Optimizing the Rock Mechanic Laboratory Operations: Simulation-Based Methodology for Investment Decision

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Abstract

The aim of the research is to optimize the rock mechanic laboratory operations for an investment decision by implementing a simulation-based methodology. The result of a well-balanced system is optimum operation. The imbalanced system, on the other hand, has a long wait time and a low utilization. It is possible to rearrange the machinery, flow process, and workforce using simulation to obtain the most balanced system.
The case study was conducted at a rock mechanics laboratory in Indonesia. The laboratory's testing stations have a massive sample queue, indicating an unbalanced system. Observation of current testing activities will help to define the critical path and assist in the development of the simulation model. The operations are optimized by minimizing the currently hidden costs, injecting new testing into the sequence, and simulating the investment options. The investment option will be weighed against the hidden costs to determine the most cost-effective.
The value of research is the usefulness of simulation in revealing the hidden costs of an inefficient system. Additional expenditure may be required to reduce the ongoing hidden costs. The simulation may also be used to determine the best investment choice for the company's expansion.

Keywords
Simulation, Optimization, Hidden Cost, Rock Mechanic Laboratory, Investment Decision

1. Introduction
Considering the current economic development, companies are forced to deal with the topic of process optimization (Potters et al., 2020). In early time, the gradient optimization techniques were commonly used in different engineering design applications due to their fast and accurate solutions (Ahmid et al., 2019). The simulation is a tool to find out an optimum system. Simulation is one of the most widely used quantitative analysis tools. To simulate is to try to duplicate the features, appearance, and characteristics of a real system (Render et al., 2012). It combines various scenarios and criteria to determine the optimal point for each activity. The queue, waiting time, delay, and low utilization are caused by an imbalance of resources and capacity. The maximum available input and the expected output are also used as parameters in the optimization approach.
In coal mining company, the rock mechanic laboratory (laboratory) performs rock-core testing for rock mechanic data. Physical properties (PP), direct shear (DS), uniaxial compressive strength (UCS), and point load (PL) are all tests of it. Each testing station has various sub-stations. It can be either standalone, sequential, or a combination. The sample queue at the test station continues to expand as a result of waiting for the previous tests and/or a specific workforce. On the other hand, the other testing stations revealed the low utilization of machinery and high standby time of workforces. The queue, low utilization, and high standby time are indicators of inefficient testing activities.

1.1 Objectives
The inefficient operation will result in a hidden cost. It may require additional investment and routine operating expenditures to be optimized. If the investment accommodates the inputs, utilization, and output, the cost spent will improve the economic value. To determine the optimum point of the testing station, simulations with various scenarios must be developed. This research will discuss the existing testing activity, identify the *bottleneck*, reveal the hidden costs, and simulate the optimum scenario for an investment option.

2. Literature Review

Operational excellence means that an enterprise is running their operations in the best possible manner (Mitchell 2015). Operational excellence necessitates a careful allocation of resources and capacity. However, not all business activities have limitless resources. Companies should do a capacity plan evaluation to ensure maximum utilization. The objective of strategic capacity planning is to provide an approach in determining the overall capacity level of capital-intensive resources—facilities, equipment, and overall labor force size—that supports the company's long-term competitive strategy best (Jacobs and Chase 2018). Risk management is a strategy for achieving operational excellence in business activity. Project risk management is defined as the systematic process of recognizing, evaluating, and replying to risk as a related task to the project, or decision-making behavior that is not known in advance, but influences the project goal (Malak et al., 2020). The risk management improvement necessitates the costs and resources. Simulation can be used to determine the optimum improvement scenario to adopt.

Simulation is defining input parameters (arrival), processing to their capacity, and the output expected. According to Jacobs and Chase (2018), in the simulation, there are at least 4 main elements that must be considered. They are distribution, pattern, size of arrival, and degree of patience. Figure 1 shows the arrival in queues, according to Jacobs and Chase (2018), with modification.

