 3.4, ..., etc.) are much more difficult for people to understand.

a. Recommendation 4: Moving pointer speedometers for production vehicles should be numbered in increments of 10, not 20 mph. It is not clear, however, if numbers should be associated with fives or tens. Numbering the tens is compatible with how people process numbers but incompatible with the way speed limits are posted (35 mph, 55 mph, etc.). Research to address this question should be conducted.

b. Comment: Recommendation 1 takes precedence over Recommendation 4. Numeric speedometers are preferred over moving pointer speedometers.

c. Comment: Many automotive engine displays are not zero-based for normal operation. For example, engine temperature displays (which are usually check read) almost never show values between 0 and 140 degrees when the engine is running. The same is true for electrical system voltage, which is invariably 13.5 volts, plus or minus 2.5 volts. Therefore, this rule does not apply to these displays.

d. Recommendation 5: If labelled with numbers, other engine gauges (oil pressure, oil level, electrical system current) should have the zero-point labelled and numbered with 1's or 10 ' s as appropriate.

Rule 7. Scale marks should be provided down to the level to which a display must be read. If a speedometer is to be read to the nearest mph, then marks showing the units should be provided. If it is read to the nearest 5 mph, then only marks at that level should be provided. It is not clear how accurately speedometers are read. That issue should be investigated experimentally.

Rule 8. Scale marks should not appear at non-integer points on a scale unless the values being displayed are not integers. According to this rule, tick marks on a speedometer in 2.5 mph increments (i.e., halfway between 5 and 10) are ill advised. Non-integer markings add to the mental effort required to read a display and make it more difficult to read.

e. Recommendation 6: Provided normal is clearly shown (e.g., range marks labelled with "ok"), it does not matter how engine gauges are labelled. Numbers, words, abbreviations, and symbols are equally informative, and any of them can be used.

Rule 9. For displays that are check read, how a scale is marked once the normal range is shown tends not to be important.

f. Recommendation 6: Provided normal is clearly shown (e.g., range marks labelled with "ok"), it does not matter how engine gauges are labelled. Numbers, words, abbreviations, and symbols are equally informative, and any of them can be used.

Rule 10. For qualitative readings two anchors may be sufficient if the measured dimension is well understood by viewers.

g. Recommendation 7: It does not matter much how a fuel gauge is labelled. Drivers understand most of the common labels (E - F) and even some of the uncommon (0/4 - 4/4) labels nearly as well.

Rule 11. Dials should have breaks between 0 and the maximum. It is not clear how big they should be.

Rule 12. Marked intervals should be at least 1/2 inch apart. (Marked intervals are those points on the scale that have numbers, shown next to them, e.g., 0, 10, 20, etc.). Some have argued for intervals of an inch or more.

Rule 13. Scale marks should be separated by at least 1/10 inch.

Rule 14. Scale marks (and pointers) should be at least .03 inches wide. Should wider marks be used, they should always be considerably less than the gap between marks to avoid figure ground reversal problems.

Rule 15. It doesn't matter if scale numbers are on the inside or outside of a dial or on the same or different side of the scale as the pointer.

Rule 16. Nonstandard marking schemes (staircase tick marks, using log scales to linearize data) offer minor, if any, performance benefits.

Rule 17. Zone markings ("ok," "normal," etc.) should be provided on displays which are check read. They make displays much easier to check read. Labelling them with words or color bands is about equally effective.

h. Recommendation 7: Every engine gauge should have zone markings.

Rule 18. Normal zones should be colored green. Danger zones should be colored red. There is debate as to whether other zones should be white or yellow.

- **Pointers**

Rule 19. For electronic displays where multiple segments are used to represent a pointer, only a single segment should be illuminated. (A cursor design is easier to understand than a fill design.)

a. Comment: This rule has been experimentally verified for engine displays but not for speedometers. Of the rules listed for pointer design, this one is likely to have a major influence on performance and is an exception to Rule 4.

Rule 20. The gap between pointer tips and the associated tick marks should be between 0 and 1/4 inch for accurate quantitative or qualitative reading.

For check reading of multiple aligned displays, longer pointers should be provided.

b. Recommendation 8: For speedometers and fuel gauges, the gap should be 1/4 inch or less.

c. Recommendation 9: When multiple gauges for engine functions (temperature, oil pressure, etc.) are provided, longer pointers should be provided.

Rule 21. The pointer width near the tip should be about equal to minor mark width.

Rule 22. If scale marks are all one color, the pointer should be a different color that contrasts well with the marks and the background.

d. Comment: If the tick marks are multiple colors, this rule may not hold. This should be investigated experimentally.

2.6.2 Quantitative Visual Displays

Figure 5-2 illustrates a few important concepts in the design of quantitative displays. *Scale range* is the numerical difference between the highest and lowest values on the scale, whether numbered or not. *Numbered interval* is the numerical difference between adjacent numbers on the scale. *Graduation interval* is the numerical difference between the smallest scale markers. *Scale unit* is the smallest unit to which the scale is to be read. This may or may not correspond to the graduation interval. A medical thermometer, for example, usually is read to the nearest tenth of a degree, our conventional indoor and outdoor thermometer to the nearest whole degree, and some high-temperature industrial thermometers only to the nearest 10 or 100 degrees.

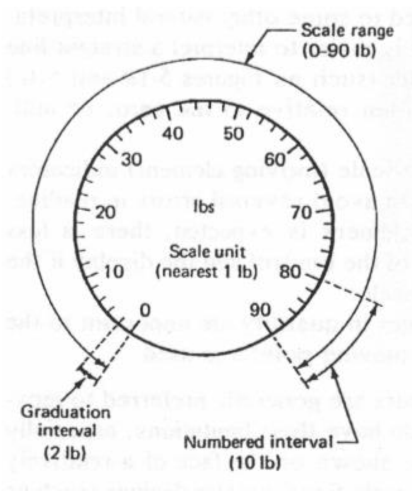

Figure 2.7 Illustration of Several Basic Concepts in The Design of Quantitative Displays

2.6.3 Qualitative Visual Displays

In using displays for obtaining qualitative information, the user is primarily interested in the approximate value of some continuously changeable variable (such as temperature. pressure, or speed) or in its trend, or rate of change. The basic underlying data used for such purposes usually are quantitative.

