Enhancement of Time-Driven Activity–Based Costing (TDABC) by using Simulation in Manufacturing Process towards Industry 4.0

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Abstract: The new industrial revolution brings changes to organizations that will need to adapt their system to sustain their business in a highly competitive market. In term of costing, most manufacturers continuously working towards reducing production costs by focusing on activities process improvement and resources as a cost driver. One of the current problems faced by most manufacturers that adopted Time-Driven Activity-Based Costing (TDABC) is lack of combined used of simulation as a tool for validation. Conventional technique also caused users estimated incorrect variables consideration to the costing system. The purpose of this paper is to provide a system for managers or decision makers to analyze results which can significantly reduce production costs by eliminating unnecessary resources with the aid of a simulation model. Simulation was proposed as new approach to determine the optimum results based on the given scenarios. An analysis on how the framework was implemented at an automotive manufacturing company was illustrated the enhancement of TDABC by using simulation. Results of conventional method using Activity Based Costing (ABC) was compared with TDABC where existing production layouts and parameters were maintained. Simulation model was created based on current situation and the results were compared to the old method. The results indicated that simulation can easily be adapted to support the planned and operational TDABC activities. Towards industry 4.0 it was proven that simulation is one of the key technologies in the new industrial revolution. Besides that, TDABC methodology in this research is more accurate and faster, by means of an enhanced decision-making process and supported organization manufacturing system.

Index Terms: Activity Based Costing, Time Driven Activity Based Costing; Simulation, Manufacturing Industry and Optimization.

I. INTRODUCTION

Many manufacturers have established their own costing methods such as traditional, Throughput costing (TPC), direct costing, order-activity (transactional) and ABC that usually involve materials, labor and overhead costs or based on the experience in costing strategy [1]. However, current traditional costing method is no longer suitable to achieve accurate costs of real-time interactions with human, products and machines of a production that is very versatile. Activity Based Costing (ABC) which was developed in the 1980s to overcome the constraints of traditional costing system before TDABC, was introduced. In short, the implementation of ABC encountered the following problems, as stated by Kaplan, Robert S., and Steven R. Anderson [2] and Almeida and J. Cunha [3]. The interviewing and survey process to obtain data was time-consuming and costly. At the same time, the collected data for ABC model were subjective, costly and difficult to validate [4]. Most ABC models were local and did not provide an integrated view of enterprise profitability opportunities. Furthermore, the model could not easily be updated to accommodate changing circumstances. It is theoretically incorrect when it ignored the potential for unused capacity. Then, in recent years, the ABC approach has evolved into a new alternative approach. An alternative approach known as Time-Driven Activity-Based Costing (TDABC) was developed to address all of the above-mentioned limitations. The difference between ABC and TDABC is that TDABC is simpler, cheaper, and faster to implement, and allows cost driver rates to be based on the practical capacity of the resources supplied [5]. In general, TDABC becomes a simple and less complex costing system by abolishing interview and survey of employees to get information on the assigned resources cost.

Nevertheless, a few problems arise when a company attempts the approach. The main issue is to measure the cost optimization system based on variable parameters that spend a lot of time using TDABC. In the end, it becomes a pressure on manufacturing managers to increase productivity and lower production costs. This study only uses a simulation to enhance TDABC. Therefore, the manufacturing managers are allowed to analyze alternative results that can significantly reduce production costs by eliminating unnecessary resources, with the aid of a simulation model.

II. RESEARCH BACKGROUND

This section discusses the theoretical background required for this research. This research necessitates the knowledge of TDABC and simulation. The concept ABC costing is upgraded to TDABC via simulation is described in the following paragraph

A. Simulation Study

Simulation models are increasingly used in problem-solving and decision making [6]. And it is going more interesting due to rise of Industry 4.0 [7].

