Jurnal Mekanikal
June 2016, Vol 39, 56-68

PARAMETRIC COST ESTIMATION FOR CONTROLLING THE DEVELOPMENT OF ELECTRIC VEHICLE PROTOTYPE

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ABSTRACT

We proposed a parametric cost estimation for analysis the feasibility of electric vehicle prototypes. The development of prototype is an important phase of developing an electric vehicle (EV). One of the important criteria in prototype stage is the feasibility of cost for developing a prototype of EV. This article aims to arrange method and application for estimating and controlling the cost of EV in prototype stage. Where, the design to cost is used to validate cost estimation of production costs of prototypes. This research begins by identifying Engineering Bill of Material (EBOM). In referring to the EBOM, organization structure and its activity are identified. We utilize a parametric method that derived from cost center and activity cost driver to arrange cost estimation model. To demonstrate the practical applicability and effectiveness of the proposed method, we implement the prototype of an EV parametric cost estimation model by using a Visual Basic Macro within Microsoft Excel. In this paper, the model for controlling the cost of development of an EV prototype is described and the cost to design is evaluated in comparison with the target cost.

Keywords: *activity cost driver, electric vehicle prototype, engineering bill of material, parametric cost estimation.*

1.0 INTRODUCTION

Electric vehicles (EVs) are alternative of transportation to solve emission and the fossil energy resources problem [1, 2]. Many developed countries have been concerned with this problem and have already developed and mass produced of EVs. But, the ability to expeditiously develop and market EVs, is one of the crucial success factors in competitive vehicle environments. As a consequence, streamlining product development processes has become an important tool to gain and sustain competitive advantage [3]. The research and development of electric vehicles (EVs) are growing around the world to achieve the better economic objectives and technical requirements [4-6]. Sebelas Maret University is actively involved in research and development (R & D) of EV in Indonesia. At the beginning, the research focuses on selection of EVs and technology system. Then, design base of EVs conducted by engineers. Based on product design, mock-up of EVs produced as the first level of prototype. The next phase is prototype verification. This stage aims to ensure that prototype operated well. In the future, EVs can be produced at mass production scale. Figure 1 shown electric vehicles development plan in Sebelas Maret University.

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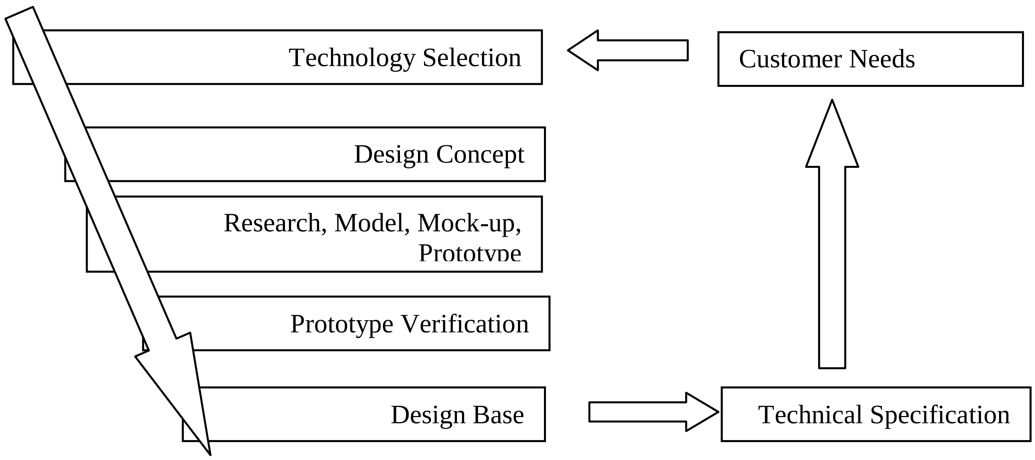

Figure 1: Electric Vehicles Development Plan

In Sebelas Maret University, product development of EVs began with a R&D team takes part as a business unit. The team receives orders from customers to make a prototype of EVs. The input of prototype production is mechanical drawing or mock-up. Then, the team makes a cost estimation of prototype to decide the selling price to the customer. The complexity levels of prototype influence the cost estimation. If the unit and customers reach an agreement, then the unit implements the production process of the prototype [7]. Because of that, the development of prototype is important phase of the product development process for electric vehicles (EVs). The prototyping stage needs attributes for themselves, such as what tool was used and new technique to create the product. Many things must be considered so that the stage of creating of a prototype is not easy. One of the important criteria in prototype stage is the cost estimation of prototype [8, 9].

