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System Dynamics Model for Lifetime Construction Aggregate Supply in Songkhla Lake Basin

Jirayus Wiwattnanukul*, **Phongpat Sontamino****,

Manoon Masniyom and Vishnu Rachpech

Department of Mining and Materials Engineering, Faculty of Engineering,

Prince of Songkla University, Thailand

* E-mail: jirayus.wwtnnk@gmail.com

**Corresponding Author E-mail: phongpat.s@psu.ac.th

ABSTRACT

Construction aggregate is an important material for almost all types of constructions. It is a material that is obtained from various rock sources through the mining process to various construction industries. This paper is a study of construction aggregate reserves and production capacity to forecast the quarry reserves depletion with statistic information of production capacity and the depleted of resources on the various scenario of production capacity in the Songkhla Lake Basin (SLB). By using a system dynamics model (SDM), it helps to understand and assist in the discussion and decide to manage rock supply with a situation that arises. The simulation results show the end of resource each scenario depending on production capacity; (a) the maximum production capacity scenario, which produce 1.0-2.0 MMT/y and deplete in 2104 or about 84 years later, (b) the mean production capacity scenario, which produce 0.5-1.5 MMT/y and deplete in 2123 or about 103 years later, (c) the minimum production capacity scenario, which produce 0.2-0.7 MMT/y and deplete in 2205 or about 185 years later, and finally (d) the random normal production capacity scenario, which produce 0.7-1.5 MMT/y and deplete in 2113 or about 93 years later.

Keywords: Songkhla Lake Basin; System Dynamics; Construction Aggregate

1. INTRODUCTION

Construction aggregate refers to crushed stone or natural sand and gravel (primary aggregates), including by-product from the industry (such as slag) and recycled waste materials (such as concrete) may be used as adjunct (secondary aggregates) for quarried materials [1]. The construction aggregate is an important raw material for the economy by being the primary raw material for all types of construction [2-3]. Most of these aggregates are obtained from quarries. The current goal of mining is to bring resources to meet human needs. This crushed rock is the most valuable non-fuel resource in the world [4-6]. Which, of course, can be said that it is non-renewable resources because it takes a long time to regenerate [7].

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In 2014, there was a forecasting of the demand for aggregates in the world market. It was found that in 2017 to 2022, the demand is likely to increase [8]. The mining sector expansion in developing countries, which make an increasing demand for minerals as the world economy has grown in recent [9]. Thailand has grown in demand of aggregate for the construction industry over the recent decade [10]. The construction market is expected to grow due to the government infrastructure projects and the household construction [11]. Although the world today can recycle aggregate materials from buildings to be used in construction widely, Thailand still lacks of the policy to reuse or recycle it [12-15].

The Songkhla Lake Basin (SLB) is the only basin in Thailand that has a large lagoon lake system covering three provinces, Songkhla, Phatthalung and Nakhon Si Thammarat. It has approximately 8,729 square kilometres of total area, which is about 7,687 square kilometres of land [16]. SLB is an important economic area and has a variety of resources. There has been a "National Economic and Social Development Plan" for a long time since 1961 to the present, supporting the sustainable development of the SLB [17-18].

Therefore, to forecast the depletion of rock reserves and to assist in the discussion and decide to manage with a situation that arises. It would be need a tool that help to plan and manage resources properly as an important issue. The SDM of rock supply allocation of resources to meet rock lifetime will help to manage the rock resource sustainability [19].

2. METHODOLOGY

System dynamics (SD) is a powerful method for describing, processing, and analyzing large complex issues or systems in terms of processes, data, organizational boundaries, and strategies [20]. It was developed in the late 1950s and was introduced by Jay Wright Forrester in the 1960s at the Sloan School of Management in the Massachusetts Institute of Technology [21-22]. System dynamics modelling is a process technique for linking various variables. Both quantitative and qualitative variables with mathematical equations with "stock and flow" which can easily adjust values and develop, expand system relationships. Creating a simulation for an understanding of the system studied can be quick, convenient, and flexible when conditions change [23-24]. Simulation is a repetitive process of generating results in which a model designed. One or more scenarios are defined from zero time to infinity [25]. Within expected logical and efficient syncing, with the organization of all reserve remaining being essential to production, such modeling requires interaction aspects between all elements of the system. This is considered dynamic and complex due to these interactions and the number of elements involved (social, technical, nature and economic) that such a system [26].