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According to researcher based on literature review [8-10], simulation can be defined as an approach to understand or study the behavior of the system (within the limits imposed by a set of criteria), by creating a model for the actual system and carry out experiments with the said model of an operating system. A simulation model is a cost-saving tool to explore different solutions for a real system that does not require an actual change in the real system [11]. Therefore, users can experiment 'what if' conditions to observe the changes in the system [12]. The simulation was embedded earlier into ABC as part of the literature review. Helberg C., Galletly, J.E., and Bicheno, J.R [13] mentioned an educational ABC simulation software package that use a sensitivity scenario. Kostakis, H., Boskou, G., and Palisidis, G., [14] used a simulation with ABC to provide cost estimation in the restaurant industry. While, Ozbayrak, M., Akgün, M., and Türker, A.K [15] state in their research that the simulation-based model in ABC to recognise cost behaviour. Meanwhile, Greasley in 2006 implemented a study of cost information on police custody operation by using a combination of simulation with ABC [16]. Additionally, in 2016, Greasley, A., and C.M. Smith also used an ABC-based costing and simulation to reduce cost at a police communications centre [17].

III. METHODLOGY

A TDABC estimates cost at a fast speed as it requires only two parameters [18]. The two key parameters supported by TDABC are, the cost of capacity in a unit time and the amount of time needed to complete an activity [19]. Time study data was collected to measure the process time in the TDABC. A framework to show how the simulation enhances the TDABC activities is generated and shown in Fig.1.
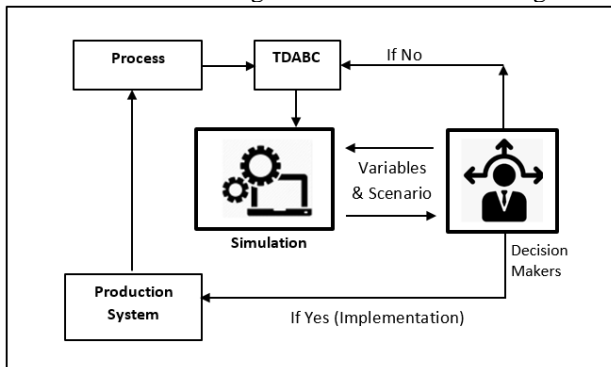

. **FIGURE 1: A TDABC FRAMEWORK BY USING SIMULATION.**

Data collection through time study was conducted to evaluate and analyze TDABC. Then, the data was transferred to the simulation. An optimization was made by interpreting the setting of the variables in the simulation. A verification process is performed against TDABC if the results were unsatisfactory. If the results of optimization were satisfactory, then the implementation process is suggested as predicted in the simulation. The experimental design and mathematical modelling can support optimization by offering alternative scenarios in making a fast and accurate costing evaluation

IV. IMPLEMENTATION EXAMPLE

A. Problem Statement

The case study was conducted in one of the automotive manufacturing parts. The core business is manufacturing and supply metal body panels, chassis parts, and modular assembly to original equipment manufacturer (OEM). In this case, the selected T11EX line assembled the Left Wheel House Comp (LH), the Right Wheel House Comp (RH) and Cross Member (C/MR) by employing a spot-welding robot for a car model. These three products run at the same assembly production line. The company faced problems where the production costing is determined traditionally and inaccurate by using ABC conventional method. Cost estimation needed to be done quickly when their customer changed the design or increased the order volume, but they do not have enough time to perform the cost evaluation. In this situation, the company may lose profits because the production cost was not determined correctly. Besides, if the revised price is too high, the company may lose the project.

B. Formulate Time Equation

Welding is one of the most complicated activity for cost estimation. At this stage, the sub-activities are divided into elements. There are autonomous robot and resources. These activities include all the element where time can vary according to the parameters affecting it. In this part of the paper, TDABC model is developed similar with the theoretical equation. Below equation is an example of TDABC model for Robot welding number 1, under sub-activity autonomous robot.

$\underline{TRobot}$ **1**

= N (Time spent in station #100LH) + X (Movement of robot from station #100LH to #100LH + Movement of robot from station #100RH to #150RH + Movement of robot from station #150RH to #100LH) + M (Time spent in station #100RH + Time spent in station #150RH)

$= 81.5\ N + 5.1X\ 1 + 4.3X\ 2 + 5.8X\ 3 + (71.9 + 79.1)\ M$
$= 81.5\ N + 5.1X\ 1 + 4.3X\ 2 + 5.8X\ 3 + 151\ M$

…. Equation (1)

C. Capacity Cost Rate for Autonomous Robot

The capacity cost rate for resources and equipment is defined as the cost capacity supplied (RM) divided by the practical capacity of resources applied (expressed in units of time: minutes). The numerator in this calculation consist of employee cost, occupancy cost and overtime cost. Management has allocated the cost of capacity applied differently to skilled operator, unskilled operator and inspector. The denominator in the calculation represents the time available for the employees performing work in the production line.

