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PERFORMANCE MANAGEMENT MODEL OF SUSTAINABLE SAFE PRODUCTION AT DEEP MILL LEVEL ZONE PT. FREEPORT INDONESIA

Eko Wahyu Tanoto[*)1], Rizal Syarief[**)], Raden Dikky Indrawan[**)]

[*)]PT Freeport Indonesia
Office Building 3 - 2nd Floor MP72, Tembagapura, Papua 99967, Indonesia
[**)]School of Business, IPB University
Jl. Pajajaran Bogor 16151, Indonesia

Abstract: One of the mine expansions that is expected to accelerate the production rate of PT Freeport Indonesia is the Deep Mill Level Zone (DMLZ) mine. The block caving mining method used at the DMLZ mine results in higher productivity levels at lower operating costs but requires ongoing equipment maintenance. This research aims to describe the factors and criteria that determine the production process, find a performance management model, and find the right strategic priorities to increase productivity at DMLZ mine. We analysed the condition of the maintenance management system at the DMLZ mine to find solutions and strategies so that equipment maintenance could be managed effectively. Sustainable Safe Production performance management is developed based on the Balanced Scorecard (BSC) approach combined with the Analytical Network Process (ANP), which is expected to determine the priority of solutions and strategies based on predetermined criteria and indicators. This performance management model considers six perspectives: finance, customers, production, safety, internal business processes, and learning and growth processes as benchmarks in measuring performance. We explained the determination of priority strategies that can be done to achieve three goals in sustainable safe production management: achieving production targets, safe and healthy mining processes, and achieving operational cost-effectiveness.

Keywords: analytical network process (ANP), balanced scorecard (BSC), performance management, safe production, sustainable production

Abstrak: *Salah satu ekspansi tambang yang diharapkan mampu mempercepat laju produksi PT Freeport Indonesia adalah tambang Deep Mill Level Zone (DMLZ). Metode penambangan block caving yang digunakan di tambang DMLZ menghasilkan tingkat produktivitas yang lebih tinggi dengan biaya operasional yang rendah, namun membutuhkan perawatan peralatan yang berkelanjutan. Tujuan penelitian ini adalah untuk menguraikan faktor dan kriteria yang menentukan keberhasilan dalam proses produksi, menemukan model manajemen kinerja serta menemukan prioritas alternatif strategi yang tepat untuk meningkatkan produktivitas di tambang DMLZ. Peneliti menganalisis kondisi sistem manajemen pemeliharaan peralatan automatisasi di tambang DMLZ sehingga dapat ditemukan solusi dan strateginya agar pemeliharaan peralatan automatisasi dapat dikelola secara efektif. Manajemen kinerja "Sustainable Safe Production" dibangun berdasarkan pendekatan Balanced Scorecard (BSC) yang dikombinasikan dengan Analytical Network Process (ANP) yang diharapkan dapat menentukan prioritas solusi dan strategi berdasarkan kriteria dan indikator yang telah ditetapkan. Model manajemen kinerja ini mempertimbangkan enam perspektif yaitu keuangan, pelanggan, produksi, keselamatan, proses bisnis internal, proses pembelajaran dan pertumbuhan sebagai tolok ukur dalam mengukur kinerja. Peneliti membahas penentuan strategi prioritas yang dapat dilakukan untuk mencapai tiga tujuan dalam manajemen "sustainable safe production" yaitu pencapaian target produksi, proses penambangan yang aman dan selamat, pencapaian efektivitas biaya operasional.*

Kata kunci: *analytical network process (ANP), balanced scorecard (BSC), manajemen kinerja, produksi berkelanjutan, produksi selamat*

[1] Alamat korespondensi:
Email: ekowahyu30ek@apps.sb.ipb.ac.id

INTRODUCTION

PT Freeport Indonesia (PTFI) has now shifted its operational productions to the underground mine DOZ (Deep Ore Zone), Big Gossan, DMLZ (Deep Mill Level Zone), and GBC (Grasberg Block Cave). One of the mine expansions expected to accelerate PTFI's production rate during this transition/diversion period is the DMLZ mine. The block caving mining method used at the DMLZ mine is expected to produce higher levels of productivity with low operating costs but requires large capital investment costs and sustainable mine maintenance (Nieto, 2011).