Cost estimation is a calculation and prediction of total cost of the product before the actual manufacturing process is performed [10-12]. The cost estimation is still challenging task, especially in the early phase of development stage [13]. There are many benefits derived from the activity cost estimate in the design stage. Accurate cost estimation will drive manufacturer to gain competitiveness in industry [14,16] because decision makers able to use for decreasing their production cost. Cost estimation also makes decision maker have a detailed calculation to evaluate the investment. Then, the values of patent and royalty from the prototype also can be determined by using the accurate cost estimation models [17-18].

This article aims to arrange parametric cost estimation method for controling the design to cost of electric vehicles in prototype stage. Where, design to cost is used to validate cost estimation of production cost electric vehicle prototype.

2.0 METHODS

This research was conducted with approaches as shown in Figure 2. This article used Sebelas Maret Electric Vehicle that developed by R & D Team as a case study. Early stage of this research is started from preliminary design. In this stage, engineering bill of material (EBOM) of EVs prototype is identified. EBOM is used in the design process and represents the product in terms of its functional sub-systems in a hierarchical manner. Then, in the making specification stage, data from preliminary design stage is used to identify organizational structure. From the organization structure, we can identify the whole activity that happened in producing a prototype.

And then, parametric method is used to develop a cost estimation model in prototype stage. Parametric cost estimation is the best estimator for a product which is still in development stages [19-20]. Parametric models are derived by applying the statistical methodologies and by expressing cost as a function of its constituent variables. These techniques could be effective in those situations where the cost drivers, could be easily identified [21].

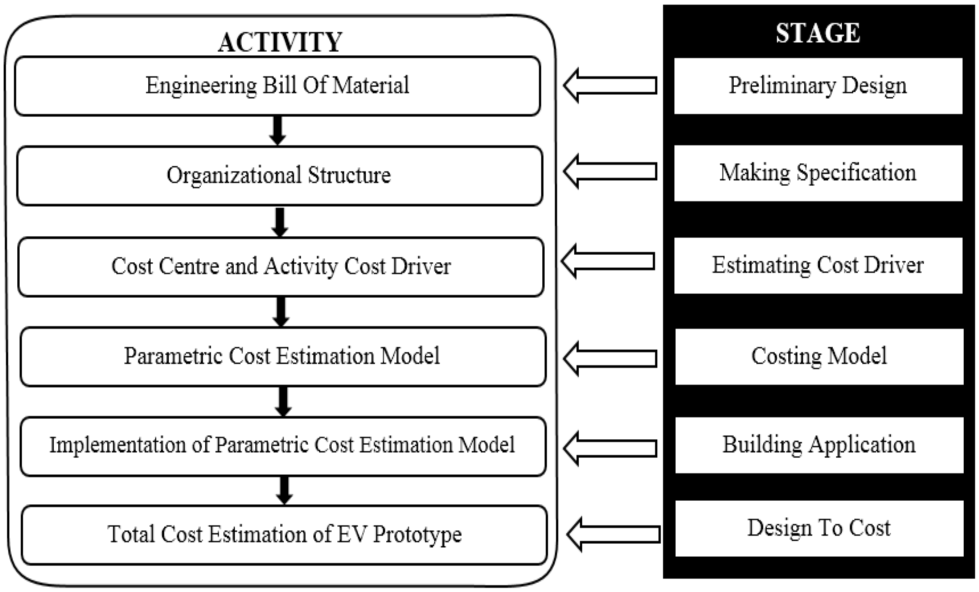

Figure 2: Methodology for Electric Vehicles Estimation Cost in Prototype Stage

It begins from determining cost center and cost driver rates. The whole activity must be identified and classified into matching cost centers. The detailed activity still restricted due to the requirement of a detailed product specification and production process [21]. After that, we generated mathematical equation based on characterizing parameters. The next stage, we built an application as implementation of the model. By using this application, users are easy to calculate a cost estimation, despite the product specification of the prototype is different. And the last is designed to cost EVs of the prototype.