Therefore, this is one suitable tool that can be used to study the production capacity and the depletion of construction aggregate resources in the Songkhla Lake Basin. The development process of system dynamics model was shown in Figure 1, which was used Vensim PLE 7.1 software by

Ventana Systems, Inc., to support the creation of scenario simulation results [27].

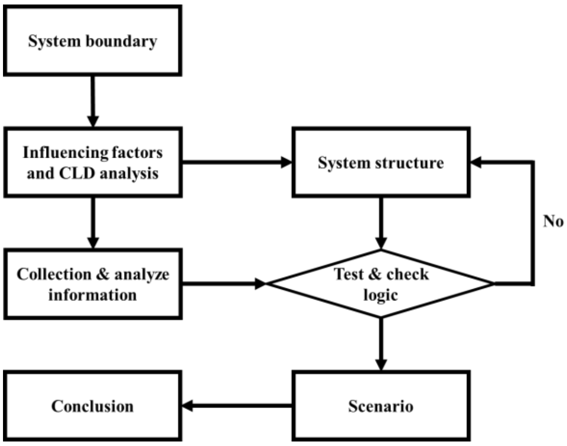

Figure 1 Research procedure flowchart

3. SD MODEL DEVELOPMENT

3.1 SLB information

Thailand has 318 quarries for construction nationwide, with estimation of reserves about 8,010 million metric tons (MMT). In the Songkhla Lake Basin (SLB), there are about of 108 million metric tons of rock reserves [28]. Nowadays, in the SLB area, there are two active quarries, which are Kris Silaporn Part., Ltd (KS) and Khao Bandai Nang Sila Co., Ltd (KBN), and tree quarries have expired in recent years, such as Thai Panich Khamai Part., Ltd (TPK), Kaodang Construction Part., Ltd (KC) and Silachai Hatyai Part., Ltd (SCH). The location of each quarry shown in Figure 2 [29], which has the production capacity and reserves was shown in Table 1 [30-32].

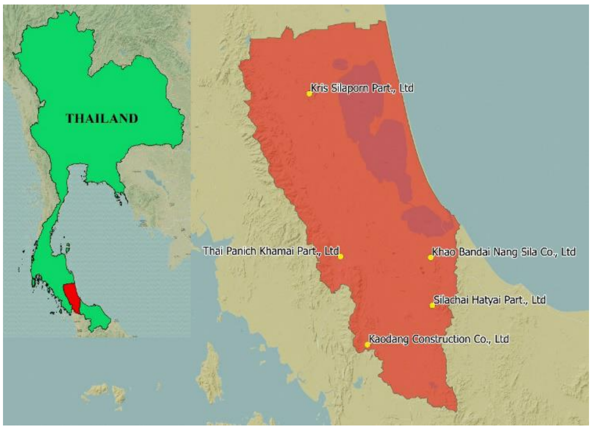

Figure 2 Location of quarries in Songkhla Lake Basin

Generally, the information of mining project plan is a guide line of working, but sometime it is inconsistent with real action. On one hand, the mining reserves run-out, but remain the mining concession period, on the other hand the remaining of mining reserves, but mining concession expired. In this paper, the SDM that generates a production capacity result by current information to forecast the depletion of reserves and resources with the following assumptions:

a) The current production capacity level reflects the limit production capacity of equipment, so each quarry remain their own capacity.

b) When the mining concession expires, if the resources is remaining, a new mining permit can be extended.

c) When the allowing reserve is depleted, if resource is remaining, resource will become new allowing reserve.

d) The resources in SLB are considered to be one that all quarries develop together.