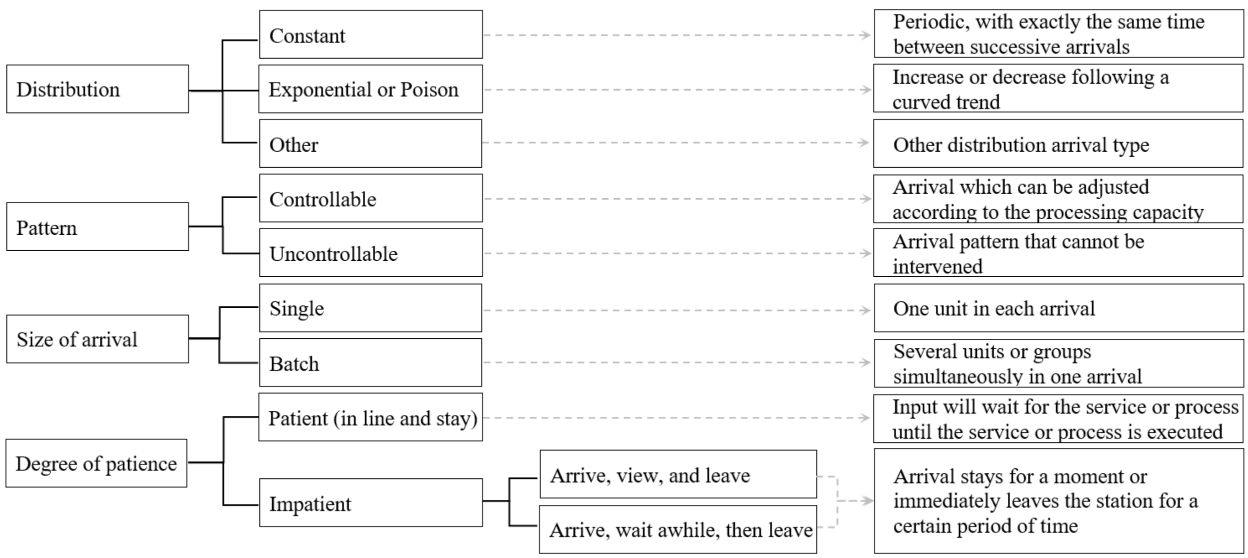


Figure 1. Arrival in queues (Jacobs and Chase 2018)

Distribution, pattern, size of arrival, and degree of patience are the key to the input stations. To simplify simulation, a complex system can be divided into levels. The business simulation within the model factory reduces the complexity of realistic systems (Potters et al., 2020). If all predecessors do not finish at the same time, multiple-input causes a queue. Moreover, if there is required un-ready input, the ready input will be in waiting time mode.

The simulation can be used at the beginning of a company's planning as well as to optimize existing operations. To address this real-life problem, the impact of lean methods on the assembly of a series production is quantified through a business simulation at a model factory (Potters et al., 2020). The simulation requires a comprehensive model to describe the real situation. The idea behind simulation is to imitate a real-world situation with a mathematical model that does not affect operations (Render et al., 2012). According to Kuhn and Schmidt (1988), the aim of simulation is to gain information about the behavior of a real (existing or future) dynamic system by using a model in order to plan and exploit its optimally (Kuhn and Schmidt 1988). The simulation requires detailed data to imitate real-world conditions and minimize the deviations. Businesses have been making increasing use of simulation modeling as a powerful technique in evaluating and analyzing alternative strategies in designing manufacturing and business system (Aghaie and Popplewell 1997). The rapid growth of technology encourages the use of computers for detail and broader simulations. The computer will minimize human error and speeds up computations for repetitive tasks. The increased complexity of design requirements and process technology requires the inclusion of additional variables in the simulation model to make the analysis more realistic and worthwhile (Palaniswami and Jenicke 1992). Simulation has grown rapidly and applied widely in various aspects. Simulation can improve the education and effectiveness of a manufacturing engineer and help develop the art of decision-making (Greasley 2004). Simulation has developed into a powerful tool for planning and optimizing existing systems. Simulation can be used to determine the most suitable improvement plan. It is also used to evaluate the performance of possibilities to be applied in the system in order to predict and evaluate decisions before they are effectively implemented (Santos and Lordelo 2019).

3. Methods

The first stage in the research is observing current activities. Imitating flow tests, machinery activity, and workforce behavior is a strategy to obtain a comprehensive picture of current laboratory activities. The second stage is the identification of un-optimum activity. The critical path method (CPM) is used to determine the time required in a testing sequence. The most time-consuming and available time in between will be shown by plotting the test period in a chart. Injecting extra testing into available time will increase machinery utilization. Schedule compression is used to shorten or accelerate the schedule duration without reducing the project scope in order to meet schedule constraints, specified dates, or other schedule objectives (Augyhana et al., 2019). The third stage is to develop the simulation model. Arena Simulation is used to run the model for over a year. To simplify, complicated activities are divided into smaller levels.

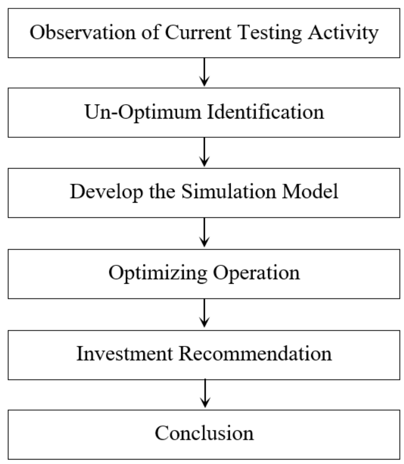


Figure 2. Methodology

Operations are optimized by modifying the simulation model under various conditions. Changes in data will have an impact on the input data, expected outputs, and data processor. Meanwhile, model changes were adding stations, removing stations, and re-routing existing stations will change the system. Arena Simulation will collect data such as waiting time, utilization, value-added time and expected output.
The last stage of the research is to provide investment recommendations. Increasing the capacity of the machinery, adding resources, upgrading workforce competencies, and combining them all necessitates the costs. Revenue and profit will increase as a result of operational excellence. Increasing the number of tests, operating efficiency, minimizing hidden costs, and their combination are the strategies to achieve it. Simulation can be a powerful tool for determining the best scenario for investment decisions. Figure 2 depicts this research methodology.