Success in the production process in underground mines is determined by the smooth operation of machines and equipment (Rybak & Rybak, 2016; Griffin & Ebert, 2006; Lesourd, 1985). Maintenance activities need to be carried out to keep machines and production equipment working in optimal conditions, and it's also to extend their economic life cycle (Parida & Kumar, 2003; 2009; Assauri, 2018). External factors in production, including the natural environtment, technological, political and legal, econonomics, and socio-culture (Günter, 1978) interact with each other to determine the effectiveness of a production process in the DMLZ underground mine. Internal factors such as manpower, technology and machinery, financial (money), allocation of time (minutes), and methods contribute to an efficient production process (Günter, 1978; Gutenberg,1983; Ishikawa, 1985; Gram, 2013). External and internal factors integrated into a management system and leadership will influence increasing productivity effectively and efficiently (Nebl, 2018; Gram, 2013; Ishikawa, 1985).

To evaluate and increase sustainable productivity, we developed a sustainable safe production performance management that focuses on the company's long-term economic performance. With this performance management, in addition to considering economic and cost variables, we also consider productivity factors and a safe and healthy mining process. Safety provides an essential value that PTFI makes safety a top priority. Integrity is a fundamental value that PTFI prioritizes honesty, transparency, and responsibility in carrying out its production process.

Previous research on performance management using the balanced scorecard (BSC) and analytical network process (ANP) has been carried out several times. The BSC approach works by translating the company's vision and strategy into objectives and measures in four different areas of perspective: financial, customer, internal business processes, and learning and growth perspectives Kaplan and Atkinson (1989). The ANP approach is one of the multiple criteria decision making (MCDM) approaches that is able to model a more complex relationship between decision levels and criteria and is not required to have a perfect hierarchical structure. Hashemi et al. (2015). Analysis using BSC and ANP was operated to develop decision-making models (Ravi et al. 2009; Tjader et al. 2009; Modak et al. 2019), to develop strategies (Leung et al. 2006; Thakkar et al. 2007; Yuksel & Dagdeviren, 2010; Yang et al. 2013; Janes et al. 2017; Hu et al. 2019; Andrade et al. 2020), measure and evaluate performance (Yu & Wang 2007; Tseng ML et al. 2010; Oztayzi & Sari, 2012; Chen et al. 2011; Domanovic et al. 2014; Ardi et al. 2019; Darestani et al. 2019). In this study, we used a combination of BSC and ANP methods to develop a Sustainable Safe Production performance management model and develop strategies and prioritize the most effective and efficient strategy to increase productivity at the DMLZ mine.

The BSC approach developed by Kaplan and Norton (1989; 2001) is used to describe the factors and criteria that determine critical key success in the production process at the DMLZ mine. The production factors owned by the company, both tangible and intangible, can be translated into a strategy map that includes four BSC perspectives to measure the company's business performance (Luis & Biromo, 2008). The ANP method (Saaty, 1999; Ascarya, 2005) can be applied to analyze more profound and more complex decision making (Saaty, 2004; Hashemi et al. 2015) in determining priorities for appropriate alternative strategies to increase productivity at the DMLZ mine. In decision making, it is crucial to consider the existence of interrelationships between criteria. In reality, there is an interdependent nature that occurs in unavoidable problems. The ANP method makes it possible to consider interdependent relationships between criteria levels regardless of the hierarchy (Hashemi et al. 2015). The BSC and ANP approaches were combined to develop a Sustainable Safe Production performance management model.