The capacity cost rate = $\dfrac{\text{Cost of capacity supplied}}{\text{Practical capacity of resources supplied}}$

…. Equation (2)

Table 1 shows the calculation of the capacity cost rate of the Autonomous Robot that accompanies different cost drivers. At this stage, the cost for different robots that perform spot welding for different products in the same assembly line is calculated. The cost of each Autonomous Robot is a multiplication of the capacity of activity rate (unit cost of activity), and the practical capacity of the spot-welding activity consumed. The practical capacity of activity is estimated by using the equation of time.

Table 1: Capacity cost rate for autonomous robot

Resources	Cost Driver	Cost of Resource (RM) (A)	Practical Capacity of Resource (B)	Capacity Rate of Resource (E.g.: unit cost of resource) (C=A/B)	Practical Capacity of Resource Consumed by Spot Weld Activity (D)	Cost of Resource Consumed by Spot Weld activity (RM) (E=C x D)
Depreciation of Assets	Cost of assets	14236.68	635641.86	0.0224	5231.71	117.19
Electricity Consumption	Consumption in KWH	5414.00	21766.04	0.2487	216.00	53.72
Robot Maintenance	Cost of assets	732.66	804.50	0.9107	121.40	110.56
Weld Cap	Number of weld cap used	738.90	984.40	0.7506	106.30	79.79
Insurance	Cost of assets	9825.93	635641.86	0.0154	4734.11	72.91
Building Rental	Building floor area	8000.00	120000.00	0.0667	3746.30	249.88
Total cost of Autonomous Robot that perform spot welding process (F)						RM 684.50
Practical Capacity of Autonomous Robot in spot welding process (G)						537.38 min
Capacity cost rate of Autonomous Robot (H=F/G)						1.2738

Table 2: Total cost of autonomous robot

Robot	Capacity cost rate of Autonomous Robot (H)	Practical capacity consumed by spot welding activity (I)	Cost of Autonomous Robot consumed in spot welding activity (J = H x I)	Cost of Autonomous Robot consumed in spot welding is used ABC conventional
1	1.2738	96.405	RM 122.80	1.2938 x120= 152.9
2	1.2738	76.519	RM 97.47	1.2938 x120= 152.9
3	1.2738	128.898	RM 164.19	1.2938 x120= 152.9
Total cost of Autonomous Robot			RM 384.46	RM 458.70

Table 2 shows the calculation to obtain the total cost of Autonomous Robot, which is RM 384.46 for a 10-hour shift (excluding break time). Based on the data shown, the highest cost goes to Robot 3 as the practical capacity consumed by spot welding activity is the highest. This indicates that Robot 3 utilizes the most capacity compared to Robot 1 and Robot 2. Robot 1 is the second highest cost holder with a total of RM 122.80. In contrary, Robot 2 has the lowest cost of RM 97.47, in which its consumed capacity is the least among the three Autonomous Robots. This is probably due to Robot 2 performed spot welding at two stations only.

D. Calculating Capacity Cost Rate for Resources

The practical resources consumed in the welding activity refers to the total amount of time the employee actually spends in the daily activities. In this case, the practical time consumed by an operator is affected by the quantity of products ordered, and the targeted volume of the product to be achieved in one day. The management has set a target of 120 units per shift in 10 hours. Hence, the cycle time for the operator to carry out the activity must time with 120 units. 120 units is chosen based on the normal volume produced at the T11EX assembly production line.

The total available capacity (in minutes) per employee is to assume an employee works for 26 days per month, 10 hours a day (originally 8 hours with an additional compulsory 2 hours overtime) after deducing the break time. As indicated in Table 3, the practical capacity of resources supplied (in minutes) is 15600 mins. Thus, the capacity cost rate for the manpower in the T11EX assembly production line under the

TDABC is RM 0.08 per minute. Based on that the cost resources consumed in welding activity is determined based on pilot run volume 120 units and welding process time individually for four operators. While the same formula was also applied to determine the cost of resource consumed in welding activity for inspectors during inspection activities.