4. Data Collection

The mechanical testing of rock cores is performed by the rock mechanic laboratory. Two drilling machines collect the rock cores. On average, each drilling machine collects 120 m rock core in two weeks. At least one sample is tested every 5 meters. When there are changes in characteristics, lithology, or geological structures, tests are also performed. The rock mechanic laboratory is managed by one Laboratory Analyst (Analyst), two Laboratory Technicians (Technicians), and one Laboratory Crew (Crew). The Crew has the lowest level of competency, while the Analyst is the most expert in rock mechanics. Lower-competency activity can be performed by a higher-competency person, but not vice versa.
The crew is in charge of *Sample Administration*. The Technician or Analyst can do this task. Meanwhile, an Analyst is required as a minimum competency in *Reporting*. The *reporting* can only be done by an Analyst. The effective

working hours of the rock mechanic laboratory are 8 hours each day. Uninterrupted activities such as *oven drying*, *drying molding*, and *soaking* are conducted within 24 hours continuously. The following are the testing steps:

a. Sample Administration
   Sample administration is the activity of receiving, registering, determining the testing order, and storing samples in the warehouse. It takes 1 hour and requires Crew as the minimum competency level.

b. Preparation
   Preparation is the activity of cutting the sample, smoothing the surface, measuring the thickness, and taking photos of the sample. The preparation requires at least two persons and takes 5 hours for 24 samples. The crew is the minimum level competency allowed.

c. Physical Properties Test (PP)
   The physical properties test is a four-weighing test performed by a single person. The technician is the minimum level competency allowed.
   - Normal weighing
     The samples are weighed immediately after they have been prepared. At this stage, there is no treatment. It takes 30 minutes for 24 samples.
   - Saturated weighing
     The sample is stored in a water-filled desiccator cup. By sucking the air trapped within the cup, it becomes an airtight soak. The soaking takes 24 hours. Then, the sample is drained for 1 hour. The weighing takes 30 minutes.
   - Hanging weighing
     It is a sample weighing in the floating force. Hanging weighing is performed by storing the sample in suspended water. It takes 1 hour for 24 samples.
   - Dry weighing
     It is removing the water contained in the oven. The oven-drying activity takes 24 hours continuously. The weighing takes 30 minutes for 24 samples.

Table 1. Testing activities

Activity	Designation	Predecessor	Duration (hours)	Activity	Designation	Predecessor	Duration (hours)
Sample Administration	A	-	1	**Uniaxial Compressive Strength (UCS)**			
Preparation	B	A	5	UCS Test	D1	B	4
Physical Properties (PP)				UCS Report	D2	D1	24
Normal Weighing	C1	B	0.5	**Point Load (PL)**			
Soaking	C2	C1	8	PL Test	E1	B	4
Draining	C3	C2	1	PL Report	E2	E1	8
Wet Weighing	C4	C3	0.5	**Direct Shear (DS)**			
Float Weighing	C5	C4	0.5	Cementing	F1	B	1
Water Drying	C6	C5	8	Cement Drying	F2	F1	96
Dry Weighing	C7	C6	0.5	DS Testing	F3	F2	3
PP Report	C8	C7	8	DS Report	F4	F3	16
				Summary Report	G	C7;D2;E2;F4	8

d. Uniaxial Compressive Strength Test (UCS)
   The compressive strength of the rock core is determined using the UCS test. The core is pressed by a hydraulic machine with constant pressure. The strength of the rock core is measured at the point of cracking. The testing takes 4 hours for 1 person. The technician is the minimum competency level allowed.

e. Point Load Test (PL)
   The point load test determines the core's ability to tolerate a focused load. The hydraulic pressure will break the sample and record the data to the computer. It can be completed in 4 hours by one person. The technician is the minimum competency level allowed.

f. Direct Shear Test (DS)
   The direct shear test determines the rock resistance to the shear force. The DS test is the most time-consuming in the testing sequence. The sample is molded in the cement, then dried for 5 days. The sample is re-molded on the opposite side and takes 1 week for drying. It can be completed by one person with a Crew as minimum

competency level. DS Test is performed by shearing the sample in the DS machine. It takes 3 hours by 3 persons and one of them must be an Analyst.

g. Reporting

Reporting is the process of collecting data for each testing station and creating summary reports. A sample set requires three days of UCS data analysis, one day of PP data analysis, one day of PL data analysis, two days of DS data analysis, and one day of summary report writing. Analyst is the sole ones that conduct data analysis and reporting. Table 1 shows a summary of testing activities.

The critical path will be determined by observing current testing activities. The critical path is the project's most time-consuming activity. Its delay will cause the delay of the entire activity. For non-critical path activity, if the delay does not exceed the critical path, it is still conceivable to delay without delaying the entire project.

5. Results and Discussion

The un-optimum station identification, CPM analysis, injecting the new testing, and simulation will be discussed in this chapter.

5.1 Un-Optimum Identification

Un-optimum station identification is started by plotting the CPM. It is shown in Figure 3 below. The early start is the beginning time of activity. It was the completion time of the previous activity which has a predecessor activity. The early finish is the time to complete an activity. The early finish is an early start added to the duration of the activity. Early start and early finish are calculated from the beginning of the activity. The late finish is the final time to complete an activity, while the late start is the completion time deducted by the duration of an activity. Late finish and late start are calculated backward from the total completion time of the activity. The time consumed of testing stations are 41 hours for the PP test, 42 hours for the UCS test, 26 hours for the PL test, and 130 hours for the DS test.