The Sustainable Safe Production model considers four BSC perspectives as benchmarks in measuring performance: financial perspective (P-KEU), customers (P-PEL), internal business processes (P-PBI), and learning and growth process perspective (P-PLG). Modified BSC for the total production management (TPM) system (Alsyouf, 2006) enhances a production perspective and social environment perspective into the model. In the case of the DMLZ mine, the customer perspective in the model is classified into three different perspectives based on their importance: paying attention to customers from the perspective of the customer itself in business (P-PEL), considering customers in relation to parts of the business that produce (P-PRO), and the perspective customers who consider safety, health, environment, and society as part of the safety community (P-SFT). In this proposed sustainable safe production performance management model, the production factors and strategies can be translated into an operational framework for the six aspects: financial perspective (P-KEU), customers perspective (P-PEL), production perspective (P-PRO), safety perspective (P-SFT), internal business processes perspective (P-PBI), learning and growth process perspective (P-PLG).

Based on the research background explained, the objectives of this research are (1) to describe the factors and criteria that determine the success of the production process at the DMLZ mine, (2) to find the suitable performance management model for the maintenance system at the DMLZ underground mine, and (3) to determine priorities for appropriate alternative strategies to increase productivity at the DMLZ mine.

METHODS

This research was conducted in the DMLZ underground mine, one of the mining areas included in the PTFI mining permit area in the Tembagapura district, Mimika Regency, Papua. The scope of this research is limited to the measurement of performance productivity concerning the equipment or machines used in the DMLZ mine. The DMLZ mine consists of several levels, namely the undercut level, the extraction level, the exhausted level, the intake level, and the crusher and conveyor system. In this study, the researchers focus on the scope of the extraction level (which includes loader & remote rockbreaker) to haulage level (remote chute & haul-truck) because, at that level, it is the center of production operations at the DMLZ mine. This research was conducted from June 2020 to April 2021.

Researchers used two types of data, namely primary data in the form of data obtained from direct observation, interviews, and questionnaires; while secondary data is obtained from internal company reports, maintenance history archives, internal company publications, budgeting, production report data, data from the SAP system, and literature reviews. Primary data collection was carried out through interviews followed by filling out questionnaires which were conducted online using Microsoft Teams, Webex, and Zoom media.

Data collection using the triangulation technique was carried out to test the credibility of the data (Sugiyono, 2019), increasing the researcher’s understanding of what was found (Stainback, 1988), and to find out the data obtained was not widespread, consistent, and did not contradict each other (Mathison, 1988). The data collection required in the ANP was carried out using a questionnaire which was filled in separately for each respondent and was conducted online using Microsoft Teams, Webex, and Zoom media. In this study, researchers used a purposive sampling method in which the selection of respondents was based on knowledge and understanding of what the researcher expected or on the consideration of being an expert and authorized person (Sugiyono, 2019). With this consideration, the experience and knowledge of the problem are more important than the prioritization technique (Aragone’s-Beltra’n et al. 2008). The number of samples did not become a measure of the validity of ANP data collection in the purposive sampling technique. Still, the requirements of respondents who are valid in ANP are that they are experts in their fields (Ascarya, 2005).

Three experts were selected based on the criteria for selecting samples “serial selection of sample units” (Lincoln & Guba, 1985). It is by selecting certain people who are considered capable and have in-depth experience of mining business processes, maintenance activities, and production in DMLZ mine, and their authorities are directly involved with the Underground Mine Automation department. The three selected experts represent experts in the field of operational maintenance (R-NS), mining safety (R-SS), and mining operations and production (R-AP). With the expert sampling technique, ANP allows modus or average to get one priority scale number. Still, in this case, the results of the expert's assessment need to be calculated by calculating the value of the rater agreement by calculating Kendall's Coefficient of Concordance (W) (Ascarya, 2005).

The data analysis method used in this research consists of descriptive analysis to explain the phenomenon and the description of the current condition of the research object. While for comprehensive problem solving and its strategy and development model, the Analytic Network Process (ANP) method is used with a Balanced Scorecard (BSC). The formulation and strategic planning in compiling the Sustainable Safe Production performance management model adopts the BSC development model (Alsyouf, 2006), which begins with conducting an in-depth analysis of the company's background, vision and mission, conditions, and business processes. The factors that are the critical success factors (CSF), which are crucial for the continuity of the business process, need to be identified. The determination of the measure of the performance success indicators (Key Performance Indicator, KPI) of each strategic goal also needs to be designed to ensure the achievement of the targets of the strategic objectives.