Table 1 Resources reserves and production capacity of rock in SLB

Resources of SLB : 108 MMT								
ID	Project planning		Actual production capacity (MT/year)				Initial reserves (MT)	Remaining reserves in 2021 (MT)
	Production capacity (MT/year)	Mining concession period (year)	Max	Mean	Min	SD		
TPK	420,000	20	292,128	192,439	27,150	71,576	5,320,000	0
KBN	400,000	13	899,113	720,148	287,489	289,952	3,736,000	855,808
KS	400,000	10	344,056	294,246	237,125	43,873	2,890,000	578,000
KC	310,000	10	198,500	155,900	129,200	37,286	3,017,000	0
SCH	150,000	10	289,560	130,476	16,320	117,627	1,738,000	0

MT = Metric tons

3.2 Causal Loop Diagram (CLD)

A basic causal loop diagram for resources reserve mining permit and production was shown in Figure 3. It was represented by two balancing feedback loops including, mining and developing reserves. This CLD considers that, the mining industry, permission is required for mining to generate production, which will reduce the rock reserves to the end. Then, request a mining permit to develop new reserves to have the capacity to produce rocks to meet demand. Of course, this product, to satisfy other human industries, cannot be missing. Therefore, a request for a mining renewal permit is required. These processes directly affect resources reduction, so this is an important variable to consider.

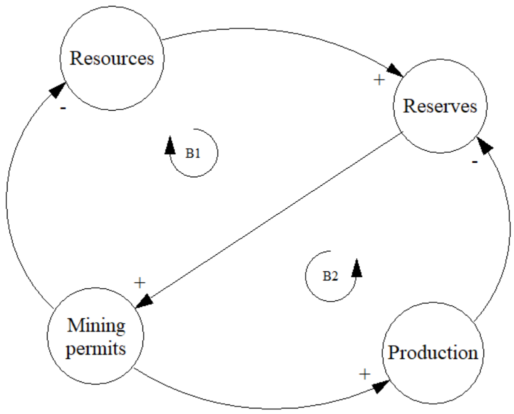

Figure 3 Conceptual CLD of the resources reserves and mining permits cycle

3.3 System Dynamics Model (SDM)

Figure 4 shows a generic model that simulates the deceasing and remaining of resources and reserves in the SLB area depending on the production rate from mining activities. The structure of model is based on the extraction process model of an ore in its environment [33]. It consists of the "stock" of reserves that change follows the "flow" of the "mining" that value depending on the production rate of each quarry with different values. When the reserves are depleted or the mining concession period expires, it will affect the "mining permit for new reserves" activated. That is a new mining concession permitted, with reserves according to " new reserve" and the period for permission according to "time delay". Then it will continue to affect this new reserve to the "flow" of developing reserves to reduce the "stock" of the resource and recharge the "stock" of the reserves. The initial reserves in the model are the remaining reserves in 2021 and the recharging of the new reserves depend on the production rate and mining concession period from the mining project plan. It describes the changes in aggregate reserves and resources that depend on the aggregate production capacity in the Songkhla Lake Basin. Table 2 shows the main variables, unit and equations of variables in generic model.