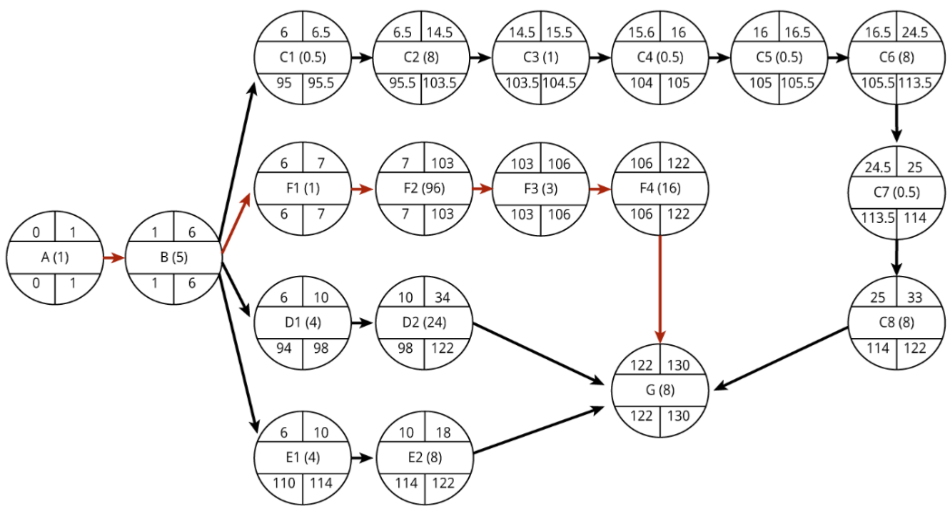


Figure 3. The critical path of rock mechanic laboratory

DS test is the critical path in the rock mechanic laboratory. It was A – B – F1 – F2 – F3 – F4 – G, for a total of 130 hours. Knowing the critical path is important to maintain the accuracy of the simulation model. If we focus our attention only on the critical path, we may have another noncritical path become critical and the project will be delayed since we have uncertainty in estimated duration (Malak et al., 2020).

Workforce and machinery limitations are the most common problem in the industry. Plotting the workforces into a chart will show the available space of an unutilized workforce. It is shown in Figure 4 below. The horizontal axis is the testing duration and the vertical axis is the available workforce. Non-personnel activities are plotted above the red line. They are *core soaking*, *core drying*, *oven drying*, and *cement drying*. *Cement drying* (F2) becomes the most time-consuming, it takes 96 hours. Although it is non-personnel activities, the *DS Test* (F3), *DS reporting* (F4), and *Summary Report* (G) still waiting for the completion of *Cement Drying* (F2) first. *Reporting* is a second time-consuming activity since only an Analyst can do it. Injecting another testing in available space is an action to maximize the utilization. However, it is necessary to plot the main-testing sequence as the limit of the available workforce.

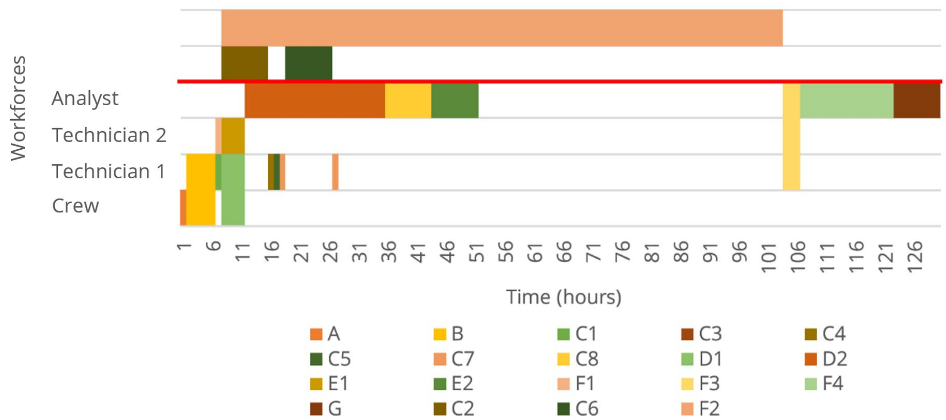


Figure 4. A complete testing sequence

Figure 5 shows the injecting of new testing in a testing sequence. The main testing activity is symbolized by a letter and/or number-suffix (example: A, B, C1, D2, F1, G). While the number-prefix symbol is an injected testing (example: 3B means B for the third drill-hole).