Data processing in designing maps and strategic objectives of the BSC to assess the effectiveness of the maintenance performance of the automation system in the DMLZ underground mine is carried out using ANP. ANP data processing was performed using Super Decisions v.3.2 software. ANP data processing is carried out in four stages, namely: 1) making ANP / Framework models; 2) making a pairwise comparisons questionnaire; 3) testing the consistency and synthesizing the results, and 4) looking for the value of Kendall's Coefficient of Concordance (W) with the help of the IBM SPSS Statistic version 26 software which is used to determine the level of agreement on the selection of related factors among respondents.

Decision-making at ANP is carried out using expert judgment through a pairwise comparisons questionnaire. The pairwise comparison assessment process is carried out until an assessment is obtained with a consistency ratio of less than or equal to 0,1; refers to Saaty (1994) provisions, which must be less than or equal to 0,1 (10%). The Overall priority values for both Normalized by cluster and limiting values will be obtained from the output of the pairwise comparisons questionnaire data processing using the Super Decisions software. In determining priorities for alternative strategy clusters, cutting points in selecting priority strategies will be based on priority weights that have a value above the average. The cutting points are assigned to priority alternative strategies that have a weight of above 0,03704 (3.70%). The accuracy of the respondent's level of agreement was tested using rater agreement analysis indicated by the Kendall W coefficient value. The Kendall W coefficient value was obtained from data processing using SPSS Statistic v.26 statistical data processing software.

Based on the explanations from the literature review and previous research, the following hypothesis of this research were developed. H1:BSC and ANP can be implemented for creating the performance measurement model and create sustainable safe production performance management in DMLZ Mine. H2: BSC can determine the criteria of Key Success Factor in achieving productivity at the DMLZ mine. H3: ANP can determine priority strategies to increase productivity in DMLZ Mine.

The research framework (Figure 1) model consists of two stages. The first stage is to determine the factors, criteria, and alternative strategies. The second stage is to determine the priority scale. The determination of the factors and criteria are elaborated from the company's vision and mission, then derived into objectives: in this study, one of the objectives is to become a sustainable mining company, a safe and productive mining company. In Sustainable Safe Production there are three main objectives, namely: 1) achieving production targets, 2) safe and secure mining processes, and 3) achieving cost-effectiveness. From the objectives, several strategic objectives and key factors must be determined to achieve sustainable safe production, which are then translated into a strategic map and a performance management model consisting of 6 (six) business perspectives before processing using the ANP method. ANP data analysis was carried out through three stages: decomposition, quantification and comparative assessment, and performing hierarchical composition and data synthesis.