3.0 RESULT AND DISCUSSION

In this case, Managing Director of R & D team is a decision maker to communicate with the buyer and/or the supplier before produce prototype. This proposed application can be used to simulate the decision.

3.1 Engineering Bill Of Material (EBOM)

The BOM is an important data parameter in product lifecycle managemen (PLM), representing product information such as hierarchical parts that are associated with a certain product. As such, it can be employed as a criterion in managing the product information throughout the product life cycle (e.g., the conceptual design, detailed design, production, sales, and disposal), in a consistent manner.

In this study, EBOM is created based on multilevel BOM. A multilevel BOM displays all components used directly or indirectly in a product [22]. EBOM of an electric vehicle is classified by electric vehicle structure development. At this point, EVs has differed with conventional vehicles, that is power and storage system. Electric vehicle uses the electric motor or traction motors for creating force leading to movement. And, the battery that used as energy storage. The EVs of EBOM classification is shown in Figure 3.

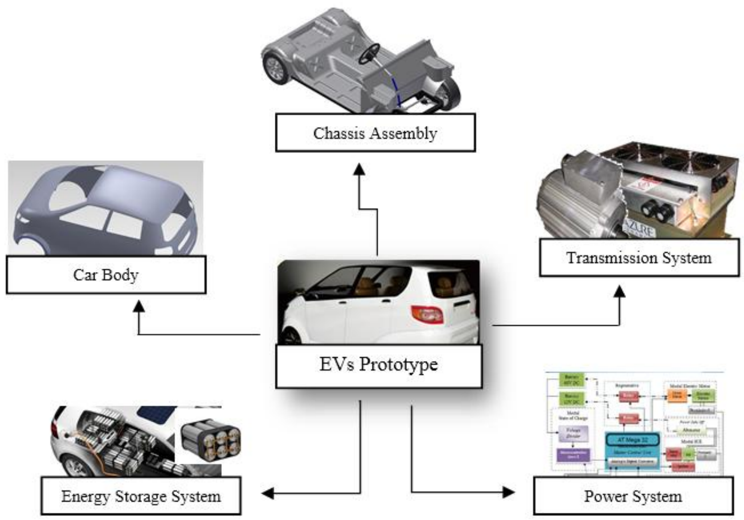

Figure 3: The EVs, EBOM Classification

In multilevel BOM, there was multilevel tree, that is a tree structure with several levels. The final product or parent product located at the level of 0 (zero) and the level number increases in the levels below. Then, in the multilevel BOM, there is a field a part number. Part number is done by semi-significant method. It is expected to facilitate the adjustment of new parts. The pattern of part numbering explains information about an item or specific components. Reference [23] shown classification code for EVs EBOM as shown in Figure 4.

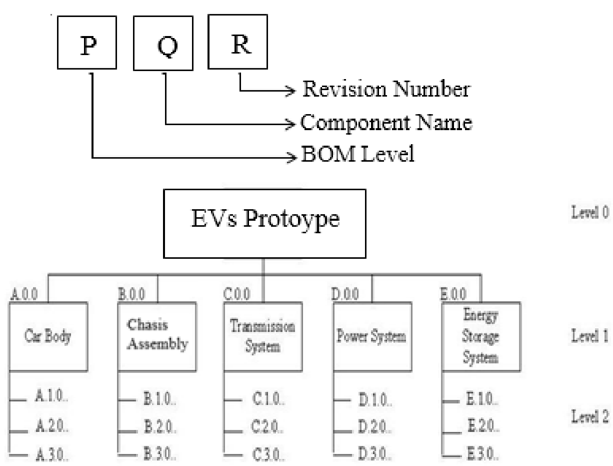

Figure 4: EVs Prototype EBOM Classification Code

In Figure 4, P denotes the BOM level, Q denotes the part name, R denotes the revision number. Part name is a number that describes the item or specific component that according to it. For example: 2 - A.1.0 - 1 means the item or component at level 2 in the car body assembly with the first revision. The leveling of EVs prototype begins a parent product that located at level of 0. To the levels below, level number increases at each tree. This prototype separated until the third level number. Level 1 consists of car body, chassis assembly, transmission system, power system, and energy storage system. Each component in level 1 has materials or assembly that needed shown at level 2. Level 2 consists of exterior and interior module, chassis, suspension, engine, battery charger, etc. Third level shows detailed information about specific parts of electric vehicle.