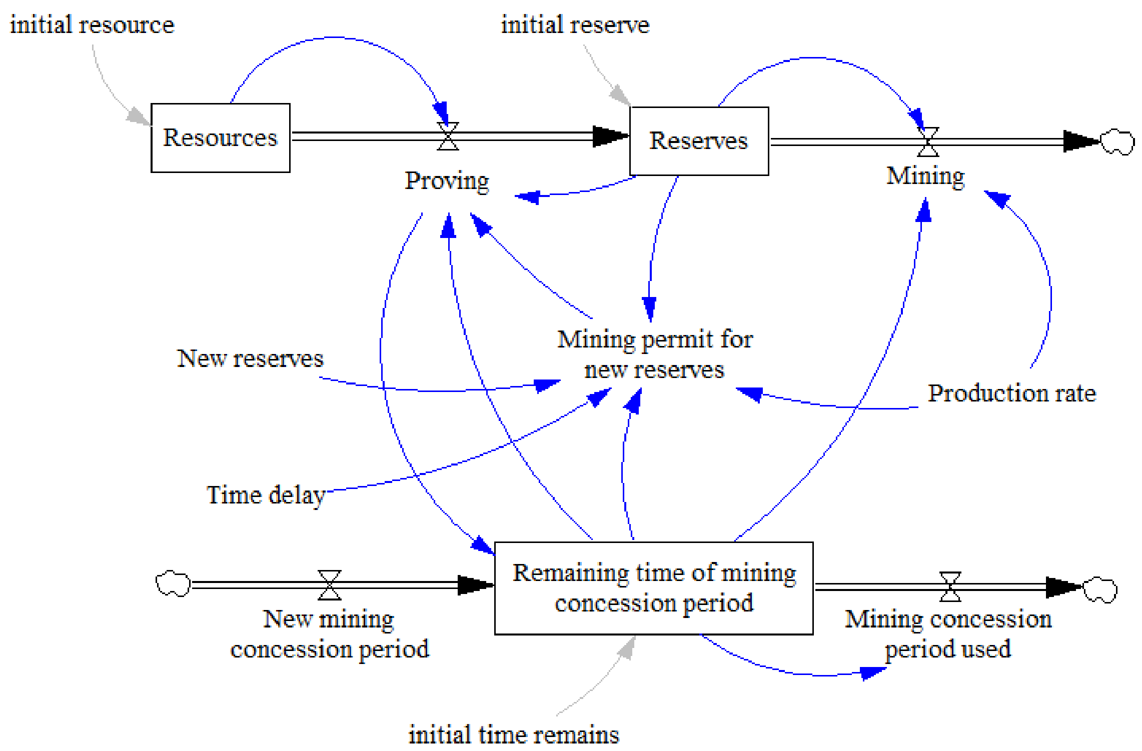

Figure 4 SDM for forecasting resources reserves and production capacity of quarries in the Songkhla Lake Basin

Table 2 Variables and equation of presented SD model

PARAMETER	UNIT	TYPE	EQUATION AND DESCRIPTION
Resource	MT	Level	INTEG (IF THEN ELSE (Resource - Proving < 0, Resource - Proving < 0 :AND: Resource = 0, -Proving), initial resource)
Proving	MT/year	Rate	IF THEN ELSE (mining permit for new reserves > 0 :AND: Reserves <= 0 :OR: Remaining time of mining concession period = 0, IF THEN ELSE (Resources < mining permit for new reserves, Resources, mining permit for new reserves),0)

Table 2 (Cont.) Variables and equation of presented SD model

PARAMETER	UNIT	TYPE	EQUATION AND DESCRIPTION
Reserves	MT	Level	INTEG (Proving - Production, initial Reserve)
Mining	MT/Year	Rate	IF THEN ELSE (Remaining time of mining concession period = 0, 0, IF THEN ELSE (Reserves < Production rate, Reserves, Production rate))
Production rate	MT	Constant	RANDOM NORMAL (min, max, mean, stdev, seed)
Mining permit for new reserves	MT	Auxiliary	DELAY FIXED (IF THEN ELSE (Reserves - Production rate <= 0, new reserves, IF THEN ELSE (Remaining time of mining concession period = 0 :AND: Reserves - Production rate > 0, new reserves-Reserves, 0)), time delay, 0)
New reserves	MT	Constant	Concession reserves
Remaining time of mining concession period	Year	Level	INTEG (IF THEN ELSE (Proving > 0, New mining concession period - Remaining time of mining concession period, - Mining concession period used), initial time remains)
Initial resource	MT	Constant	Resource remains of SLB
Initial reserve	MT	Constant	Reserve remains of each quarry
Initial time remain	Year	Constant	Mining concession period left of each quarry
New mining concession period	Year	Rate	Mining concession period of each quarry
Mining concession period used	Year	Rate	IF THEN ELSE (Remaining time of mining concession period = 0, 0, 1)
Time delay	Year	Constant	Constant

4. RESULTS

4.1 Validation of the model

The validation of the model focusing on a quarry (TKP). The case of TPK, a quarry that was previously operated in this area but has expired. The data of TKP production rate are collected, then it was separated into 2 parts. The first part uses to statistical analysis, and the second part for checking and comparison between actual data (Base Data) and simulation data. It was used to test the simulations by comparing the simulation results with actual capacity in the years 2017-2020 (with the statistical values during 2007-2016: max = 292,128 MT/y, min = 27,150 MT/y, mean = 196,617 MT/y and standard deviation = 82,227 MT/y) [31], then performed using "random normal distribution" or technically called "Truncated Normal Distribution", it is a method of generating a random distribution from the statistical value [34]. Thus, the simulation value generated by the random distribution under the statistical values. Finally, the resulting simulations shows the same trend as actual production capacity (Fig. 5).