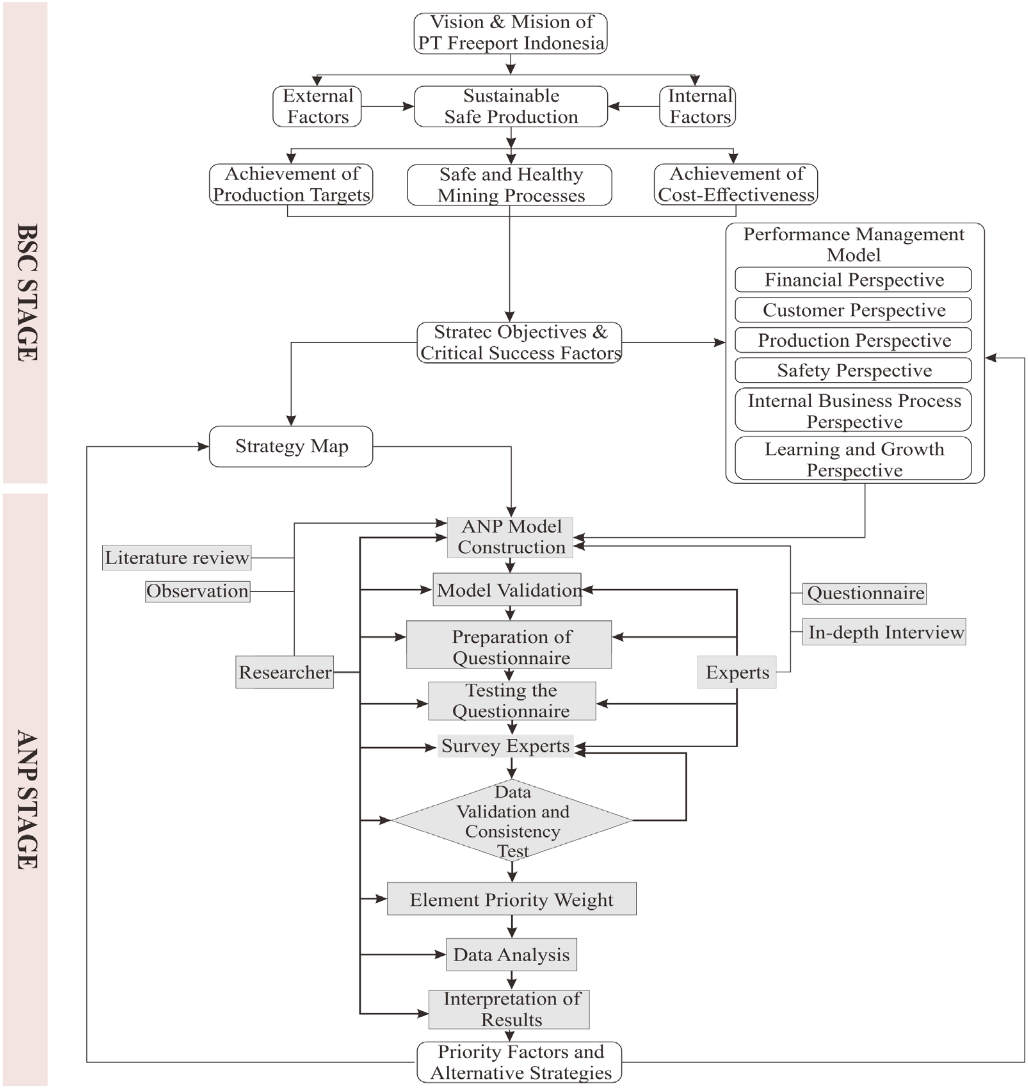

Figure 1. Research framework

RESULTS

ANP Construction for Sustainable Safe Production

From literature studies and several previous studies, the problem of sustainable safe production performance management in the DMLZ mine can be developed from the modified BSC model (Alsyouf, 2006) through the ANP method approach (Figure 2). An approach with the ANP method can be made by dividing several perspectives and factors into several clusters covering aspects of the objective variable of sustainable safe production. There are eight clusters in the proposed ANP model, one cluster for sustainable safe production goals, six clusters for the six sustainable safe production perspectives, and one cluster for alternative strategy clusters. The alternative strategy cluster consists of 27 alternative strategies, starting from AS-01 to AS-27.

The following is an abbreviation of the Figure 2. AS-01 (Performance Evaluation and Assessment), AS-02 (Focus on Handling Cost-Related), AS-03 (Investing in Safety Culture), AS-04 (Investment in Safety Resources), AS-05 (Collaboration & Synergy), AS-06 (Maintenance Knowledge Management), AS-07 (Storage & Stock Management), AS-08 (Controlling Maintenance Costs), AS-09 (Optimizing Utilization of New Technologies), AS-10 (Reducing Number of Service Complaints), AS-11 (Reducing Production Downtime), AS-12 (Improved Machine Availability), AS-13 (Improve Performance Efficiency), AS-14 (Increase Production Capacity), AS-15 (Improve Innovation Capability), AS-16 (Improve Customer Satisfaction), AS-17 (Improve Safety Achievements), AS-18 (Increase Productivity), AS-19 (Improve Repair Quality Levels), AS-20 (Reduce Accidental Equipment Damage), AS-21 (Implementation of Breakdown Analysis Systems), AS-22 (Implementation of

Maintenance Strategy and Management), AS-23 (Receipt of Materials Supply & Spare Parts), AS-24 (Skills & Competence Development), AS-25 (Efficient Use of Resources), AS-26 (Faster & Timely Delivery), and AS-27 (Worker Alignment to Goals).