Multilevel EVs Prototype EBOM is used to determine how many components are needed to build a prototype. It is also used as a reference to estimate total cost required for producing a prototype. It is shown in Table 1.

Table 1: Multilevel EVs Prototype EBOM

No. Part	Description	Qty	Unit of measure	Decision
1.A.0.0	Car Body	1	each	make
2.A.1.0	Exterior Module	1	module	make
2.A.1.1	Interior Module	1	module	buy
3.A.1.0	Cabinet Body	1	unit	make
3.A.2.0	Door System	4	each	make
3.A.1.1	Seat system	1	module	buy
3.A.2.1	Dashboard	1	unit	buy
3.A.3.1	Pedal & steering	1	module	buy
1.B.0.0	Chassis assembly	1	unit	make
2.B.1.0	Chassis	1	module	make
1.C.0.0	Transmission system	1	module	buy
1.D.0.0	Power system	1	unit	buy
1.E.0.0	Energy storage	1	unit	make

3.2 Organizational Structure

Based on BOM structure, organizational structure was built. The organizational structure is based on the main component of electric vehicle development. We suggested organizational structure as shown in Figure 5.

From the organization structure, we can identify the whole activity that happened in producing a prototype. Managing director (MD) leads the whole organization and executive director (ED) has two experts that support production a prototype. The structure built based on functional each research group. Main division are engineering and financing. Both divisions have great influence to finish a prototype. There is five research group, called Research Group (RG) 1 until 5, respectively. An Engineering manager leads the Engineering Division. The engineering division consists of four research groups (RG), they are design-styling (RG 1), body compartment (RG 2), chassis and power system (RG 3), and battery management (RG 4). The financial division consists of one research group, that is supporting research and administration (RG 5).

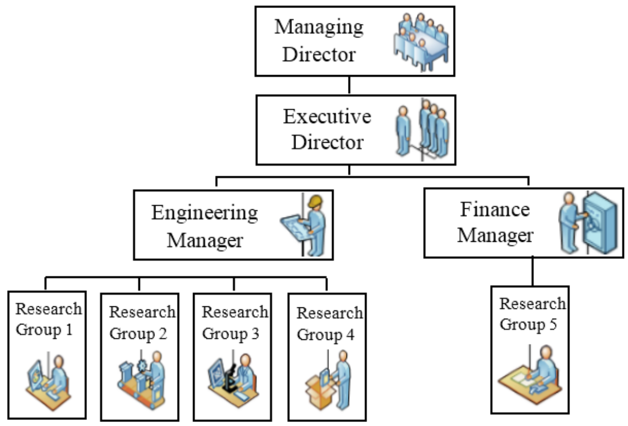

Figure 5: Organization Structure of EVs Research and Development (R & D TReam)

3.3 Cost Centre And Activity Cost Driver

Estimating cost center is based on organizational structure and its activities [20]. Whole activities must be identified and classified into matching cost centers. Cost center was identified similarly by RG of Engineering and Financial Division. Both divisions are the core of activity for producing prototype. The engineering division produces a main component of the prototype electric vehicle. Finance manager also chosen as a cost center because it supports the whole engineering activities. Table 2 lists cost centers and their cost drivers based on RG of the prototype electric vehicle.

Table 2: Cost Centres and Cost Drivers for EVs Prototype

Cost Centre	Cost Driver
Managing Director (MD)	Work Hours
Executive Director (ED)	Work Hours
Research Group 1 (RG 1)	Designing Hours
Research Group 2 (RG 2)	Work Hours, Molding Hours, Material Used
Research Group 3 (RG 3)	Work Hours, Material Used
Research Group 4 (RG 4)	Work Hours, Machining Hours
Research Group 5 (RG 5)	Work Hours

An activity cost driver is an factor that directly explains the cost incurred by activity. This equation is able to do a parametric estimate, which uses rate based on characterizing parameters. It covers the total cost of the research group and represents the total cost of the prototype electric vehicle. Cost driver of each cost center will be different. The activities in each department make cost driver various but the similarities are still consists. For example, designing hours only happen at RG 1. The both of MD and ED have a similar cost driver that is working hours. It is certain that in every department consisting of various activities.