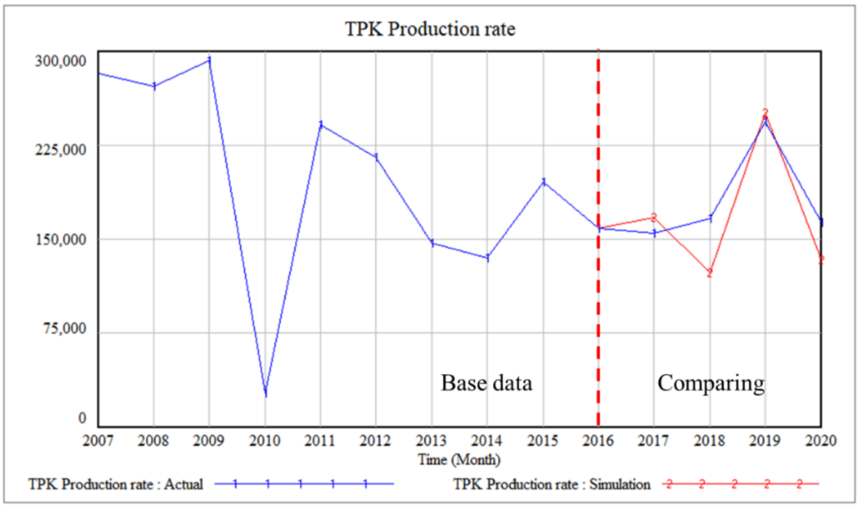

Figure 5 Comparing the production rate of TPK between forecasting and in the actual operation

4.2 Simulation result in the short term

At present (2021), the SLB has two active quarries, KS and KBN. Focusing on the short term period until the mining concession period expired. The simulation consists of 4 scenarios: (a) max production capacity scenario (b) mean production capacity scenario (c) min production capacity scenario and (d) random normal scenario. The KS mining simulation results show that, scenarios (a), (b), and (d) were similar, which the reserves depleted and the mining concession period expired in 2023. While scenario (c) is ended in 2024. Likewise, in the case of KBN, running out of reserves, which not much different with KS simulation result, scenario (a) in 2022, (b) in 2023, (c) and (d) in 2024, see details in Figure 6 and 7.

In a big picture of SLB quarries, it was a combination of KS and KBN quarries simulated, which was shown in Figure 8. It caused by mining reserves run-out and expired mining concession expired in 2023 for scenarios (a) and (b), and in 2024 for scenarios (c) and (d).

Therefore, in the short term scenario, lifetime of rock aggregate supply inside of SLB will be finish in 2024, the longest case. After that, it will need 100% aggregate from outside of SLB, in case of no new quarry permit.