- Quantitative Basis for Qualitative Reading

Quantitative data may be used as the basis for qualitative reading in at least three ways: (l) for determining the status or condition of the variable in terms of each of a limited number of predetermined ranges (such as determining if the temperature gauge of an automobile is cold, normal, or hot); (2) for maintaining some desirable range of approximate values [such as maintaining a driving speed between 50 and 55 mi/h (80 and 88 km/h)]; and (3) for observing trends, rates of change, etc. (such as noting the rate of change in altitude of an airplane). In the qualitative use of quantitative data, however, evidence suggests that a display that is best for a quantitative reading is not necessarily best for a qualitative reading task. Some evidence for support of this contention comes from a study in which open-window, circular, and vertical designs are compared. In one phase of this study, subjects made qualitative readings of high, OK, or low for three ranges of numerical values and also employed the same three scales to make strictly quantitative readings. The average times taken show that, although the open-window (digital) design took the shortest time for quantitative reading, it took the longest time for qualitative reading. In turn, the vertical scale was best for qualitative reading but worst for quantitative reading. Thus, different types of scales vary in effectiveness for qualitative versus quantitative reading.

TIMES FOR QUALITATIVE AND QUANTITATIVE READINGS WITH THREE TYPES OF SCALES

	Average reading time, s	
Type of scale	Qualitative	Quantitative
Open-window	115	102
Circular	107	113
Vertical	101	118

Figure 2.8 Average Type for Qualitative and Quantitative Readings with Three Types of Scales

2.6.4 Dynamic Display Established Principles

Two design principles have been established which relate to the visual design of dynamic representations, the split-attention principle (Ayres & Sweller, 2005) and the contiguity principle (Mayer, 2005).

a. Split-Attention Principle

The split-attention principle means users' comprehension of multimedia materials is hindered when they have to split their attention between and mentally integrate several sources of physically or temporally disparate information, which is necessary for understanding the material (Ayres & Sweller, 2005). This effect occurs when a video is shown with subtitles, when animations presented with explanatory texts that change dynamically with the animation, or when a video and an animation are presented next to one another. People will only experience a split-attention effect if both sources of information are essential for deep understanding and are of a relatively high level of difficulty for them. In order to avoid slit attention in dynamic visualization, designers involve the placing of labels, instructions, and explanations next to the object to which they refer, placing related objects near one another, and avoiding the presentation of two dynamic sources of information (such as video and animation) at the same time (Plass, et al., 2009).

b. Spatial and Temporal Contiguity Principle

This principle describes how to provide related sources of information close to one another, rather than separated, improves learning by reducing extraneous visual search tasks (Plass, et al., 2009). Examples for this effect are narrations shown after the corresponding visual information was shown (temporal contiguity), or labels that are not integrated with the corresponding visualizations (spatial contiguity). Designers can avoid comprehension problems due to spatial contiguity by locating related objects next to another rather than far from each other, and problems due to temporal contiguity by presenting related information at the same time rather in succession.

c. Representation type of information

The consideration of the type of representation a designer will choose for key information is critical. The key information of a dynamic visualization design will be enhanced when it is represented in iconic (pictorial) form rather than only in symbolic (textual) form (Plass, et al., 2009). These are applied for materials that induce high cognitive load, and for someone who has low prior knowledge in the subject matter informed (Lee, et al., 2006; Plass, et al., 2009).

d. Color Coding

Color coding principle states that color used to highlight important features and attributes for instructional information of visual displays results in enhanced understanding. It emphasizes key design features and create connections between various sources of information along the media. It also may facilitate reductions in working memory and search requirement in simulations (Plass, et al., 2009).

2.7 State of The Art

A research conducted by Kim, et al. (2011) about designing dashboard display for driver. It describes how to design dashboard display so that it is able to support drivers, their information needs, and their cognitive capabilities. Furthermore, the study also what display design features that are critically linked to issues of divided attention and driving performance.

When designing a dashboard display, the following factors should be considered (Kim, et al., 2011).

a. Low clutter. Simple, low clutter designs should be used for the whole dashboard. Ample “white space” is needed, particularly between individual features of the dashboard.
b. Contrast of size. Reserve maximum contrast of size for the center panel, especially for the speedometer, since this feature is what drivers reference most often when driving.
c. Color. Use color for elements plus background fills, rather than for elements only. The contrast of size had more of an effect than color in increasing the performance of a design. Designs with color and fill performed about the same as designs with no color.

CHAPTER 3

RESEARCH METHODOLOGY

Chapter 3 explains the methodology of research. The methodology of this research consists of the sequential step to do this research. The step is systematically arranged according to research objectives.

