Estimate Activity Duration with Resource Capacity Approach in Project Production Phase, Case Study: Pump Packaging Production System

Anton Pane(✉), Yusuf Latief, and Leni Sagita Riantini

Civil Engineering Department, Faculty of Engineering, Universitas Indonesia, Kampus Baru UI, Depok 16424, Jawa Barat, Indonesia
{anton.pane,latief73}@ui.ac.id

Abstract. Estimate activity duration, is a process in Project Schedule Management whose output will be Input to develop schedule process. The accuracy of the estimated duration of the activity is an important point in accuracy of the project schedule in general. Case study on production facility PT. ABC, pump packaging company. They set the desired delivery accuracy level at least 95% (−5%), so it is necessary to develop a new duration estimation system that is integrated between resources (labor, equipment and availability of area/Space) that can be translated into resource capacity, to be used in a more accurate estimate activity duration method. The duration estimation approach in previous studies used and or developed with common methods, including three-point estimation/PERT, analogy, parametric, expert judgment. Several studies also use new approaches such as anchoring method, competency-based duration estimation, duration specification limit duration and estimate activity duration with productivity influence approach. This study proposes development of a new method of estimate activity duration with capacity-based resources. With categories, labor resources, equipment resources, material resources and new variables of location/space resources which are then translated in to resource capacity. The methodology used is archival analysis and statistical analysis for secondary data as well as expert validation questionnaires for primary data on implementation methods, preparation of Work Breakdown Structure (WBS), define activity, estimate activity resources and estimate resources capacity. Simulation of estimate activity duration using monte carlo with heterogeneous of resource capacity. The study resulted implementation method with 10 (ten) processes, 6 (six) WBS levels consisting of level 1 projects, level 2 work groups, level 3 consisting of 13 sub-work, level 4 work packages, level 5 with 83 activities and level 6 with 87 resources that have been entered in 83 activities. Labor resources were identified 13 types, equipment resources 19 types, material resources 30 types and location/space resources 13 types with their respective capacities have been analyzed. Simulation Model with monte carlo can be presented with resource input parameters and provide forecasting project activity duration with standard error <0.001 days.

Keywords: estimate · pump · packaging

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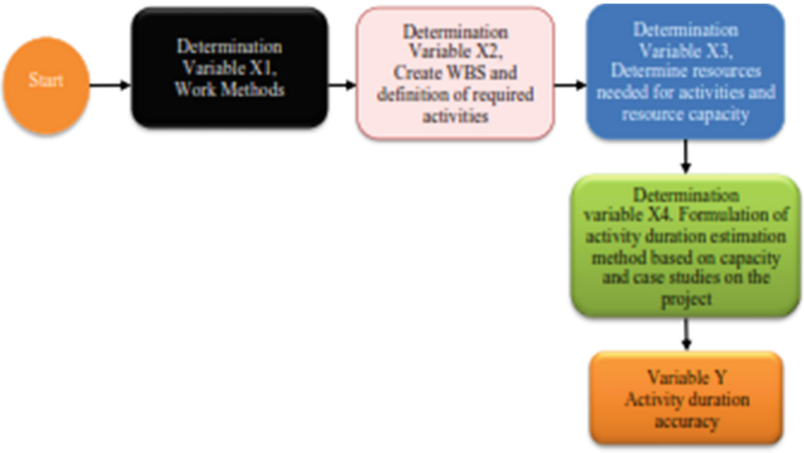

Fig. 1. Research operational model flow chart

1 Introduction

Accuracy of project schedules on pump fabrication and packaging work is greatly influenced by the accuracy and detail duration estimation process at the activity level. The precise duration of the activity level makes the overall project schedule have in good accuracy. Rough order of magnitude (ROM) accuracy information at the project execution level, ranged from ±10% [1]. Classification of good schedule performance in the construction period in the range ≤8% (average), >4% (good) [2].

In PT. ABC, existing calculation system cannot meet the desired level of accuracy that is at least 95% (−5%). So, it is necessary to develop a new duration estimation system that is integrated between resources (labor, equipment, materials and availability of location/Space) that can be translated into resource capacity, to be used in a more accurate method of estimating activity duration. Based on the problem formulation and the research question, research objectives and Operational Model as shown in Fig. 1.