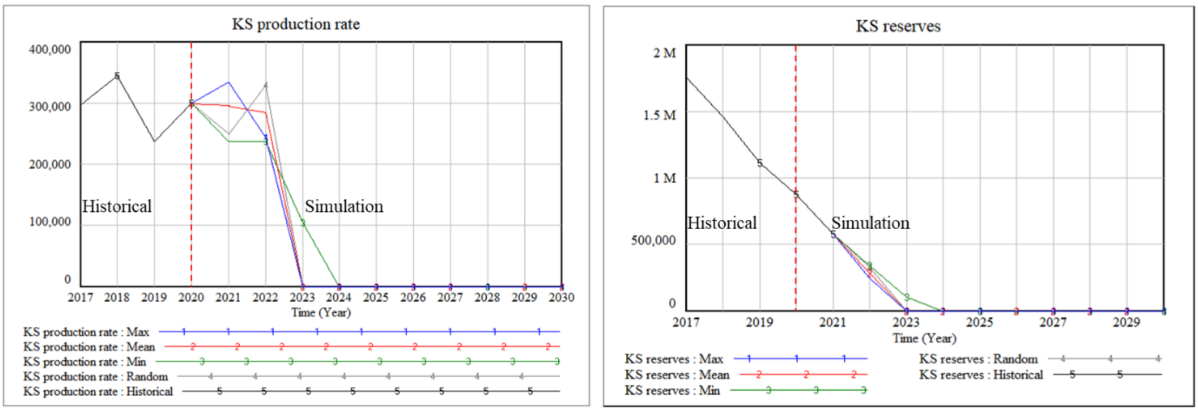

Figure 6 KS Simulation Results

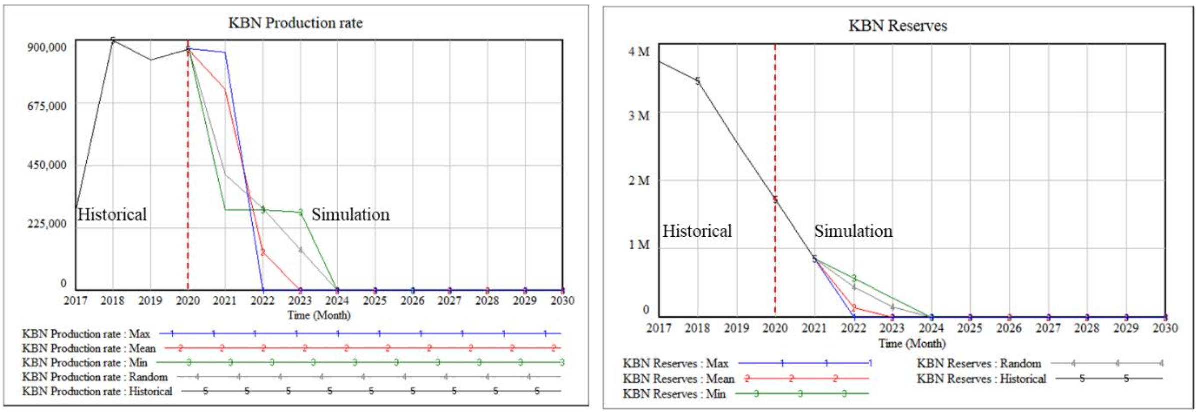

Figure 7 KBN Simulation Results

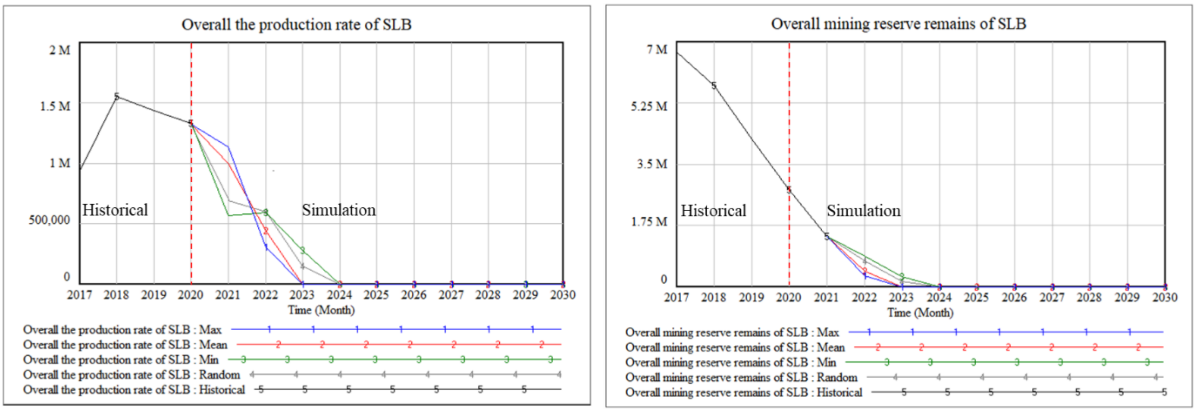

Figure 8 Short Term SLB Simulation Results

4.3 Simulation results in long term

Because of the short term simulation still have a huge of rock resources available. It is a high potential to produce aggregate inside SLB continuously. So, the long term simulation is focusing on the lifetime until an empty rock resources in SLB. There are five quarries in the database including, KS, KBN, TPK, KC and SCH, which were used in simulation. The assumption of this simulation was developed with the conditions of reserves to recharge immediately when existing reserves run-out or expire. Simulations results (Fig. 9) show that KBN quarries is a highest production capacity, which has a cycle period of 6 -8 years, while the mining concession is 13 year. It is a situation where resource development permission to recharge reserves within a short period of time and this behavior results in a faster resource decline. KS and SCH quarries have a production capacity consistent with reserves and concession period. The reserves run-out in the same period of concession expired. KC quarries was unable to extract all the reserves due to the mining concession expired, while the mining reserve remains about 1.3-1.4 million metric tons. That is, the KC quarries can continue operating for about 10 years with this production capacity level. There are two possibility cases of TPK quarries operations, able and unable to operate until the reserves run-out under the period of the mining concession by the simulation generated by random normal function with a production capacity value between minimum and maximum capacity.