3.1 Flowchart of Research Methodology

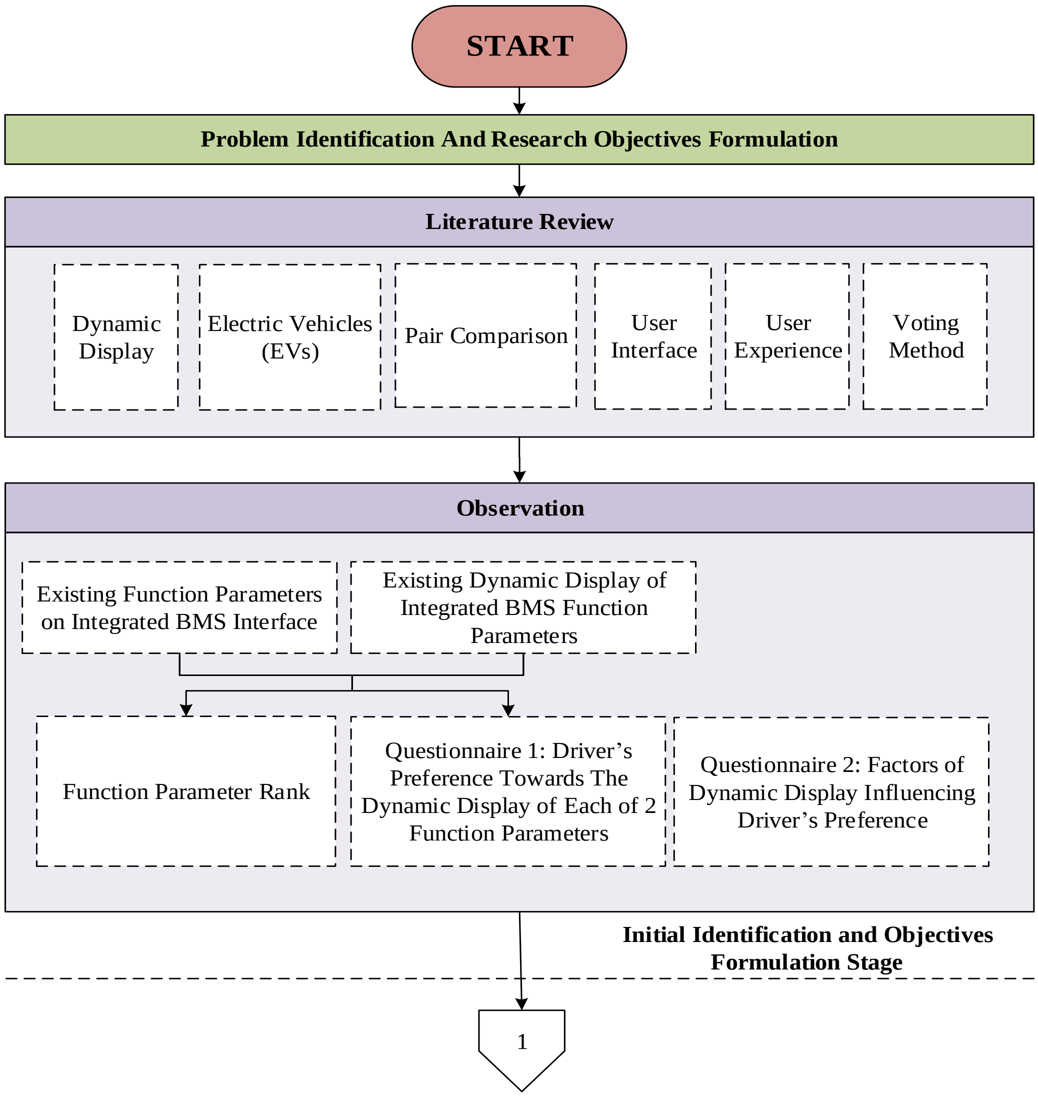

Figure 3.1 Research Methodology

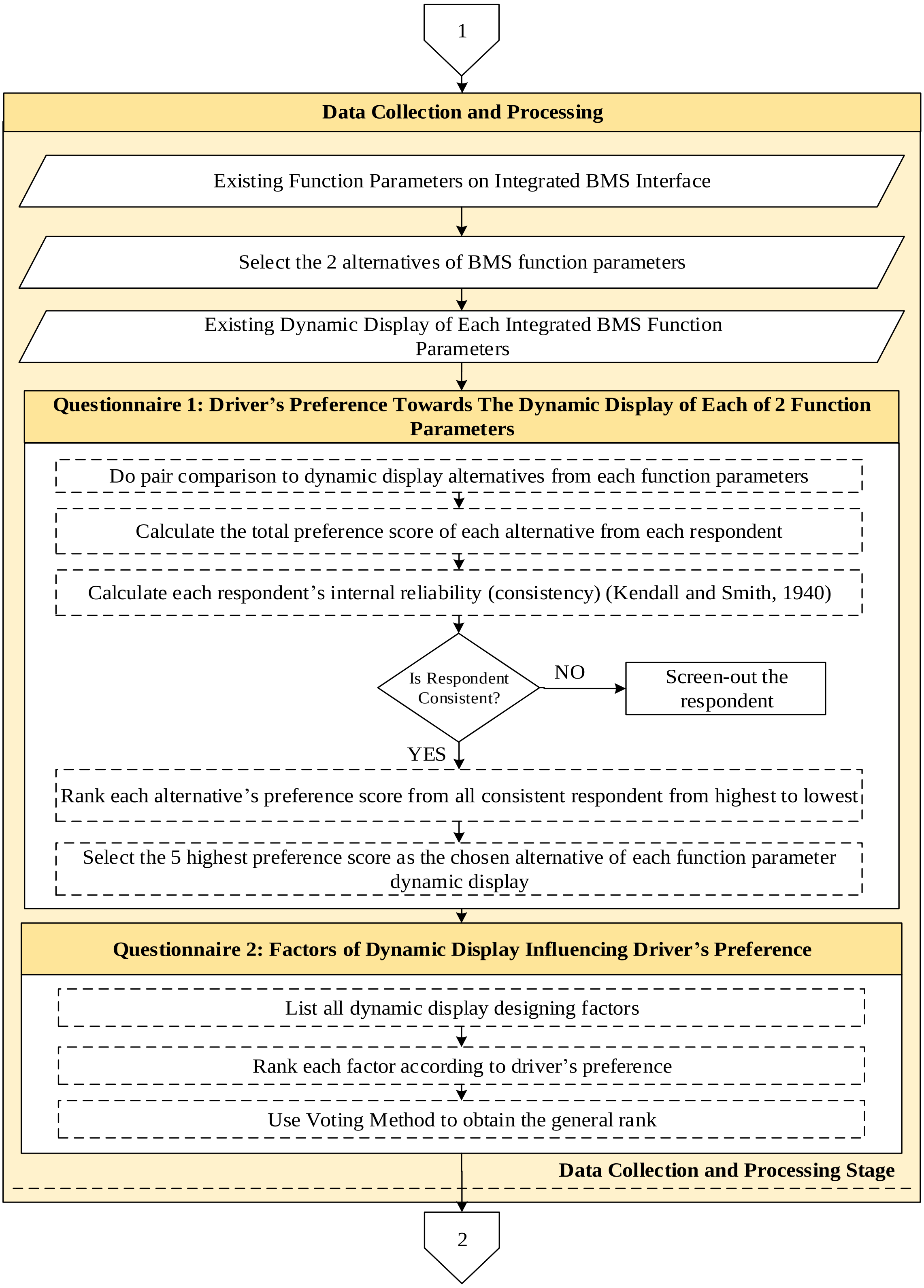

Figure 3.1 Research Methodology

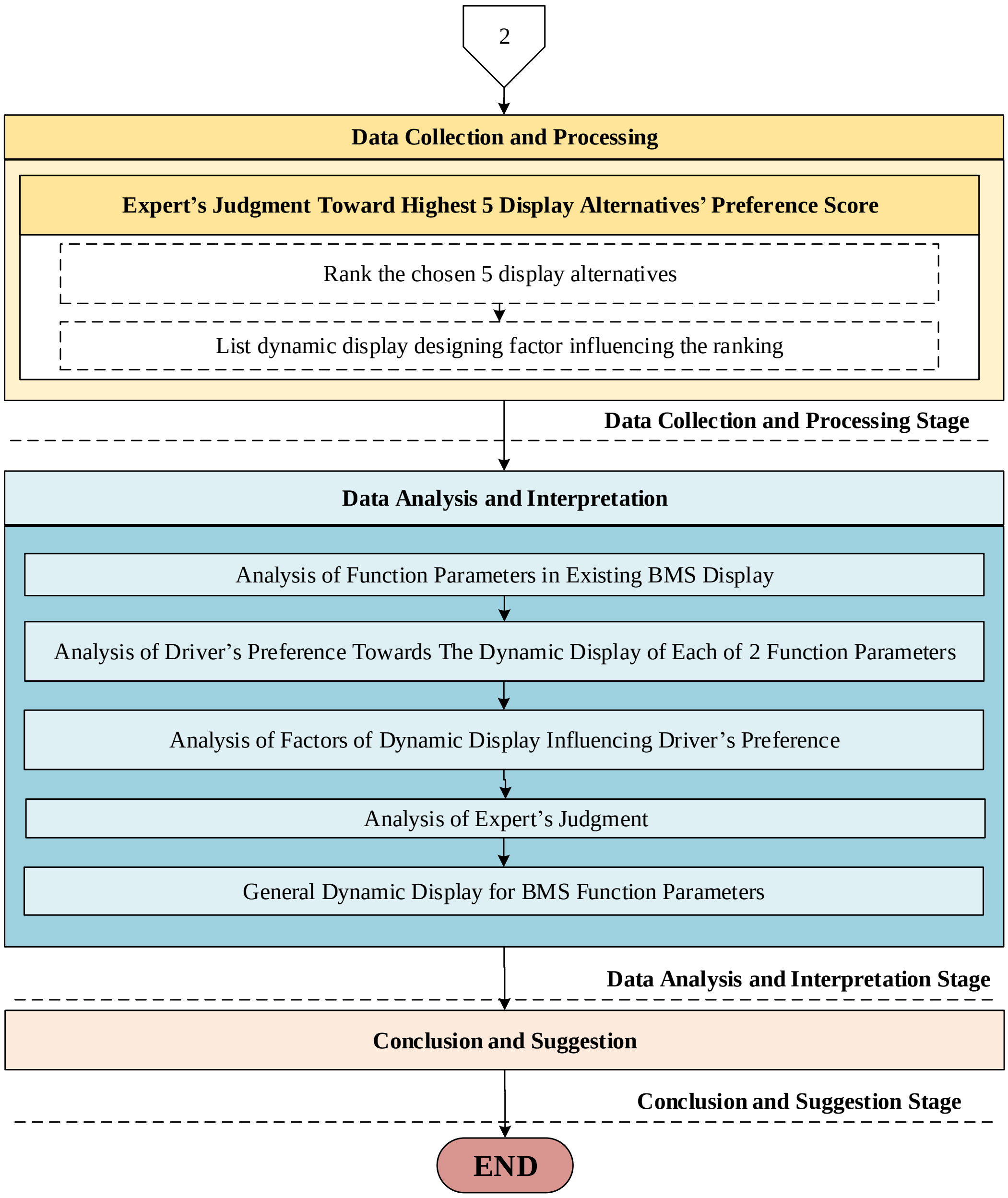

Figure 3.1 Research Methodology

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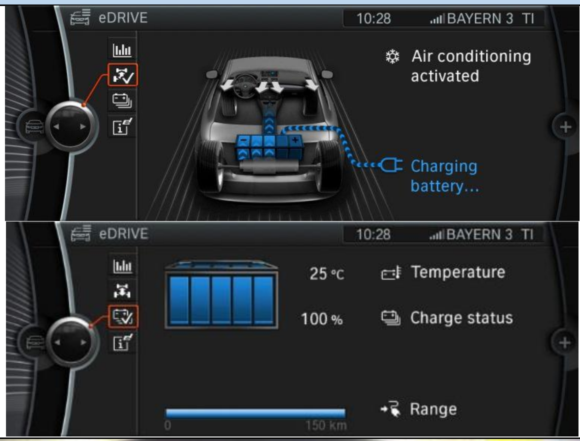
CHAPTER 4
DATA COLLECTION AND PROCESSING

This chapter provides about data collection and processing. The initial data needed are priority functions that must be included to the integrated BMS. After determining them, the alternatives of each function's dynamic display will be determined. The display alternatives were generated by combining one characteristic of dynamic display from common fuel-vehicle dashboard display. There are total 34 display alternatives for each function parameter.

4.1 Existing Functions Parameters and Dynamic Display of Battery Management System

EV is not a new thing in automotive industry. Therefore, different dynamic displays of integrated BMS are already available on several EV brands and BMS developer, such as BMW, KIA, Ford, etc. Below are the figures of existing dynamic display of integrated BMS from various resources.

Table 4.1 Existing BMS Display on EV Brands and From BMS Developer

EV Brands/BMS Developer	Series/Type/Model	Year of Production	BMS Display
BMW	BMW M135i (source: autobytel.com)	2012	
Lamborghini	Huracan LP610-4 (source: lamborghini.com)	2014	

4.2 Dynamic Display Alternatives of Integrated Battery Management System

After getting some literatures regarding dynamic display including its types and characteristics, the combination alternatives of dynamic display for BMS function parameters can be arranged. For the sake of better comprehension, the combination will be put in some categories. However, until the moment this research was conducted, there had not been any literature nor past research, which directly and clearly explained about this categorization. Thus, this research develops its own categorization of dynamic display types for an integrated BMS. The categorization was determined with basis from Sanders & McCormick (1992) and will be elaborated after. Each category has level(s) and each level has sub-level(s). Each of them will be combined to create an alternative of dynamic display of integrated BMS.