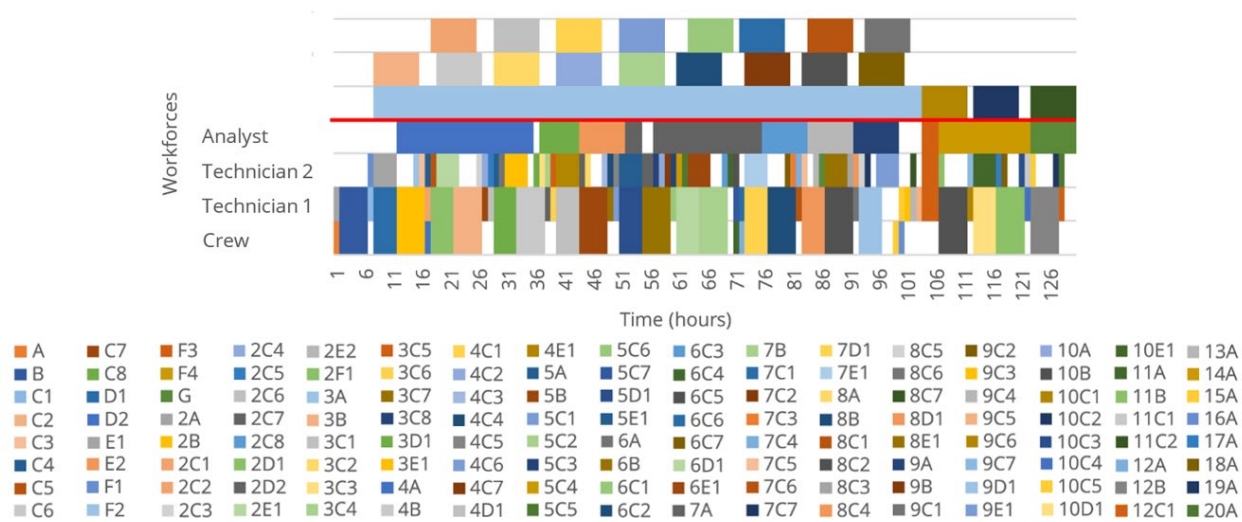


Figure 5. Injecting another testing

A complete testing sequence takes 16.25 days. The *Administration* is the most completed activity (20 samples). *Cement Drying*, *DS Testing*, *DS Report*, and *Summary Report* are the least completed activity (1 sample). It was the *bottleneck* of a testing sequence. All reporting also becomes another *bottleneck*, since only the Analyst can do it. Table 2 shows the testing frequency in a testing sequence.

DS testing takes ten times as long as other tests. Another fact is that reporting can be accomplished in one-fifth, or 20%, of the time spent for testing. It requires extra *DS Testing* toolsets as well as an additional qualified person for analysis and reporting. *The administration* is an independent activity in the rock mechanic laboratory. It can do a lot more tasks without any further treatment. However, when the core sample was taken from their container during the *Preparation* activity. It must be treated to prevent the loss of water content. The additional work required to maintain testing quality will increases the hidden cost.

Table 2. Testing frequency

Activity	Designation	Testing Frequency	Activity	Designation	Testing Frequency
Sample Administration	A	20	**Uniaxial Compressive Strength (UCS)**		
Preparation	B	12	*UCS Test*	D1	10
Physical Properties (PP)			*UCS Report*	D2	2
Normal Weighing	C1	12	**Point Load (PL)**		
Soaking	C2	11	*PL Test*	E1	10
Draining	C3	10	*PL Report*	E2	2
Wet Weighing	C4	10	**Direct Shear (DS)**		
Float Weighing	C4	10	*Cementing*	F1	2
Water Drying	C6	9	*Cement Drying*	F2	1
Dry Weighing	C7	9	*DS Testing*	F3	1
PP Report	C8	3	*DS Report*	F4	1
			Summary Report	G	1

To obtain an accurate simulation, many parameters are needed. Meanwhile, with manual analysis, a large and complex simulation implies a larger possibility for human error. Arena Simulation software is required to simulate various scenarios and reduce human error.

5.2 Arena Simulations

Simulation is a method for analyzing a running system using a mathematical model. At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components or to predict performance under some new conditions being considered (Law and Kelton 2000). Law and Kelton draw the position of simulation in a system in Figure 6 below:

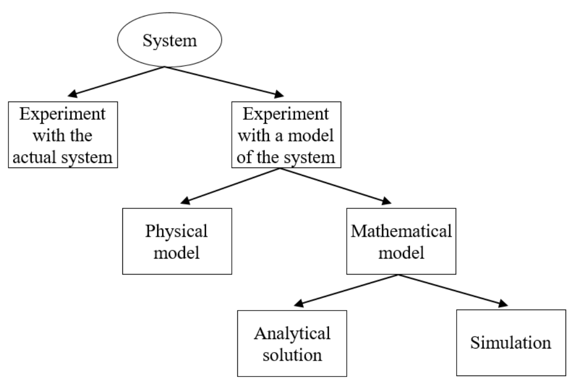


Figure 6. Way to study a system (Law and Kelton 2000)

The idea behind simulation is to imitate a real-world situation mathematically, then to study its properties and operating characteristics, and, finally, to draw conclusions and make action decisions based on the results of the simulation. In this way, the real-life system is not touched yet, until the advantages and disadvantages of what may be a major policy decision are first measured on the system's model (Render et al., 2012). Schmidt and Taylor (1970) in (Law and Kelton 2000) proposed the definition of simulation, a system is defined to be a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end (Schmidt and Taylor 1970) in (Law and Kelton 2000).

This simulation aims to determine the most effective formation, the most efficient in terms of time, and the best additional investment to be implemented. To achieve the simulation aims, a comprehensive and traceable model is required. Modeling represents a considerable part of the work of an applied mathematician and requires a thorough knowledge, not only of applied mathematics but also of the scientific discipline to which it is applied (Allaire 2007). The computer-based simulation model is commonly used. Computer models are increasingly used for maximizing processes' efficiency and products' quality (reliability, durability, performance, robustness, etc.) in a faster, and cheaper way at the design and manufacturing stages (Costa and Fontes 2020). Figure 7 shows the simulation model of the rock mechanic laboratory.