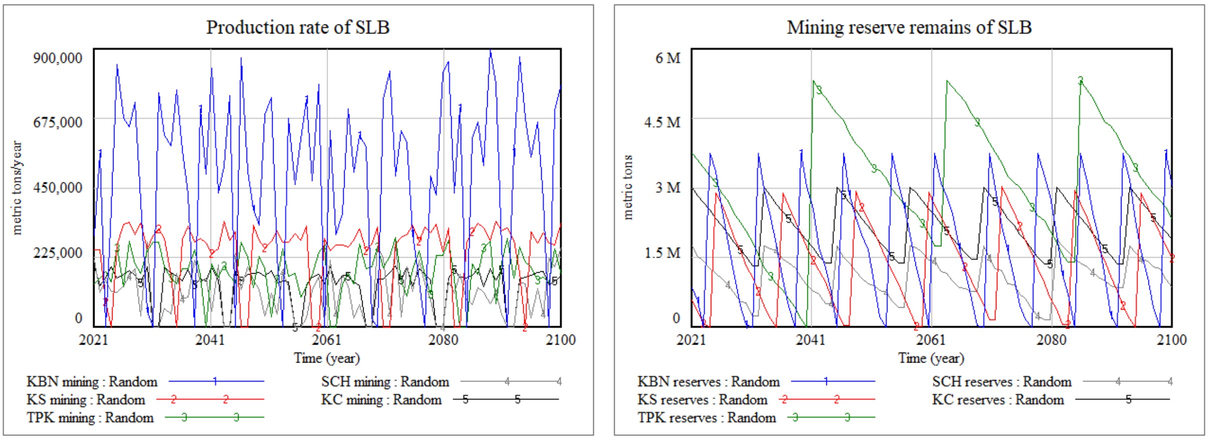

Figure 9 System behavior cycle from conditions of SDM in each quarry in case of random simulation

Simulation results in a big picture of overall the production rate and mining reserves of SLB show behavior of swing graph. Swing down in some periods when the reserves of some quarries are depleted, leading to a decline in the production capacity levels and swing up in the next periods by assumption of recharging reserves leading to an increase in production capacity. Swing depending on the production capacity level for the random scenario. In other scenarios, have a steady production capacity that swings depending on the timing of reserves run-out or recharge. That effect to reserves behaving similarly, reserves change with production capacity and recharging with the initial reserves parameter. This behaves the same for all scenarios with a swing in the range of about 5-12 million metric tons because recharged reserves are the same, differ in resources depletion periods. These show the behavior of an endless cycle of depletion and recharging of the reserves until the resource depletes (Fig. 10).

Therefore, This SDM made a complex system easy to understand, that the behavior effects a continuous decrease in resources depending on the timing of the reserves development and production capacity interrelated. The simulations of each scenario forecasting resource depletion times differently due to production capacity levels. The simulations of each scenario have a production capacity range and depletion year of resources (Fig. 11) are as follows: (a) maximum production capacity scenario: with 1.0-2.0 MMT/y and depleted in 2104 or about 84 years later (b) mean production capacity scenario: with 0.5-1.5 MMT/y and depleted in 2123 or about 103 years later (c) minimum production capacity scenario: with 0.2-0.7 MMT/y and depleted in 2205 or about 185 years later and (d) random normal production capacity scenario: with 0.7-1.5 MMT/y and deplete in 2113 or about 93 years later.