Table 4.2 Specification of The EV Battery

Battery Type: LiFePO4 (Lithium Iron Phosphate)					
Minimum Voltage	:	2.5 V	Capacity	:	60Ah
Nominal Voltage	:	3.2 V	The maximum charging voltage	:	4 **(**for initial charge)
Maximum Voltage	:	3.9 V	Operating temperature (°C)	:	-45°C up to 85°C (discharging)

4.3 Questionnaire of Dynamic Display Alternatives Pair Comparison

To determine the most preferred alternative of dynamic display of both battery state of charge and voltage, a pair comparison questionnaire is generated. This questionnaire will compare a-pair-of-two alternatives among the 34 alternatives. The total number of pairings are determined by using $t(t\text{-}1)/2$, where t defines number of items to be compared (Brown & Peterson, 2009).

$$\text{Total number of pairs} = t(t-1)/2 = 34(34-1)/2 = 561 \text{ pairs}$$

Since there are quite number of questions, these 2 questionnaires were created by using online questionnaire form, which is typeform.com. This online platform can accommodate hundreds question in a single form. Respondent will be able to access the questionnaire through the link provided. Below are the links for the questionnaire:

Table 4.3 List of Questionnaire Link

Questionnaire	Link
Battery State of Charge (no. 1-561)	Bit.ly/BMSTEST1b
Battery Voltage (no. 1-280)	Bit.ly/BMSTEST1c
Battery Voltage (no. 281-561)	Bit.ly/BMSTEST1d

There are 4 respondents involved to fill the questionnaire. All respondents taken based on criteria driving capability.

Internal Reliability (Consistency) of Battery State of Charge and Battery Voltage Display Alternative Pair Comparison

After obtaining the preference score of each display alternatives, individual respondent's internal ability will be calculated. Internal reliability measures the level of agreement among a given respondent's between-choices. This is commonly determined by using the number of circular triads among a respondent's choices. According to Brown and Peterson (2009), the circular triads can be determined by using this formula below:

$$C = \frac{t}{24}(t^2 - 1) - \frac{1}{2}\sum(a_i - b)^2$$

C : number of circular triads from an individual respondent

t : number of items (alternatives) in the set = 34

a_i : preference score of item i

b : average preference score = $\frac{t-1}{2} = \frac{34-1}{2} = 16.5$

The internal reliability is calculated by using this formula below:

$$\zeta = 1 - \frac{C}{C_{max}}$$

C_{max} : maximum number of possible circular triads

Since $t = 34$, then the C_{max} will be:

$$C_{max} = \frac{t(t^2 - 4)}{24}$$

$$C_{max} = \frac{34(34^2 - 4)}{24} = 1636.25$$

Below is the recapitulation of circular triads C and internal reliability ζ of both SOC and Voltage questionnaire from each respondent. Refer to APPENDIX I for the complete data of internal reliability calculation.

Expert's Judgement Towards Respondents' Preference Score

After getting the result of 5 most preferable display alternative for battery state of charge and voltage, expert's judgement is required in order to give consideration about each alternative. They are member of an organization that conduct research and develop electric vehicle in an educational institution in Surabaya. An interview was conducted with those 3 experts.

Below are the profiles of the expert:

Table 4.4 Expert's Profile

	Background Field	Position	Working Period
Expert A	Industrial Engineering	Financial and Business Manager	2012 - now
Expert B	Mechanical Engineering	Director of Research and Development	2012 - now
Expert C	Mechanical Engineering	Engineer of BMS Battery Pack and Controller	2012 - now

The interview resulted that all 3 experts have the same order of preference of display alternative of battery of charge. However, each of them has different consideration of each display alternative despite having similar preference. Below is the rank order from the 3 experts towards 5 most preferred display alternatives.

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CHAPTER 5
DATA ANALYSIS AND INTERPRETATION

This chapter provides information about analysis and interpretation of data gathered in Chapter 4. It will explain about the results of the most preferred dynamic display for battery SOC, voltage, and the general result of the findings. This chapter also gives detail about the design factor influencing respondents in selecting the preferred alternative of dynamic display.

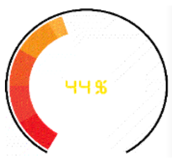
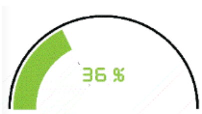
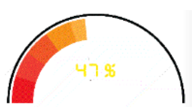
5.1 Function Parameters in Existing BMS Display

From the literature review, it is known that the most available function parameters on the various existing integrated BMS display are battery SOC, temperature, voltage, speedometer, current, range remaining, battery capacity, and energy consumption. This indicates that these function parameters become the most crucial parameter in order to monitor the condition of EV battery. These function parameters need information input from the battery, so they can process it to get an output. Since these function parameters are crucial, it will be difficult for EV driver to understand his battery performance right away. Eventually, this will lead to early damage without the driver being aware.

5.2 Battery State of Charge Dynamic Display

According to sub chapter **Error! Reference source not found.**, the most p referred dynamic display for respondent is digital display with check reading.

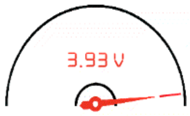
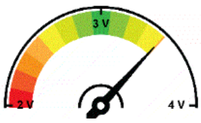
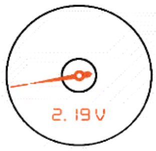
Table 5.1 The Highest 5 Preference Score for Alternatives of Battery SOC Dynamic Display

Total Circular + With Check Reading	Total Semicircular + No Check Reading	Total Semicircular + With Check Reading	Total Digital + No Check Reading	Total Digital + With Check Reading
				
112	110	112	112	119

5.3 Battery Voltage Dynamic Display

According to the previous sub chapter, the most preferred dynamic display for battery voltage is digital and analog (mechanic), both accompanied by check reading.