Table 3 also show the cost rate based on ABC conventional method where the data will be used to do comparison between TDABC and ABC. However, data ABC is determined directly based on number of product produced and time involved of each activity carried out by operators and inspectors.

Table 3: Capacity cost rate for resources

Wages	Man Power	Cost Driver	Cost of Resource (RM) (A)	Practical Capacity of Resource (B)	Capacity Cost Rate of Resource (E.g.: unit cost of resource) (C=A/B)	Practical capacity of resource consumed in welding activity (D)	Cost of resource consumed in welding activity (E = C x D)	Cost Rate based on ABC conventional method (RM)
Wages for skilled operator	Op.1	Working hours	1267.80 (Basic + OT)	26days x 10hrs x 60mins = 15600 mins	$C=\frac{RM\,1267.80}{15600\,mins}$ = RM0.08/min	127.6 s x 120 units = 15312 s = 255.2 mins	RM 20.42	198.6s/60x120x 0.08 = RM 31.80
	Op. 2					103.1 s x 120 units = 12372 s = 206.2 mins	RM 16.50	259.1/60x120x 0.08 = RM 41.45
Wages for un-skilled operator	Op. 3	Working hours	1250.10 (Basic + OT)	26days x 10hrs x 60mins = 15600 mins	$C=\frac{RM\,1250.10}{15600\,mins}$ = RM0.08/min	84.9 s x 120 units = 10188 s = 169.8 mins	RM 13.60	159.1/60x120x 0.08 = RM 25.13
	Op. 4					67 s x 120 units = 8040 s = 134 mins	RM 10.72	81s/60x120x 0.08= RM 12.96
Wages for inspectr	Insp. 1	Working hours	1267.80 (Basic + OT)	26days x 10hrs x 60mins = 15600 mins	$C=\frac{RM\,1267.80}{15600\,mins}$ = RM0.08/min	105.2 s x 120 units = 12624 s = 210.4 mins	RM 16.83	129.2s/60x120x 0.08 = RM 20.70
	Insp. 2					172.8 s x 120 units = 20736 s = 345.6 mins	RM 27.65	172.8s/60x120x 0.08 = RM 27.6
	Insp. 3					56.6 s x 75 units = 4245 s = 70.75 mins	RM 5.66	61.1s/60x120x 0.08 = RM 9.78
Total Cost of Resources							RM 111.38	RM 169.42

The TDABC of a spot-welding assembly line is calculated in terms of two elements, namely Autonomous Robot and resources. Table 4 shows comparison between the total cost of the T11EX assembly line using TDABC and ABC method. The total cost TDABC for each shift is RM 495.84, which is 10 hours of production run, whereas the total cost for the assembly line for a month, 2 shifts per day, and 26 days per month is RM 25,783.68. While the total cost for each shift using ABC method is RM628.12. Then, from the data shows costing activities by using TDABC is nearest to the actual cost recorded by the company. Therefore, only data TDABC are applied into simulation model for optimization.

Table 4: Total cost of the T11ex assembly line

Cost Element in T11EX line	TDABC (RM)	ABC Conventional (RM)
Autonomous Robot	RM384.46	RM 458.70
Resources	RM111.38	RM 169.42
Total TDABC of T11EX assembly line	RM495.84	RM 628.12

According to Table 5, the cost elements in the existing costing method of the company are tabulated. This is to show the breakdown of operating costs for a capital-intensive process. The significant cost components shown in the table 5 is the capital cost of equipment (44%) and operator cost (24%).

The equipment cost is estimated in terms of the purchase price for each robot and its tooling. On the other hand, the loan period is 3 years, which is a typical commercial interest rate, and the annual cost of this loan repayment is included in the annual cost of the system.