As shown in Table 1, Table 2 and Figure 5, the process started with a discussion about mechanical drawing that involving design engineer of RG 1. The cost center that employed in this activity consists of RG 1, RG 2, and RG 5. The designing time is determined by total hours used to generate a design of cabinet body. Furthermore, the working hours are needed as an activity driver of a design engineer for designing a mechanical drawing. After the coordinator of RG 2 receives the drawing from the designer, then the process plan generated. The cabinet body is ready to produce after the planning process which was confirmed by the coordinator. The purchasing and delivering of materials are the two activities for material handling.

Then production activities involved, such as set up the fixtures, molding, and machining. The run test activity on the part needs longer time than the other activity due to get better quality product. Finishing activity is painting cabinet body to finalize production of cabinet body. Next stages, production of chassis and power system was built by RG 3 and the battery management was produced by RG 4. All of the coordinator of its RG has responsibilities with assembly activities. General activities to produce the cabinet body of EVs is shown in Table 3.

Table 3: General Activities For Produce Cabinet Body Of Evs

Activities	**Activity Driver**	**Cost Center Used**
Design	Hours	Design Eng. RG 1
Mechanical Drawing	Hours	Design Eng. RG 2
Generate Process Plan	Hours	Coordinator RG 2
Generate Price Quotes	Fixed Cost	Administrator RG 5
Purchase Material	Number Of Orders	Administrator RG 5
Material Delivery	Part Length	Technician RG 2
Setup Fixture	Number Of Setup	Technician RG 2
Setup Molding	Number Of Mold Setup	Technician RG 2

3.4 Parametric Cost Estimation Model

The next stage is generating mathematical equation based on characterizing parameters. A parameter which is used to generate an equation comes from defined activity cost driver. Reference [20] developed a parametric cost estimation model for electric vehicle based on its cost center and cost driver, which is expressed as follows:

$$TC_P = TC_{Coi} + TC_M \qquad (1)$$

Equation (1) below generated to calculate total cost of a prototype based on cost center. Each cost components have different formulas.

$$TC_M = \sum_{i=1}^{2} TC_{Di} \qquad (2)$$

$$TC_{D1} = k_1 \times R_1 \qquad (3)$$

$$TC_{D2} = k_2 \times R_2 \qquad (4)$$

Equation (2) is calculating total cost based on activities used by managing and executive director. The detail formula for each director refers to (3) and (4)

$$TC_{Coi} = \sum_{i=1}^{n} TC_{PCoi} \qquad (5)$$

Equation (5) is calculating total cost of components. The components of prototype developed by the engineering are denoted in different formula due to involving different activities and various parts. Each component consists of parts supported. So, total cost of parts is needed to calculate, refers to (6)

$$TCP_i = \sum_{i=1}^{n} P_i \qquad (6)$$

Some part of prototype were produced through various activity driver's. Some other parts were bought are consumed. Equation (7) shows the general formula to calculate cost of parts.

$$P_i = \sum_{1}^{\text{number of parameter}} (ACD_i \times ACDR_i) + a \qquad (7)$$

For activities shown in Table 3, the following input parameters are used for estimating the cost of cabinet body. That is part length, number of orders, the number of setups, the number of mold setup, machining hours, number of paints used, designing hours. All activities in cabinet body's production are driven by those parameters. The total cost of design and development cabinet body refers to (8).

Total cost = d_1 x part length + d_2 x number of orders
+ d_3 x number of setups + d_4 x number of mold setup + d_5 x machining hour + d_6 x number of paints + d_7 x designing hour + a_1 (8)

Where d_1, d_2, d_3, d_4, d_5, d_6, d_7, and a_1 are factory-dependent coefficients, which are determined by activity driver rates. These constant are equal to $d_1 = 0.4$, $d_2 = 7.2$, $d_3 = 0.8$, $d_4 = 1.5$, $d_5 = 6$, $d_6 = 15$, $d_7 = 48$, and $a_1 = 1.2$.

Notations and explanations for the parameter model are described as Table 4.