Table 5.2 The Highest 5 Preference Score for Battery Voltage Dynamic Display

Total Semicircular + With Check Reading	Total Semicircular + With Check Reading	Total Digital + With Check Reading	Total Semicircular + No Check Reading	Total Circular + With Check Reading
				
78	75	74	72	72

5.4 Expert's Judgement Analysis

The expert's judgement shows that all 3 experts got the same rank order toward display alternative of battery SOC with similar reason albeit their difference in background field. They chose analog + semicircular with check reading display as their 1st display alternative. They considered about the effectivity of the display alternative for driver *(end-user)* of electric vehicle and efficiency of space on dashboard panel. However, there is different view among them regarding battery voltage display alternative. Only Expert C stated that battery voltage is significant to be displayed for driver.

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CHAPTER 6
CONCLUSION AND SUGGESTION

This chapter gives information about the conclusions regarding the research process that has been conducted. Several suggestions will also be given as a reference for improvement of future researches that is related to this research.

6.1 Conclusion

Based on previous chapters of data processing and analysis, there are several conclusions that can be provided by considering the objectives stated in the beginning of this research. Those conclusions are:

1. Most available function parameters on the various existing integrated BMS display are battery SOC, temperature, voltage, speedometer, current, range remaining, battery capacity, and energy consumption. This final project only took battery state of charge and voltage into the experiment.
2. Expert's The most preferred dynamic display for battery SOC is digital with check reading (119 times selected) by respondent. The consistency of their preference score ranges from 0.75 - 0.99.
3. The most preferred dynamic display for battery voltage is digital-mechanic semicircular with check reading (78 times selected).

6.2 Suggestion

Suggestions that could be given for future researches related to the topic of dynamic display for an integrated BMS are:

1. Further observation about the dynamic display for other BMS functions parameters.
2. Communicate with various party in order to gather information about electric vehicle, such as electric vehicle community.

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APPENDIX I

Internal Reliability Data

Respondent 1			Battery State of Charge				Battery Voltage			
Number of items $t = 34$	b	Maximum Possible Circular Triads (C_{max})	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)
1	16.5	1636.25	8	72.25	12	0.993	12	20.25	274	0.832543927
2			10	42.25			21	20.25		
3			9	56.25			13	12.25		
4			11	30.25			25	72.25		
5			16	0.25			2	210.25		
6			18	2.25			17	0.25		
7			13	12.25			3	182.25		
8			15	2.25			22	30.25		
9			14	6.25			8	72.25		
10			15	2.25			16	0.25		
11			16	0.25			9	56.25		
12			17	0.25			20	12.25		
13			28	132.3			5	132.25		
14			29	156.3			14	6.25		
15			30	182.3			4	156.25		
16			31	210.3			16	0.25		
17			6	110.3			22	30.25		
18			4	156.3			29	156.25		
19			7	90.25			25	72.25		
20			5	132.3			31	210.25		
21			2	210.3			6	110.25		
22			0	272.3			16	0.25		
23			3	182.3			8	72.25		
24			1	240.3			19	6.25		
25			20	12.25			19	6.25		
26			21	20.25			24	56.25		
27			22	30.25			17	0.25		
28			23	42.25			23	42.25		
29			24	56.25			2	210.25		
30			25	72.25			22	30.25		
31			26	90.25			3	182.25		
32			27	110.3			23	42.25		
33			32	240.3			32	240.25		
34			33	272.3			33	272.25		

Internal Reliability Data

Respondent 2			Battery State of Charge				Battery Voltage			
Number of items $t = 34$	b	Maximum Possible Circular Triads (C_{max})	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)
1			19	6.25			32	240		
2			25	72.25			27	110		
3			16	0.25			33	272		
4			29	156.25			31	210		
5			11	30.25			12	20.3		
6			18	2.25			10	42.3		
7			9	56.25			12	20.3		
8			16	0.25			4	156		
9			5	132.25			28	132		
10			10	42.25			23	42.3		
11			3	182.25			29	156		
12			9	56.25			27	110		
13			5	132.25			15	2.25		
14			8	72.25			12	20.3		
15			7	90.25			14	6.25		
16			11	30.25			6	110		
17	16.5	1636.25	12	20.25	393	0.759817	15	2.25	626	0.617417876
18			15	2.25			18	2.25		
19			14	6.25			19	6.25		
20			16	0.25			20	12.3		
21			7	90.25			13	12.3		
22			8	72.25			12	20.3		
23			9	56.25			10	42.3		
24			11	30.25			11	30.3		
25			22	30.25			18	2.25		
26			28	132.25			15	2.25		
27			32	240.25			15	2.25		
28			31	210.25			13	12.3		
29			27	110.25			11	30.3		
30			26	90.25			15	2.25		
31			25	72.25			15	2.25		
32			28	132.25			10	42.3		
33			24	56.25			8	72.3		
34			25	72.25			8	72.3		

Internal Reliability Data

Respondent 3			Battery State of Charge				Battery Voltage			
Number of items $t = 34$	b	Maximum Possible Circular Triads (C_{max})	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)
1	16.5	1636.25	16	0.25	24	0.9853323	16	0.25	417	0.745149
2			19	6.25			19	6.25		
3			19	6.25			19	6.25		
4			21	20.25			19	6.25		
5			10	42.25			10	42.3		
6			14	6.25			14	6.25		
7			8	72.25			4	156		
8			8	72.25			7	90.3		
9			17	0.25			18	2.25		
10			22	30.25			20	12.3		
11			19	6.25			24	56.3		
12			24	56.25			23	42.3		
13			13	12.25			13	12.3		
14			15	2.25			13	12.3		
15			6	110.25			12	20.3		
16			10	42.25			14	6.25		
17			25	72.25			24	56.3		
18			25	72.25			25	72.3		
19			27	110.25			26	90.3		
20			28	132.25			27	110		
21			2	210.25			3	182		
22			3	182.25			2	210		
23			0	272.25			1	240		
24			1	240.25			1	240		
25			24	56.25			21	20.3		
26			30	182.25			22	30.3		
27			29	156.25			24	56.3		
28			31	210.25			24	56.3		
29			8	72.25			12	20.3		
30			9	56.25			17	0.25		
31			6	110.25			10	42.3		
32			7	90.25			12	20.3		
33			32	240.25			32	240		
34			33	272.25			33	272		