Table 5: Cost elements in existing costing method

Spot Weld Robot (RM)		Resources (RM)	
Robot maintenance	110.56	Inspector 1	16.83
Weld Cap	79.79	Inspector 2	27.65
Insurance	72.91	Inspector 3	5.66
Building Rental	249.88	Operator 1	20.42
Depreciation of Assets	117.19	Operator 2	16.50
Electrical Consumption	53.72	Operator 3	13.60
		Operator 4	10.72

E. Building the model

Each of these data corresponds to specific objects, such as, the component arrival time is positioned in the Create Module while the time spent in each workstation, and the number of operators are positioned in the Process Module. Since there are a total of three products that run in the same assembly line, this model is considered a multi-line model. The model is created and simulated as shown in Fig. 3.
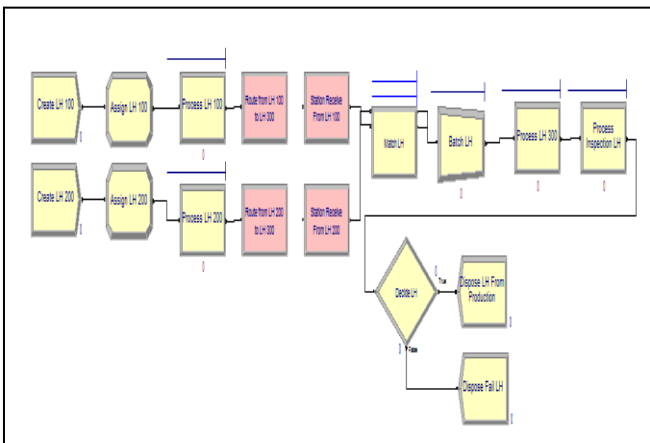
Figure 3: Simulation model

F. Model Validation

The model was validated by comparing the TDABC data with the manually calculated data. It was carried out to ensure the simulation model can predict the cost structures accurately.

Table 6: Comparison of TDABC in simulation and TDABC calculated manually.

| Resource	TDABC in ARENA simulation (RM)	TDABC calculated manually (RM)	Accuracy (%)
Operator 1	20.02	20.42	98.04
Operator 2	16.54	16.50	99.76
Operator 3	13.98	13.60	97.21
Operator 4	10.55	10.72	98.41
Inspector 1	16.69	16.83	99.17
Inspector 2	27.95	27.65	98.92
Inspector 3	5.61	5.66	99.12

The results are tabulated in Table 6. Based on the results shown above, the highest accuracy is 99.76%, which belongs to Operator 2. On the other hand, the lowest accuracy belongs to Operator 3. Overall accuracy is from 97% to 99%.

The minimum accuracy criteria by ISO 15197:2013 stipulates that the measurements result must be at least 95% [20]. Therefore, the output data from the costing calculated in the ARENA simulation is acceptable, and the accuracy is considered impeccable as it is in the higher percentile range of acceptance.

V. RESULTS AND DISCUSSION

The usage of each resource is tabulated in Fig. 4. From the graph, it is clear that some of the operators' utilization are higher, whereas some are barely utilized. The utilization of resources reveals which operator works more (high utilization) and which operator works less (low utilization). The highest utilized resource is Operator 3 with 80.15%, while the lowest utilized resource is Inspector 3 with 11.48%. A few scenarios were constructed to predict the cost changes in Simulation based on the utilization of each resource. The scenarios vary by eliminating unnecessary resources in the production line.
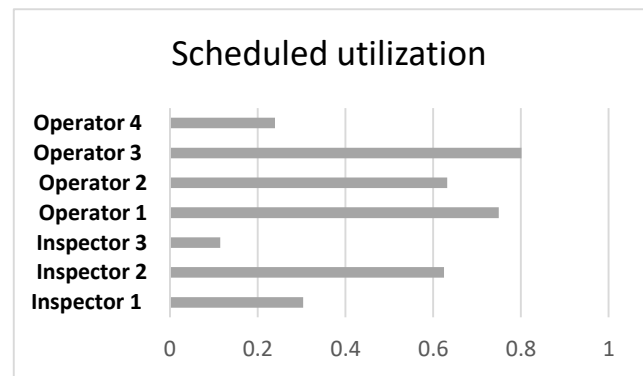
Figure 4: Scheduled Utilization

In reference to Table 6, Scenario 1 represents the current cost for the production line, which is RM 5,791.76. The total cost of production calculated per month is on the basis of 26 days with 2 shifts a day. In Scenario 2, Operator 2 and Operator 4 are eliminated. In the simulation, the activities performed by Operator 2 are added to the activities of Operator 1. Other than that, the job performed by Operator 4 is now allocated to Operator 3. The result of the total cost of production per month for Scenario 2 is RM 4,893.72, which is a reduction of 15.51% of the current cost of the production line.