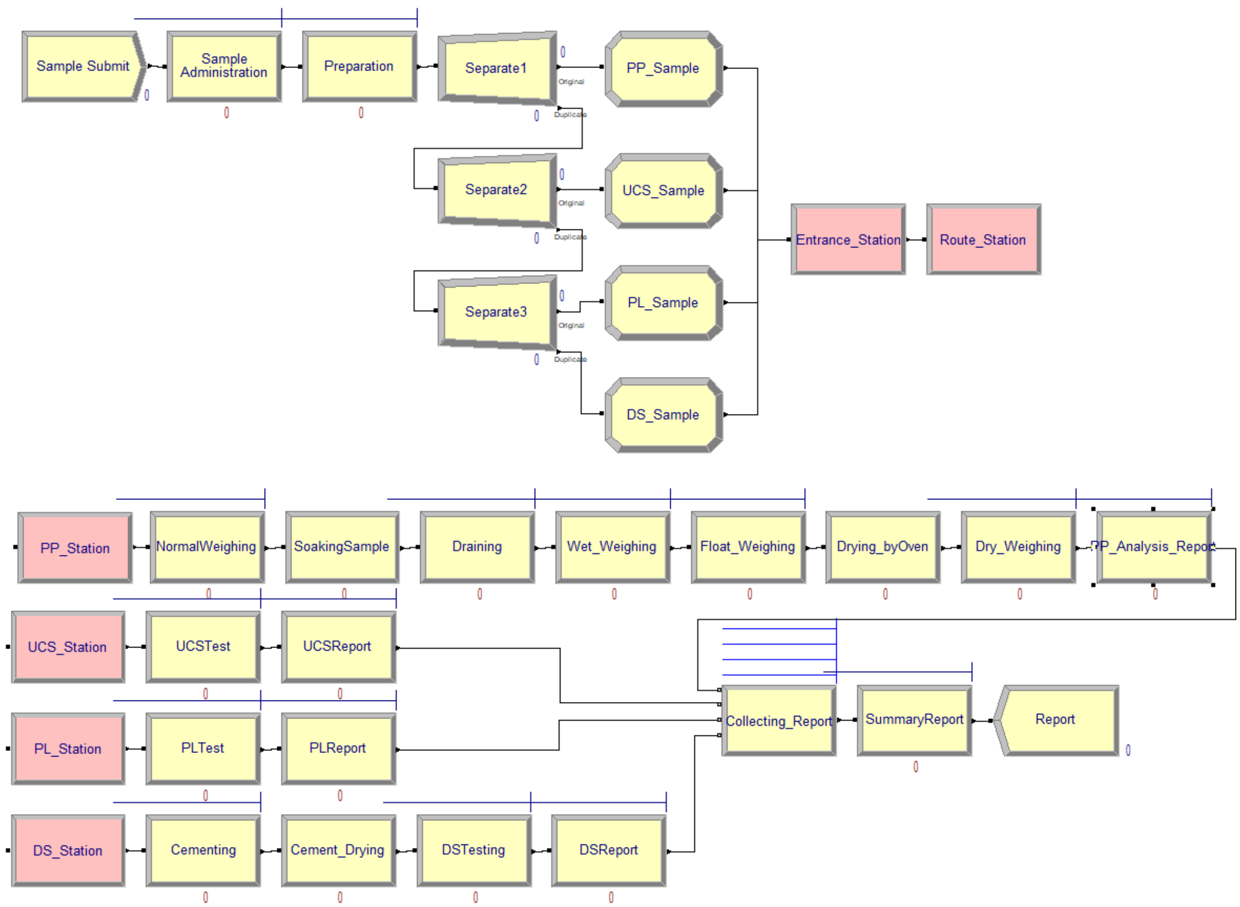


Figure 7. Arena simulation model at rock mechanic laboratory

Creating the simulation model requires a thorough understanding of the system. To design and analyze computer experiments is more of a science than an art, and it is not a one-time task. It requires critical thinking and not simply some clicks from a mouse (Costa and Fontes 2020). Critical thinking is needed to determine the logic model and its assumption. The advantage of using simulation over the queuing models is that fewer assumptions need to be made. Also, much more complex situations can be analyzed using simulation (Jacobs and Chase 2018).

The computer-based simulation in this study was performed using Arena Simulations from Rockwell Automation Inc. In the model, *Preparation* is followed by *separate1*, *separate2,* and *separate3*. The separate block is a duplicate of the previous entity and attached by the assigned block. The assigned block is tasked to provide the entity ID to fit the testing sequence. The assignment inputs are attributes and entities of the testing sequence. The next block is the *entrance* and *route*. The *entrance* has responsible for recombining the previous shared entity ID. It used station type and zero delays in value-added allocation. Although the merge is put in the entrance block, the *route* will be put into each test station according to the sequence ID. The testing sequence is divided into 4 testing stations, they are *PP_Station*, *UCS_Station*, *PL_Station*, and *DS_Station*. The next process is matching the block to combine all entities. The *Collecting_Report* required all entities to be completed first. Its task is to find all entities that match. Each station's parameters are as follows (Table 3):

Table 3. Stations parameter

Activity	Logic Action	Delay Period (hour)			Resources
		Min	Most	Max	
Sample Submit	Random time between arrivals	2	-	26	none
Sample administration	Seizing, delaying, and releasing	0.5	1	1.5	1 Crew
Preparation	Seizing, delaying, and releasing	4	5	6	1 Crew and 1 Technician
NormalWeighing	Seizing, delaying, and releasing	0.5	0.6	0.7	1 Technician
SoakingSample	Delaying	8	8	8	none
Draining	Seizing, delaying, and releasing	0.8	1	1.2	1 Technician
Wet_Weighing	Seizing, delaying, and releasing	0.3	0.5	0.7	1 Technician
Float_Weighing	Seizing, delaying, and releasing	0.3	0.5	0.7	1 Technician
Drying_byOven	Delaying	8	8	8	none
Dry_Weighing	Seizing, delaying, and releasing	0.3	0.5	0.7	1 Technician
PP_Analysis_Report	Seizing, delaying, and releasing	6	7	14	1 Analyst
UCSTest	Seizing, delaying, and releasing	3	4	7	1 Crew and 1 Technician
UCSReport	Seizing, delaying, and releasing	16	20	30	1 Analyst
PLTest	Seizing, delaying, and releasing	3	4	5	1 Technician
PLReport	Seizing, delaying, and releasing	6	7	14	1 Analyst
Cementing	Seizing, delaying, and releasing	0.5	1	1.5	1 Technician
Cement_Drying	Delaying	96	96	96	none
DSTesting	Seizing, delaying, and releasing	2	3	4	1 Analyst and 2 Technician
DSReport	Seizing, delaying, and releasing	14	15	22	1 Analyst
SummaryReport	Seizing, delaying, and releasing	6	7	14	1 Analyst