Table 4: Definition of Notation

Notation	Definition
ACD_i	Number activity cost driver used i (unit)
$ACDR_i$	Activity cost driver rate (IDR/unit)
TC_P	Total cost of a prototype (IDR)
TC_{COi}	Total cost of component i (IDR)
TC_{PCOi}	Total cost of parts *i* (IDR)
TC_M	Total cost used by managers (IDR)
TC_{Di}	Total cost of director activities i (IDR)
TCD_1	Total cost used by managing director (IDR)
TCD_2	Total cost used by executive director (IDR)
A	Other cost (IDR)
i	Type of director (1,2) for TC
	Type of components (1,2,3,4,5) for TC_{PCOi}
	Type of parts (1,2,3,…,n) for P_i
k_1	Work hours of managing director (IDR)
k_2	Work hours of executive director (IDR)
P_i	Cost of parts i (IDR)
R_1	Managing director cost driver rate (IDR/hrs)
R_2	Managing director cost driver rate (IDR/hrs)

3.5 Implementation of Parametric Cost Estimation Model

The parametric cost estimation model of EVs prototype is implemented using Visual Basic Macro within Microsoft Excel. Some previous research using Macro Excel language as based on simulation and application because of the simplicity and easiness [24-26]. Then, Macro Excel language makes the user can simply modify the program and novice easily [27-29].

In previous research, we developed the parametric cost estimation application determines cost estimation of EVs prototype [5]. In the application, the user also can interface directly with the spreadsheet, entering the number of researchers, design time, process time, technician cost, and percentage of profit mark-up.

The application performed to calculate the price of the prototype. The input is a mechanical drawing of the prototype. Then the expert of R & D team makes a complexity justification of the prototype. The justification will influence the calculation based on parameters. The default parameter will run the model to generate a price of the prototype. After the price generated, the application asks approval from the customers.

Home page of the application was shown in Figure 6. It consists of mechanical drawing or prototype and product description. The R & D team makes a justification of complexity level of prototype based on product description. The justification was shown in option bar that can be chosen by the user. The user can decide the complexity level of prototype to click the option of justification. The changes justification will represent different default parameter provided by the model based. Then the user can calculate the price of prototype by clicking the calculate button.

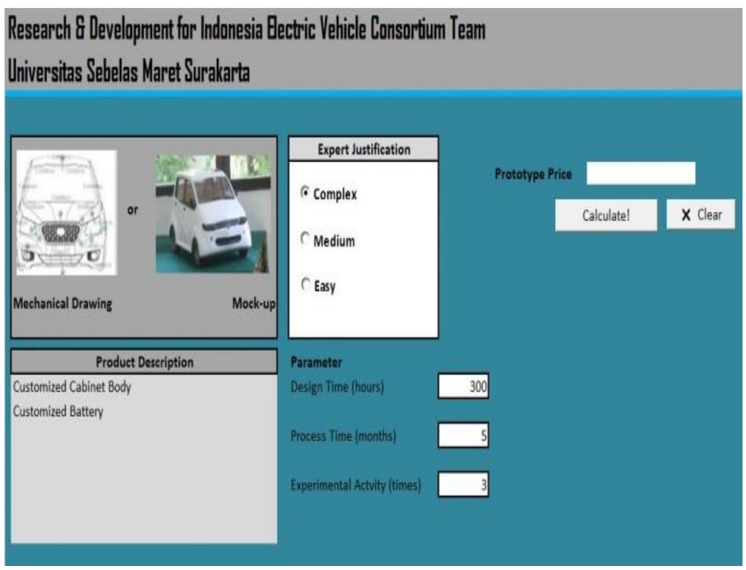

Figure 6: Home Page Of Application

The estimated price of the prototype will be shown in a message box and home page. The estimated price should be asked for customer and get the approval decision. If the customer approves the price, then the user clicking “Yes” button. Then invoice will be printed and the R & D Team is starting to order the required materials and component. Otherwise, if the price proposed by the application was rejected by the customer, the user can make adjustment to recalculate the price. The “No” button should be clicked to show the adjustment page. That page consists of default numerical that used by the model to generate a price of the prototype. The message box was shown in Figure 7.

At the adjustment page, the user can change the number in the box as they want. The user can make adjustment two times. The adjustment classified by four types. Figure 8 shows the adjustment that can be changed by the user. It consists adjustments of production process cost, mark-up over production cost, and the number of experimental activities.