2 Literature Review

Level of Accuracy (LOA) is an accuracy level that specifies an acceptable range used in determining realistic estimates of activity duration and may include contingency amounts [3]. The accuracy of project estimates will increase as the life-cycle of the project progresses. For example, project in the initiation phase may have a rough order of magnitude (ROM) in range of −25% to +75%. In project implementation phase, as more information becomes known, definitive estimates can narrow the accuracy range to −5% to +10% [3]. [4] classify project duration performance to five scale, (5) good if faster >4%, (4) quite good if faster between 0%–4%, (3) average if Late <−8%, (2) a little late if late −8%−−16% and (1) bad if late >16%.

Work method of pump packaging refers to work life-cycle itself, which is arranged per work center with finish to start sequence. Packaging process starts from material procurement, material arrival inspection, preparation, fabrication, unitization, accessories

installation, final inspection and function test, factory acceptance test with customer and delivery after QC pass [5].

Create WBS is the process of dividing project deliverables and project work into smaller components making it easier to manage. The main benefit of this process is that it provides a framework on what should be delivery [3].

Define activities is the process of identifying and documenting the specific actions to be performed to produce a project deliverable [3]. According to [6] and quote by [7], specified WBS Level consists of:

- WBS Level 1: Project Name,
- WBS Level 2: working groups/divisions,
- WBS Level 3: Sub jobs,
- WBS Level 4: work package,
- WBS Level 5: Activity,
- WBS Level 6: Resources

Estimate activity resources is the process of estimating a team's resources, the types and quantities of materials, equipment, and supplies needed to perform project work [3]. Duration is an estimate of how long it takes to complete a job in one activity [8]. Estimation is a quantitative assessment of possible quantities or outcomes [1], in terms of project schedule should always include some indication of accuracy (eg, % percent) [8]. Activities are part of the work scheduled carried out throughout the project [3]. Estimate activity duration is the process of estimating the length of the period of work required to complete an individual activity with the estimation of resource availability, to obtain the amount of time each activity takes to complete, this process takes place throughout the project [3].

Capacity management involves managing amount of what is owned and used by the organization to do the work, as office space, production facilities, warehouses, and in other ways for the work to be done [9]. Capacity entities are space, labor, equipment, and materials. Space represents the physical location owned by the company, and it is where the company's work is carried out, including manufacturing facilities, office space, and warehouses. Labor capacity is amount of labor that an organization employee to perform a job, encompassing both direct labor and indirect labor. Labor capacity in units of time is equal to the number of individuals in the organization and the hours that each individual performs work. Equipment, identical to machinery and technology, equipment capacity is obtained between the highest speed, multiplied by the number of hours in operation. Material capacity is material that the organization has and the number of units needed to determine each finished product. [9] also stated that resource heterogenization can increase capacity with the same competence.

To simulate the relationship and accuracy between resources and capacity in estimate activity duration used Monte Carlo simulation, which involves establishing the probability distribution of a studied variable and then performing random sampling of the distribution to generate the data. When the system contains elements that exhibit behavior that tends to be uncertain or probabilistic [10]. [11] explains that the simulation must be done with computer models to mimic the actual events or to make predictions. The model commonly used is deterministic, that is, the results obtained will be the same no

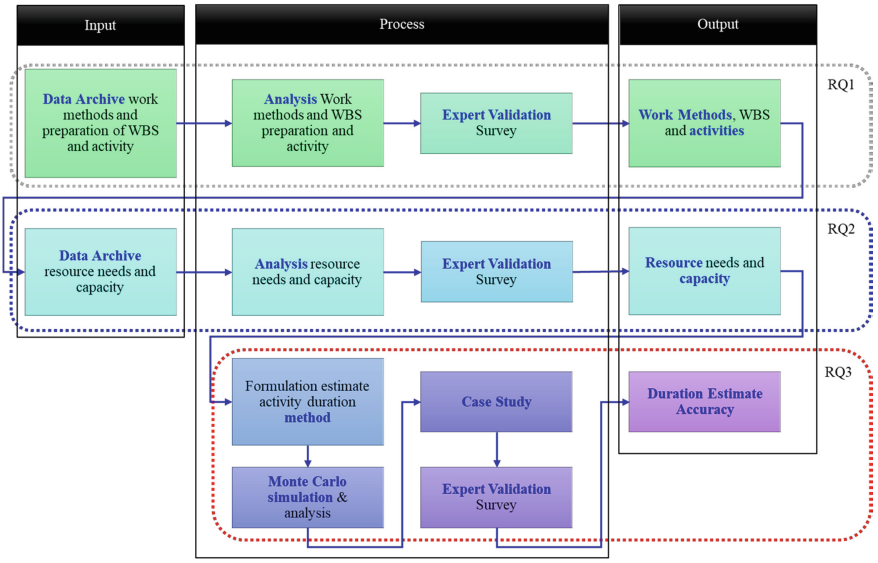

Fig. 2. Research process flow chart

matter how many times the recalculation is done. [11] also say, to create a Monte Carlo simulation model using Excel, 5 steps are required.