Internal Reliability Data

Respondent 4			Battery State of Charge				Battery Voltage			
Number of items $t = 34$	b	Maximum Possible Circular Triads (C_{max})	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)	a_i	$(a_i - b)^2$	Number of Circular Triads (C)	Internal Reliability (ζ)
1	16.5	1636.25	10	42.25	262	0.8398778	18	2.25	874	0.465851795
2			18	2.25			24	56.3		
3			10	42.25			19	6.25		
4			17	0.25			22	30.3		
5			4	156.25			15	2.25		
6			16	0.25			28	132		
7			5	132.25			11	30.3		
8			16	0.25			24	56.3		
9			8	72.25			14	6.25		
10			14	6.25			20	12.3		
11			6	110.25			13	12.3		
12			14	6.25			24	56.3		
13			3	182.25			19	6.25		
14			8	72.25			18	2.25		
15			5	132.25			19	6.25		
16			10	42.25			22	30.3		
17			27	110.25			16	0.25		
18			31	210.25			22	30.3		
19			22	30.25			16	0.25		
20			26	90.25			22	30.3		
21			4	156.25			2	210		
22			15	2.25			2	210		
23			4	156.25			3	182		
24			15	2.25			5	132		
25			32	240.25			18	2.25		
26			33	272.25			26	90.3		
27			27	110.25			14	6.25		
28			27	110.25			19	6.25		
29			19	6.25			9	56.3		
30			21	20.25			18	2.25		
31			20	12.25			7	90.3		
32			22	30.25			17	0.25		
33			24	56.25			14	6.25		
34			28	132.25			21	20.3		

APPENDIX IV

Interview Script 1 – Expert A (January 19th, 2018)

I : Interviewer

N : Narasumber/Interviewees

I : Apa peran Bapak di Molina ITS saat ini?

N : Saya terlibat dengan perencanaan biaya, dan di masa depan yang berhubungan dengan perencanaan produksi dan sistem manufaktur, termasuk suplainya. Karena latar belakang saya teknik industri, saya tidak terlibat dalam desain BMS.

Apakah Bapak mensuplai BMS dari supplier?

Tidak. BMS adalah teknologi kunci yang harus dikuasai sendiri, bukan disuplai oleh supplier. Nanti bagian sendiri yang mendesain BMS, dan ada perusahaan yang tugasnya merakit BMS.

I : Menurut Bapak untuk sebuah BMS yang baik harus memuat fungsi apa saja untuk ditampilkan agar pengemudi bisa mengetahui kondisi sebenarnya dari baterai?

N : 1. Informasi tentang berapa sisa baterai (SOC) dari mobil listrik yang dikendarai pengemudi. Sistem BMS yang harus secara otomatis mengatur kinerja baterai mobil listrik. Sama saja dengan *handphone*, pengemudi hanya tahu persentase baterai, tanpa mengetahui sistem didalamnya untuk menampilkan informasi tersebut.

2. Informasi tentang konsumsi energi, seberapa lama baterai akan bertahan dan berapa jarak yang bisa ditempuh bergantung dari cara pengemudi mengendarai mobil (misal seberapa besar akselerasi, kebiasaan mengebut, dsj).

I : (Menampilan pilihan tampilan SOC dan tengangan baterai) Dari 5 alternatif tampilan SOC dan tegangan ini, bagaimana urutan tampilan dari yang paling sesuai hingga paling tidak efektif untuk pengemudi mobil listrik?

N : SOC = C, E, D, A, B

I : Apa pertimbangan Bapak dalam memilih tampilan SOC?

N : Warna, bentuk, ukuran. Bagi saya yang rabun jauh dan rabun dekat tampilan digital saja tidaklah cukup. Apabila ukurannya kecil maka penglihatan saya terhadap angka akan berbayang. Angka 1 bisa menjadi 11. Maka dari itu adanya tampilan analog akan memudahkan saya untuk menangkap informasi pada *dashboard* mobil dengan cepat. Yang penting saya dapat mengetahui perkiraan sisa baterai mobil saya. Kecuali ukuran *font* pada tampilan digital cukup besar, maka saya tidak akan masalah dengan tampilan digital. Ukuran panel *dashboard* pun juga penting karena akan menentukan ukuran fungsi-fungsi yang ditampilkan di dalamnya. Pemilihan warna dan kontras juga penting agar saya bisa melihat panel *dashboard* dengan jelas. Informasi dengan *background* gelap dan tulisan yang terang membuat saya lebih sulit dalam melihat informasi (terutama yang berupa tulisan) dengan jelas ketimbang dengan informasi dengan *background* terang dan tulisan gelap.

Interview Script 2 – Expert B (January 19th, 2018)

I : Interviewer

N : Narasumber/Interviewees

I : Saya mencoba membuat desain tampilan BMS yang cocok untuk pengemudi mobil listrik. Ada beberapa fungsi yang harus ditampilkan untuk pengemudi. Apa saja fungsi-fungsi yang harus ditampilkan itu?

N : Pengemudi tidak perlu diperlihatkan semua perameter yang ada pada BMS. Untuk pengemudi (sebagai *end-user*) hanya ditampilkan kecepatan, SOC, temperature baterai, konsumsi energi pada panel *dashboard*. Kalau ingin melihat semua parameter BMS secara khusus, misal tegangan dan arus setiap sel baterai, pengemudi bisa melihat aplikasi khusus BMS secara langsung.

I : Mengapa tegangan dan arus baterai tidak perlu ditampilkan?

N : Karena parameter tersebut sudah tercermin pada tampilan SOC. Kalau untuk pengemudi cukup indikator yang penting saja.

I : Untuk menampilkan parameter-parameter tersebut, aspek-aspek desain apa saja yang diperhatikan?