Arena Simulation calculates each station's value-added time and waiting time. Table 4 shows the accumulation of value-added time and waiting time of a single sequence simulation and a year simulation.

Table 4. Accumulation value-added (VA) and waiting time

Activity	1 Sequence		1 Year		Activity	1 Sequence		1 Year	
	VA	Waiting	VA	Waiting		VA	Waiting	VA	Waiting
Sample Administration	0.92	0	51.27	0.73	*PLTest*	4.66	0.37	211.52	0.90
Preparation	4.69	0	261.60	3.23	*PLReport*	8.91	20.52	451.38	43.64
NormalWeighing	0.37	0	25.79	0.40	*Cementing*	1.23	5.03	52.29	4.96
SoakingSample	8.00	0	416.00	0	*Cement_Drying*	96.00	0	4992.00	0
Draining	0.90	0	52.95	1.41	*DSTesting*	2.61	0	149.97	64.71
Wet_Weighing	0.58	0	26.77	0	*DSReport*	15.23	0	877.86	56.21
Float_Weighing	0.64	0	27.21	0	*Collecting_Report1*		77.92		131.65
Drying_byOven	8.00	0	416.00	0	*Collecting_Report2*		94.55		162.57
Dry_Weighing	0.49	0	24.75	0.20	*Collecting_Report3*		85.65		185.37
PP_Analysis_Report	7.73	15.47	461.90	81.09	*Collecting_Report4*		0		0
UCSTest	3.51	0	206.99	4.40	*SummaryReport*	12.80	0	450.73	43.45
UCSReport	22.04	0	1151.72	49.56					

With a 2.2 percent deviation from the CPM approach, the model is appropriate. The *Collecting_Report* is the most time-consuming activity. A year requires 185.37 hours. Waiting time is a hidden cost. From the perspective of the machinery, it should perform more testing than in standby mode. It is capable of completing more tests during the same depreciation period. Meanwhile, from the perspective of finance, the workforce is still being paid, even if they are still on standby while waiting for the next testing. They are seen in Figure 8 below. Figure 8 shows that the Analyst is the most overworked workforce in both the single-sequence (0.500) and year simulation (0.448). He was 7-time busier than the others. The DS Tool and Analyst are the most targeted to improvement programs.

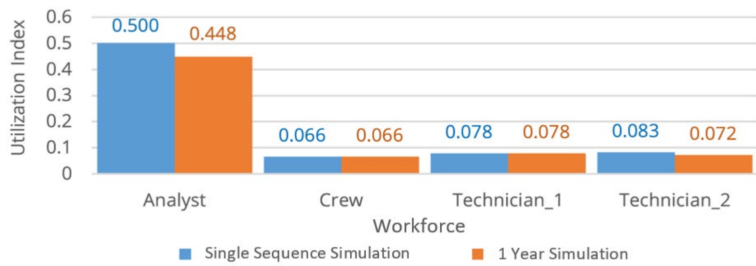


Figure 8. Workforces utilization

5.3 Proposed Improvements

The hidden cost is generated by an unbalanced system; on the other hand, it needs costs to balance it. It is necessary to select the best scenario in the investment option. Scenario simulations were carried out by simulating various combinations of machinery and workforce improvement. There have been over 40 combinations made; these are the most related:

a. Scenario 0; It is an existing condition, 1 DS tool, 1 Analyst, 2 Technicians, and 1 Crew.
b. Scenario 1; Additional of 1 DS tool. Workforces are still the same as the existing ones.
c. Scenario 2; Additional of 2 DS tools and recruit of 1 Analyst.
d. Scenario 3; Additional of 2 DS tools and recruit of 2 Analysts.
e. Scenario 4; Additional of 3 DS tools and recruit of 2 Analysts.
f. Scenario 5; Additional of 2 DS tools and upgrading the Technician's competencies of reporting.
g. Scenario 6; Additional of 2 DS tools, upgrading the Technicians, and recruit of 1 Analyst.
h. Scenario 7; Additional of 2 DS tools and upgrading the Analyst competencies, which is twice-faster in reporting.