3 Research Method

The research process and variable in this study as shown in the flow diagram in Fig. 2.

3.1 Research Instruments and Data Collection Methods

There are two independent variables (X), work method (X1) and preparation of WBS (X2) to define the activity should answer as RQ1. For variables X1 and X2, the research instrument used is archive analysis. Work method and WBS were validated with expert survey phase 1.

WBS and activity list that have been validated by experts in RQ1 become inputs for answer RQ2. Indicators and dimensions of estimate resource and capacity, sent to experts for validation phase 2 using questionnaire. Output variables RQ1 and RQ2 will as input to answer RQ3, the formulation of activity duration estimates is carried out based on four types of resources (labor, equipment, material and space) using essential capacity theory. The results were simulated by Monte Carlo method to define accuracy of estimation.

Primary data collection for expert validation is done by Delphi method, referring to [7] experts who will be asked for validation at all stages are 5 people with at least 15 years of experience as a planner, project control, production manager or project manager in business area of pump fabrication and packaging with a minimum of Bachelor education. Input and notes from experts will be used for improvement.

Secondary data collection to answer RQ1 and RQ2 is done by archival analysis to determine pump packaging work method, WBS until activity, estimate resources need and its capacity using internal data PT. ABC. To answer RQ3, the formulation of activity duration estimation methods based on four types of resource, it's capacity and essential capacity theory was carried out by simulation with Monte Carlo method to obtain the accuracy of duration estimation.

3.2 Data Analysis Methods

Data analysis in this study is mostly based PMBOK 6th edition and using delphi method. According to [12] when the feedback given in round 3 indicates that ≥75% of the experts agree, the category is considered as being relevant, whereas if the feedback indicates <75% group agreement, the individual opinion tends to shift towards the group opinion. Data analysis is done deterministically to answer RQ1 and RQ2 with expert validation, then to answer RQ3 used probabilistic analysis with Monte Carlo method. Analysis of data from archive using descriptive statistics by statistic program IBM SPSS 25. Estimate activity duration with human resource capacity approach using the formula [9], reprocessed.

$$Time = \frac{Output}{Operation/time} \tag{1}$$

Capacity material come from longest material procurement time among the materials needed in one activity, calculated with formula [3] reprocessed:

$$Material\ duration = Max \sum \text{Procurement time} \tag{2}$$

Duration calculation using PERT analysis, with the formula from [3].

$$tE(mean) = \frac{(t0 + 4tM + tP)}{6} \tag{3}$$

$$\sigma(standard\ deviation) = \frac{(tP + t0)}{6} \tag{4}$$

$$\sigma^2(variance) = \left(\frac{(tP + t0)}{6}\right)^2 \tag{5}$$

After activity duration estimation is done, validation of activity duration estimation with heterogenous 4 (four) types of resources as shown in Table 1 from [9], reprocessed.

Heterogenous parameter using resources capacity ratio, space to labor (S-L) is used to ensure the work location space in accordance with the cumulative needs of labor resources space. The space requirement per labor resource is at least 40 ft2 or 3.7 m^2 [13]. Space is sufficient if the space-labor ratio is ≤1. Space to equipment (S-E) is used to ensure job site space in accordance with the cumulative needs of equipment space, space is sufficient if the equipment-space ratio ≤1. Space to materials (S-M) is used to ensure the space of material storage locations in accordance with the cumulative needs of material dimensions, space is sufficient if the space-Material ratio is ≤1. Labor to

Table 1. Production capacity with heterogeneity of resources

Resources	Labor	Equipment	Material
Space (S)	S-L	S-E	S-M
Labor (L)		L-E	

equipment (L-E) is used to ensure that the equipment needed is in accordance with the number of labors, equipment is sufficient if the labor-equipment ratio is equal to $\leq$1. Monte Carlo simulation using an excel program with a model developed by self. According to [11], there are five steps to create a monte carlo simulation model using excel.