Figure 7: Message Box That Shows Estimated Price and the Question Of Customer Approval

If the first adjustment generates estimated price above the desired price so the user try to readjust the parameter. After the final adjustment made, the offer for approval sent to the customer. If the customer receives the prizes offered so the process continued to contract assignment. Otherwise, if the customer rejects the offered price so the R& D team will reject the order of prototype.

After the adjustment was done, the user clicking the calculate button to generate the adjusted price. Then the process shows the adjusted price and message box that asking for approval. This page will be able to readjust until the generated price meets with the demand.

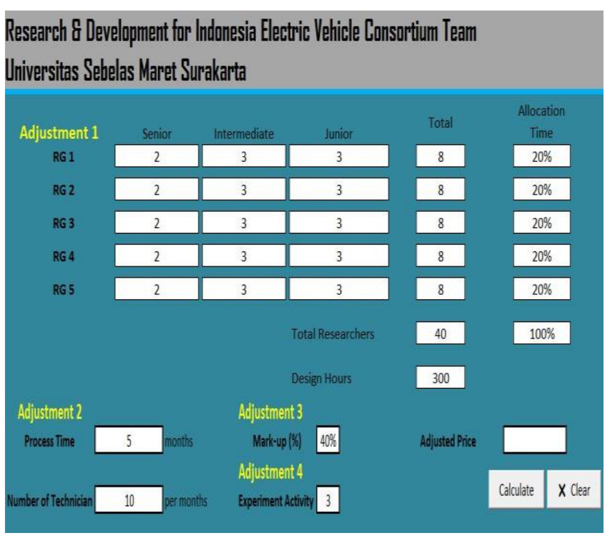

Figure 8: Designing Cost Adjustment

3.6 Total Cost Estimation of EV Prototype

The last stage is analyzing major part of total cost estimation. A cost estimation can then be performed on the basis of these values. The biggest expenses can show which department or part have the largest percentage of total cost. It also represents that still have the opportunity to make cost reduction. A department which has too many non-value added activities can eliminate the activities. The result presents not an actual cost estimation such that performed in the EVs prototype, but the process of the proposed estimation method as shown in Figure 9.

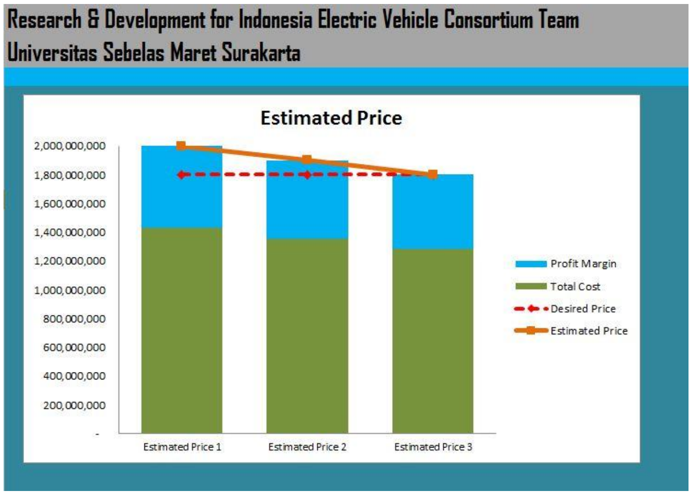

Figure 9: Total Cost Estimation

Based on numerical example, it can be proved that the method and application of design cost of EVs in prototype stage. The proposed model can be to determine the minimum budget that needed to produce a prototype. This application can be used as a consideration in the feasibility analysis before a prototype produced.

4.0 CONCLUSION

In this paper, we developed a parametric cost estimation model and implementation of electric vehicle prototypes. The proposed model can be used to generate a quick calculation of total production cost of a prototype. Then, the proposed application can be implemented to perform the production cost and price determination of EVs prototype with different complexity level. In addition, the macros excel have given the user the ability to perform cost analysis of prototype without access to costly simulation packages. Future research is aimed for adding the user feedback and for considering the budget constraint.

ACKNOWLEDGEMENTS

The part of this research is supported by The Ministries of Research, Technology, and Higher Education with HIBAH KOMPETENSI Research Program (Contract No. 041/SP2H/LT/DRPM/II/2016, Feb. 17, 2016).

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