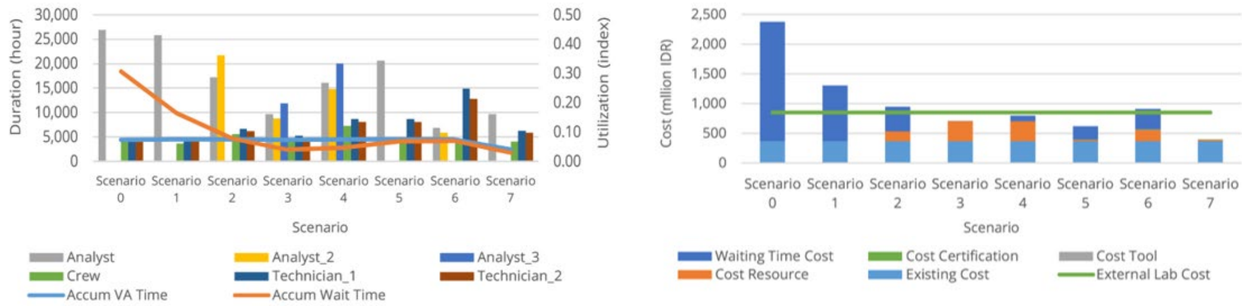
Plotting the simulation result shows the trend for better understanding. Table 5 and Figure 9 show all these:

Table 5. Scenario simulation

Category/Scenario		0	1	2	3	4	5	6	7
Time (hour)	VA Time	4432	4469	4478	4449	4478	4474	4489	2489
	Wait Time	18453	9919	4676	2436	2814	4069	4229	1842
Utilize index	Analyst	0.45	0.43	0.29	0.16	0.27	0.34	0.11	0.16
	Analyst_2			0.36	0.15	0.25		0.10	
	Analyst_3				0.20	0.33			
	Crew	0.07	0.06	0.09	0.07	0.12	0.07	0.07	0.07
	Technician_1	0.08	0.07	0.11	0.09	0.15	0.14	0.25	0.10
	Technician_2	0.07	0.07	0.10	0.08	0.14	0.13	0.21	0.10
Cost (million IDR)	Existing Cost	366	366	366	366	366	366	366	366
	Cost Add Resource			168	336	336	24	192	24
	Cost Add Tool		1	2	2	3	2	2	2
	Cost Certification						8	8	8
	Waiting Time Cost	2,008	938	410	0	91	218	343	0
	External Lab Cost	849	849	849	849	849	849	849	849

Figure 9 (a) is the duration of the testing and utilization of the workforce. The blue line curve is the value-added time (VA Time). It does not have significant changes in various scenarios. The brown line curve is the waiting time of the testing activity. The addition of DS tools has made a significant difference in reducing waiting time. However, the fourth DS tool decreases the waiting time slightly. The bar chart depicts workforce utilization. The most balanced workload has a higher index with uniformity. It will be fairer if it is compared to another at the same level.

Figure 9 (b) depicts the scenarios' hidden costs and additional investment costs. The green line represents the maximum cost of external testing. *Scenario 0* is the current situation. It has the highest wait time (equal to 2,500 million IDR). *Scenarios 0, 1, 2,* and *6* show that testing at an external laboratory becomes less cheap than testing at one's own laboratory. In *Scenarios 3* and *4,* the addition of two Analysts significantly reduces the waiting time, then becomes slight at the third Analyst.



(a) (b)

Figure 9. Scenario simulation and costing scenario

The Analyst is the most expensive member of the staff (orange column-chart). *Scenario 5* is aimed at improving the Technician's reporting skills. It requires training fees and salary adjustments. Increasing the salary of the Technician is still more efficient than hiring the Analyst. According to these comparisons, *Scenario 5* is the most cost-effective scenario at the moment. *Scenario 7* optimizes the report's completion time. Reporting is subjective; it is dependent on the Analyst's expertise. It cannot be implemented at this time, but it will be faster if the Analyst's expertise is upgraded.

5.4 Recent Data and Finding

Vyas (2013), concluded in her study that project quality may be affected by project crashing and develop trade-offs among time, cost and quality. Project crashing is developed to determine the appropriate activities for crashing at a minimal cost. Malak et all (2020), concluded in their study using Monte Carlo simulations that the improper estimation for completion duration can affect the budget, worker, company's reputation, and planned schedule. Cost estimations and project scenarios were always the first steps in every external-clients project. It ensures that the project completion objective is always met.

The projects of the Rock Mechanic Laboratory serve the needs of the company. This project appears to be a routine activity that is reliant on available resources. So far, there have been no complaints from rock mechanic data users, implying that activities seem to be well-run. The hidden cost of waiting time is the most inefficient aspect of regular projects that serve internal clients.

This research is subjected to a rock mechanic laboratory in Indonesia. The analysis is limited by the maximum input and output expected according to current needs. Other companies may have different characteristics. It needs a comprehensive study to apply similar optimization.

6. Conclusion

Optimizing the company's operations is a part of operational excellence. A simulation is one of the methods used to achieve optimization. Simulation plays a role in planning and optimizing the current system. Simulation imitates real conditions to determine the most effective and efficient strategy. The simulation can also be used to detect the system's *bottleneck*.

Routine activities that have been running for a long time may seem to be an optimal process. The majority of the workforce at the rock mechanic laboratory believe their job was done properly. Following an evaluation, it was revealed that there are many hidden costs. Waiting time is the most significant hidden cost in the regular project that serve internal client, spending at least 2,500 million IDR every year. The simulation is also important in decision-making. The optimum investment choice is selected accurately through simulation.
The rock mechanic laboratory has a huge samples queue at their testing station. Simulation is used to optimize the operation. It was revealed that the most time-consuming activity is DS Test, and the highest work overload is the Analyst. Since most testing activities need the completion of the predecessors test first, they generate a significant waiting time. Both can be a bottleneck and cause significant hidden costs. The additional investment of two DS tools, as well as the upgrading of the Technician's competency, is the best decision for optimizing operations.

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