4 Data Analysis

4.1 Data Analysis Work Methods

Referring to method of data analysis, that if the expert agrees $\geq$75%, the indicator can be considered relevant. Analysis data for work method developed from SOP - production process & quality In-Step Production [14], which consists of 9 processes, that are:

1. Design
2. Procurement
3. Arrival
4. Preparation
5. Fabrication
6. Unitization
7. Mounting accessories
8. Inspection and testing
9. Shipping

4.2 Data Analysis Create WBS

Expert validated work method, WBS level 1, 2, 3, WBS level 4 and WBS level 5, as input for create WBS standards of pump packaging, as shown in Fig. 3.

WBS packaging pumps level 1, 2, 3 and 4 as shown in Fig. 4. Level 2 can be more than one on a multi-project, level 3 consists of 6 sub-work, and level 4 consists of 28 work packages.

Data collection for estimate resources analysis results at WBS level 6. Resources are divided into four types, for Human Resources (Labor) experts agree on 25 types. For equipment resources, experts agree on 19 types of resources. For material resources, experts agree on 30 types and location resources (Space), experts agree on 13 types. Primary data collection validation experts conducted surveys to 5 (five) experts to validation of construct, indicators, sub indicators and dimensions of estimation and resource capacity. Secondary data collection for the capacity of each resource, using the internal

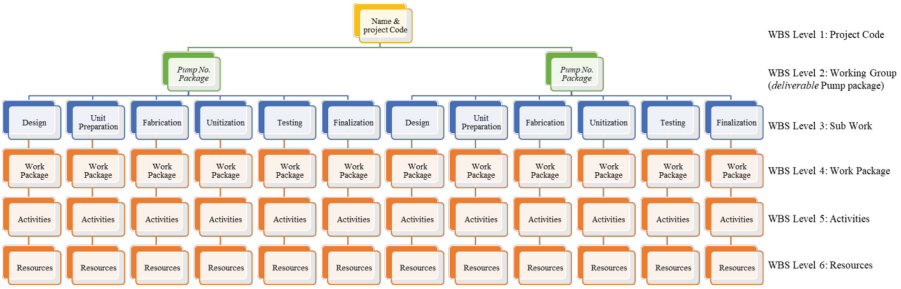

Fig. 3. WBS 6 level Pump Packaging

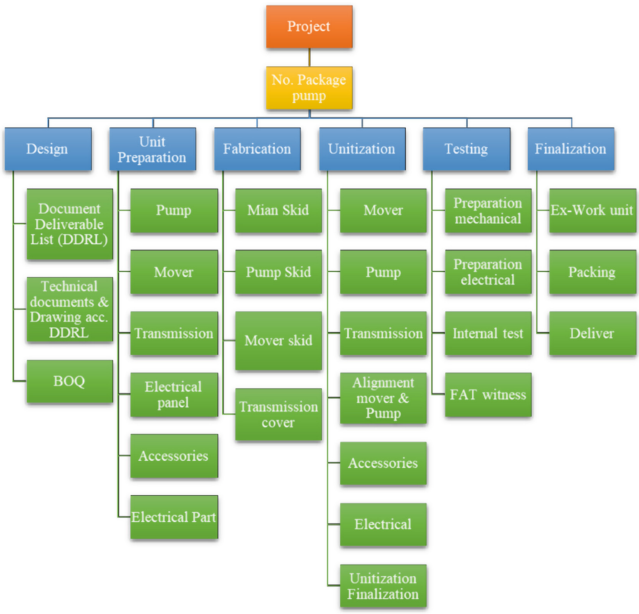

Fig. 4. Hierarchs WBS pump packaging level 1, 2, 3, 4 WBS Level 5 consists of 86 activities on 27 work packages.

archive data of PT ABC. Labor capacity analysis is carried out on all resources, summary of statistical analysis results can be seen in Table 2. Recapitulation of statistical analysis results for capacity material can be seen in the Table 3.

Analysis capacity of space refer to available square area per work centre as per work method, data archive from factory layout.