Table 6: Cost matrix based on different scenarios

Cost Matrix			
Resources	**Scenario 1**	**Scenario 2**	**Scenario 3**
Operator 1	✓	✓	✓
Operator 2	✓	X	✓
Operator 3	✓	✓	✓
Operator 4	✓	X	✓
Inspector 1	✓	✓	X
Inspector 2	✓	✓	✓
Inspector 3	✓	✓	X
Total cost of production per month (RM)	5791.76	4893.72	4936.36
Percentage difference	-	15.51% ↓	14.77% ↓

On the other hand, Scenario 3 eliminates two of the lowest utilized resources, namely Inspector 1 and Inspector 3. The activities performed by Inspector 1 and Inspector 3 are assigned to Inspector 2. In this case, the total cost of production per month for Scenario 3 is reduced to RM 4,893.72 with a difference of 14.77%. Based on the result of cost matrix in simulation, the company can decide whether to implement these scenarios of costing method in their production assembly line. The total cost of resources calculated using TDABC for T11EX line is RM 5,791.76 per month. The company's management who intend to reduce the cost can do so by eliminating unnecessary resources. The comparison of those two scenarios shows the cost reduction for both is relatively close, namely 15.51% and 14.77%.

According to the decision makers, they able used the simulation model to suggest some improvement scenarios for obtaining the best proposal according to predefined performance indicators. Furthermore, the decision makers are able to propose a set of decision choice based on their ranges and variables for optimal solutions.

A. Benefits of simulation embedded to TDABC

From the research conducted, the management is able to organize a cost analysis through the simulation embedded with TDABC which predicts what will happen to the production line when the resources are eliminated. The simulation model allows experimenting with different input values; resources, without having to change it in the actual production line as it is very time-consuming and may affect the whole production line. Other benefits from the observation are:

a). Easy to incorporate specific operation time, and other parameters through the simulation.

b). More visibility to process efficiency and capacity utilization.

c). The simulation model is designed based on the actual process layout and easy to recognize and imagine.

d). Inexpensive and fast to maintain, and update cost production based on customer design changes.

A Time-Driven Activity-Based Costing (TDABC) analysis of an assembly and robot-welding production line was conducted at an automotive manufacturing company. The TDABC model was developed for analysis. In this model, a detailed time equation was formulated for an autonomous robot and resources to estimate the capacity cost rate of the spot-welding activity. The total assembly and production cost for the T11EX line for testing run 120 units is RM 495.84. This paper also compares the accuracy of existing costing method namely ABC conventional with same parameter. ABC conventional method is higher which is RM628.12 compared to TDABC. In this research, TDABC is a more accurate costing model compared to the existing costing model because of the cost allocations and cost drivers used, rather than just making cost assumptions.As a result, this model acts to optimize and reduce the cost of T11EX assembly line by eliminating unnecessary resources. It indicates the simulation can easily be adopted in TDABC to support the planning and operational activities.

V. CONCLUSION

As a conclusion, this paper proposed a new integration between TDABC and simulation for optimizes assembly process and reduces assembly cost through practical capacity of its resources. It thinking about the technological revolution employed data process in assembly process through emerging technology of Industry 4.0. This is a platform from which to inspire manufacturers, suppliers and partnerships on issues related to the current technology.

Now the decision making processes are based on simulation options to obtain the accurate decisions. The concepts were applied to automotive manufacturing assembly process line. Through the TDABC theory, costing method was applied where actual time driven from the actual processes were captured into the simulation model. And the effects of various uncertainties in the costing system such as robot breakdown and absence of operations can be determined and simulated. The results show that, simulation can be developed to enhanced as decision support system into the costing system. Simulation model can be manipulate based on new parameters for improvement process without interrupt existing process setting. Lastly, in future, to improve the process data gathering it is better directly taking from the server via sensor instead of manually through the time study. From the research, it may replace processes that today are done manually may render certain jobs obsolete which very tedious to industrial technical staffs. In the other hand, it may also create new categories of jobs and opportunities that currently do not exist in the market. In the other hand this also encourages the company to speed-up the process of decision making by the manufacturing managers related to the improvement process and costing matters.

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