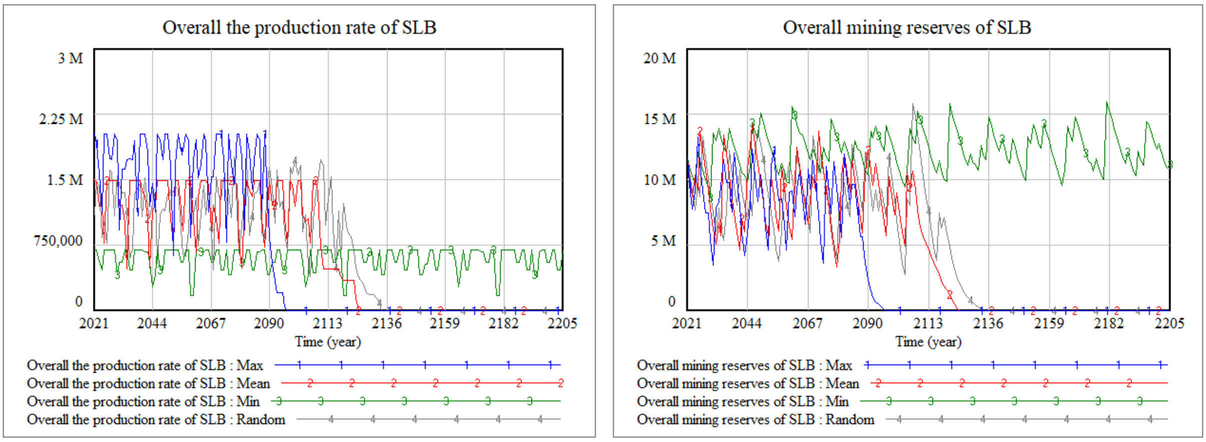

Figure 10 Overall system behavior of production rate and mining reserves of SLB

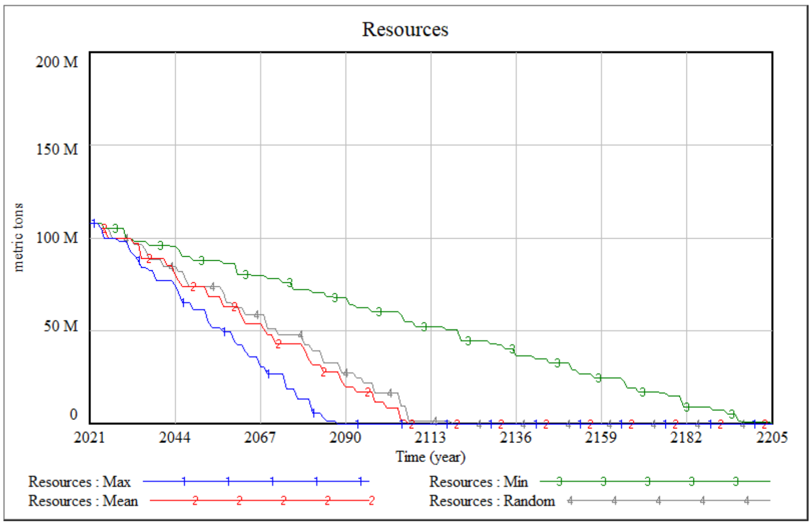

Figure 11 Forecasting depletion resources of SLB

5. CONCLUSIONS

The existing information analyzed and simulated with SDM, which forecasting the end of the current quarry, with each scenario dependent on production capacity important, especially in the case of KBN quarries. There will be no mining operations in the SLB area to serve the demand in the area if not properly managed soon. The underlying assumption used as a basic policy formulation and decisions, the model present within the context of the area. That's to maintain the stabilization of production capacity. The assumption presented in this way leaves less room for misinterpretation and easier understanding of system structure. The behavior over time graphs used to present the endless process of the developing resource to mining. These assumptions (definitions) can be modified and resulting changes in behavior patterns. The simulation results of each scenario are as shown in Table 3.

Finally, several factors involved in deciding to allow the development of mineral deposits for mining such as Socio- economic, environment, resources availability, etc. The important factor is a resources demand for human activities [35] that trend increase. These can be study and develops from this SDM to manage other conditions.

Table 3 Ending the year of current quarry and depletion year of resource for each scenario.

Scenario	Short term result (A.D.)			Long term result (A.D.)	Production capacity (MMT/y)
	KBN	KS	Sum	Resources depletion	
Max	2022	2023	2023	2104	1.0-2.0
Mean	2023	2023	2023	2123	0.5-1.5
Min	2024	2024	2024	2205	0.2-0.7
Random	2024	2023	2024	2113	0.7-1.5

6. ACKNOWLEDGEMENTS

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