4.3 Estimation of Normal Activity Duration and Resources Heterogeneous

Normal duration estimation of each activity is calculated by using and referring to the answer RQ2, estimation of activity duration with labor resource capacity approach

Table 2. Recapitulation of statistical analysis for labor resource capacity data

Data analysis	Sub indicators																			
	X3.1.1	X3.1.2	X3.1.3	X3.1.4	X3.1.6	X3.1.7	X3.1.8	X3.1.9	X3.1.12	X3.1.13	X3.1.14	X3.1.16	X3.1.17	X3.1.19	X3.1.20	X3.1.21	X3.1.22	X3.1.23	X3.1.24	X3.1.25
	Document control	Pump Engineer	Production Engineer	Fitter	Rotating engineer	Manager Engineering	Manager IT	Manager Purchasing	Painter	Project Coordinator	Project Engineer	PPIC	Quality Control	Asset officer	Procurement officer	Electrical technician	Technician level1	Technician level2	Technician NDT	Welder
Capacity-P	1	1	1	0.3	5	1	1	1.0	0.1	1	1	1.0	0.1	1	1	0.1	0.1	0.1	0.1	0.3
Capacity-M	2	6	2	1	1	21.5	5.5	23	1	1	3	14	1	14	7	1	1	1	1	1
Capacity-O	24	276	24	1	1	274	27	129	1	9	80	133	1	79	58	1	1	1	1	1

Table 3. Recapitulation of material resources capacity analysis

Data analysis	X3.3.1	X3.3.2	X3.3.3	X3.3.4	X3.3.5	X3.3.6	X3.3.7	X3.3.8	X3.3.9	X3.3.10	X3.3.11	X3.3.12	X3.3.13	X3.3.15	X3.3.16	X3.3.17
	Discharge Accessories	Suction Accessories	Cable Wiring Accessories	Bolts and nuts	Instrument	Cable	Cable tray acc.	Material NDT	Material protecting	Material Paint	Material Weld	Material Pipa dan fitting	Material Skid	Packing	Panel Boks	Part Elektrikal
Capacity-P	128	128	62	62	128	108	46	17	19	55	20	62	19	65	67	131
Capacity-M	13	13	8	9	13	8	33	17	14	15	7	12	14	27	27	14
Capacity-O	2	2	2	1	2	2	15	13	5	7	1	1	8	1	4	2

Table 4. Calculation of duration and heterogenous resources

WBS code	Level 5: Activity	Level 6: Resources		Resources Capacity				Duration		
		Resources	Type	Q'ty	Dimension (m^2)	Capacity-P	Capacity-M	Capacity-O	tP (b) (days)	tM (days)	tO (a) (days)
(1)	(2)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(14)	(18)	(22)
1.1.1.1.1	Create DDRL documents								1.00	0.33	0.01
1.1.1.1.1.1		Project Engineer	Labor	1	3.7	1.00	3.00	80.00			
1.1.1.1.1.2		Computer	Equipment	1	0	0.00	0.00	0.00			
1.1.1.1.1.3		Office	Space	1		0.00	64.00	0.00			

WBS code	Level 5: Activity	Level 6: Resources	PERT			Heterogenous			
			(tE)	(σ^2)	(σ)	(S-L)	S-E)	(S-M)	(L-E)
(1)	(2)	(4)	(23)	(24)	(25)	(28)	(29)	(30)	(31)
1.1.1.1.1	Create DDRL documents		0.39	0.03	0.16	0.06	0.00	0.00	1.00
1.1.1.1.1.1		Project Engineer							
1.1.1.1.1.2		Computer							
1.1.1.1.1.3		Office							

using formula (1) and formula (2), also using PERT analysis, with formula: (3), (4), (5). Examples of calculations in table 4.

4.4 Monte Carlo Simulation

Monte-Carlo simulation for activity duration estimation was developed using Ms. Excel. Simulation example selected activity for DDRL document creation, WBS number: 1.1.1.1.1. Simulation steps as follows:

1. Parametric Model of estimating the duration DDRL document creation activity is:
    a. Mean (tE): calculated by formula (1), taken from column (23), Table 4 = 0.39 days.
    b. Standard deviation (σ): calculated by formula (3), taken from column (25), Table 4 = 0.16 days
2. Random input, using the excel function (=NORM.INV (rand (), mean (tE), standard_deviation). The number of random number intervals is at least 10,000.
3. Model displayed result include central tendency, spread, interval, significance, and probability. The result will always move every program in running, in this simulation it uses the F9 function.
4. Central tendency of the spread shown is average, standard error, median,
5. Spread shown are standard deviation, minimum value, maximum value, range
6. Custom Interval, With alpha (α) = 0.01 or 0.05 the interval shown is % interval, lower bound (Q (α/2), upper bound (Q(1 − α/2)
7. Probability are displayed interval Qα/2 (Pr(y > A), probability Q (Pr (y < B), validation probabilities A and B with % interval(Pr (A < y < B), as well as validation Alpha (α). (1 − α/2)
8. Repeat steps 2 and 3 all the way to n iterations, n = 100, done by setting the maximum iteration in Ms Excel
9. Result analysis are analyzed with histograms, statistical summaries and confident intervals. The appearance of histograms and UDF curves is carried out by compiling a table of intervals, frequencies and cumulative frequencies. Simulation for all activities can be done on the model as shown in Fig. 5.

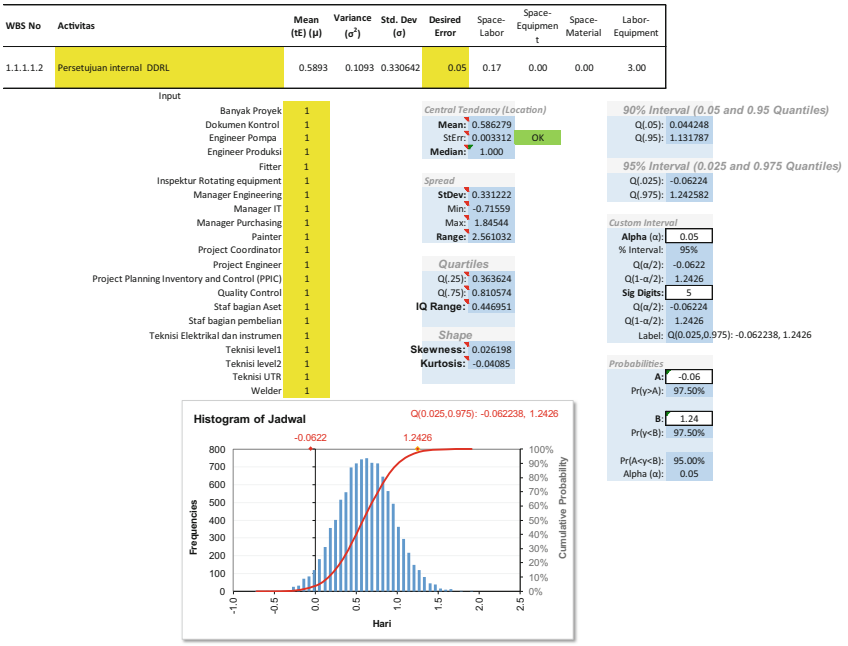

Fig. 5. Monte Carlo simulation Model for activity duration estimation

5 Conclusion

This study produced three results as answer to research questions, that are:

1. The work method of pump packaging it is known that 9 (nine) sequential processes in work method of pump packaging, that are design, procurement, arrival, preparation, fabrication, unitization, installation of accessories, inspection and testing and delivery.
2. Work Breakdown Structure (WBS) pump packaging can be agreed upon by experts consisting of 6 levels.
3. From WBS level 6 experts agreed 86 activities in implementation of pump packaging work. This predetermined activity can be used for the next process, that are develop schedule in the pump packaging project.
4. From the answer 2nd research question, the experts agree that the resources needed for the implementation of pump packaging work consist of 4 (four) types, that are labor resources consisting of 25 types. Equipment resources, the experts agreed on 19 types of resources. Material resources, experts agree on 30 types and location resources (Space), experts agree on 13 types. This resource estimate is an input to develop schedule process.
5. The answer RQ2 also produces the capacity of each resource related to activity duration of pump packaging project using the theory of essential capacity management of [9]. This resource capacity is used as an input component to estimate duration of

each activity that has been determined by the resource. So that the estimated duration can be accurate in accordance with the capacity of resources.

6. After the resource capacity is known, estimate duration activity can be done, this study also proposed a model using Monte Carlo simulation method. This simulation can show the impact of changes in project inputs on the duration of each activity with a standard error <0.01 days.

   Specifically, the results of this study can be used for further research in terms of schedule management of pump packaging fabrication projects in particular, but can also be used as a scientific reference for Project Time Management in general. Monte Carlo simulation can also be used in project fabrication workshops as basis for decision making by project management team related to project schedule, cost and risk management.

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