N : Kami sebagai orang mekanik tidak terlalu mengerti dengan unsur-unsur desain. Bagi kami yang penting adalah menapilkan fungsi tersebut agar orang bisa menegrti. Terakhir kali kami mencoba mendesain BMS kami dibantu oleh orang-orang DKV (Desain Komunikasi Visual). Setelah itu kami ada perbaikan desain dari segi warna. Kami masih memerlukan pengetahuan desain dari segi ergonomi dan seninya.

I : *(Showing 5 display alternatives of battery SOC)* Bisa tolong Bapak urutkan mana tampilan SOC dan tengangan baterai yang menurut Bapak dari yang paling mudah hingga sulit dimengerti oleh pemngemudi mobil listrik?

N : SOC = C, D, E, A, B;

I : Apa pertimbangan Bapak ketika memilih tampilan tersebut?

N : Kalau gambar (analog) lebih enak dilihat, apalagi kalau perubahannya cepat. Kalau angka tidak enak dilihat ketika nilai yang ditunjukkan berubah dengan cepat. Angka lebih enak dilihat ssebagai informasi tambahan saja. Tapi kalau SOC agak jarang yang berbentuk setengah lingkaran seperti ini, biasanya berbentuk bar yang menyerupai baterai.

I : Mengapa Bapak lebih memilih bentuk setengah lingkaran?

N : Karena ada keterbatasan dari panel *dashboard* itu sendiri. Kalau setengah lingkaran tidak terlalu memakan *space* panel *dashboard*. Yang penting ukurannya disesuaikan untuk

Interview Script 3 – Expert C (January 19th, 2018)

I : Interviewer

N : Narasumber/Interviewees (Agus Mukhlisin, S.T., M.T.)

I : Apa peran Bapak dalam perancangan mobil listrik?

N : Saya mencoba mendesain tampilan BMS yang cocok, mudah dipahami pengemudi agar dalam berkendara pengemudi tidak kesulitan memahami fungsi BMS yang ditampilkan pada panel *dashboard* mobil listrik.

I : Menurut Bapak fungsi apa saja yang harus ditampilkan pada panel *dashboard* mobil listrik?

N : SOC, kecepatan, tegangan.

I : Mengapa tegangan perlu ditampilkan bagi pengemudi?

N : Perlunya saat terjadi *fail* tiba-tiba pada pada sistem BMS ketika mengisi daya baterai mobil listrik. Tampilan tegangan akan memberitahu pengemudi untuk mematikan *charger* secara manual.

I : Apa yang Bapak perhatikan ketika mendesain tampilan BMS untuk pengemudi?

N : Harus jelas untuk *end-user*, mudah dipahami

I : Bagaimana dengan ukuran dan warna? Apakah ada pertimbangan tertentu?

N : Ya pokoknya ditentukan agar orang-orang bisa melihat dan mengerti dengan mudah.

I : (Menunjukkan pilihan tampilan SOC) Mana tampilan SOC yang

N : SOC = C, E, D, A, B

I : Kenapa tidak memilih yang digital?

N : Menurut saya tampilan digital (untuk SOC) kurang menarik, kalau analog sepertinya lebih bagus.

I : Kenapa lebih memilih tampilan yang C daripada E?

N : Karena memikirkan *space* yang tersedia pada panel *dashboard*. Kalau bentuk setengah lingkaran akan lebih mudah dan lebih bagus ketika ditata ke dalam panel *dashboard*.

I : (Menunjukkan pilihan tampilan Voltage) Kalau untuk tegangan, menurut Bapak mana tampilan yang baik untuk pengemudi?

N : Kalau tegangan saya lebih cenderung ke digital (opsi D, lihat 0) saja daripada analog.

I : Kenapa?

N : Agar lebih jelas informasi yang dijelaskan. Lagipula saat di jalan pengemudi tidak perlu terlalu memperhatikan tegangan. Pengemudi perlu memperhatikan tegangan saat melakukan pengisian ulang atau penggantian baterai, dimana kondisi mobil listrik dalam keadaan berhenti.

I : Urutannya setelah itu seperti apa?

N : D, A, C, B, E

BIOGRAPHY

Ninda Lastri Yulia was born in Serang, July 23rd, 1995. She had lived in 4 different places in Indonesia before pursuing her bachelor's degree in Institut Teknologi Sepuluh Nopember, Surabaya. She is a graduate of SD YPS Singkole, Soroako in 2001, SMP YPS Singkole, Soroako in 2010, and SMA Pribadi Bilingual School Bandung in 2013.

She enrolled Industrial Engineering Department of Institut Teknologi Sepuluh Nopember, Surabaya in 2013. During her campus life, she was active in organizational and committee activities. In her first year she took part as member of ITS Student Choir organization and Smart and Fun Area committee in ITS EXPO 2014. She was also active being a teacher volunteer for HMTI Mengajar, a weekly social activity held by Industrial Engineering Student Association. Her sophomore year was occupied by continuing her membership in ITS Student Choir organization and got a role as coordinator of Wahana Budaya in ITS EXPO 2015. In the same year, she also took a role as Steering Committee of HMTI Mengajar and Steering Committee of Industrial Engineering Games (IE Games) 10th edition. Her college life was also fulfilled by some international exposures. She joined a volunteering program abroad named "Sawasdee Thailand Project" held by AIESEC in Thailand for 1.5 months. She was teaching English for elementary school students in rural area of Nakhon Pathom Province.

Not only volunteering abroad, Ninda also participated as a volunteer in ITS International Office. She was responsible in Workshop (now Internationalization and Development) Division. Her role was spreading internationalization vibe throughout the ITS for both students and academic staff. She took part in arranging student sessions, workshops, and trainings for students regarding global competencies. In ITS International Office she got a lot experience and got to enhance her soft skill. Her soft skills have sharpened through her leadership training, organizational and intercultural experiences.

Last year in university, she was focus on her final project which titled "Designing Dynamic Visualization of Battery Management System for an Electric Vehicle". This final project included in Cognitive Ergonomics field. In the future, she has interest in cognitive ergonomics, human resources management, and design. She wants to pursue international career and contribute to the society. In leisure time, she loves singing, drawing, and reading comic. For any inquiries, she can be reached through email: nindayulia23@gmail.com