Data Synthesis and Analysis

From the results of filling out the respondent's questionnaire, after validating the data, the inconsistency value for the cluster level and the criteria level has inconsistency values in the range of values between 0-0,07672 for respondent 1 (R-NS), has an inconsistency value between 0-0,07104 for respondent 2 (R-SS), and has an inconsistency value in the range of values between 0- 0,06894 for respondent 3 (R-AP). Thus, it can be considered consistent because it has an inconsistency ratio value of less than 0,1. The data provided by the three respondents can be used as a basis for data analysis and interpretation of the results. Based on the results of SPSS data processing, Kendall's W coefficient value for the answers of the three respondents regarding the model perspective was 0,964 (96.4%). It can be concluded that the experts are relatively in agreement in answering the priority criteria for the sustainable safe production perspective, and the geomean value can draw conclusions from the combined perspective priority values obtained from the three experts in the study.

The Factors and Criteria

The results of the priority analysis on the perspective cluster (Figure 3) show that the first priority order is the internal business process perspective (P-PBI) with a weight of 25,68%. The second priority is the production perspective (P-PRO) with a weight of 23.58%. The third priority is a growth and learning perspective (P-PLG) with a weight of 17.65%. The fourth priority is a financial perspective (P-KEU) with a weight of 14.78%. The fifth priority is a safety perspective (P-SFT) with a weight of 10.32%. The last priority is the customer perspective (P-PEL), with a weight of 7.46%.

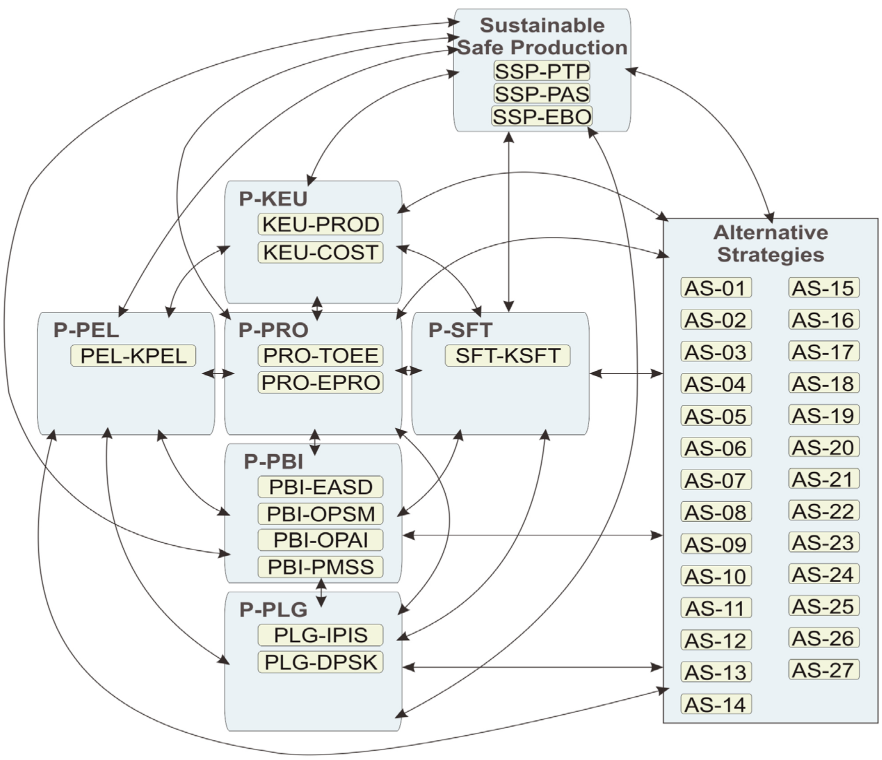

Figure 2. The validated ANP for sustainable safe production model

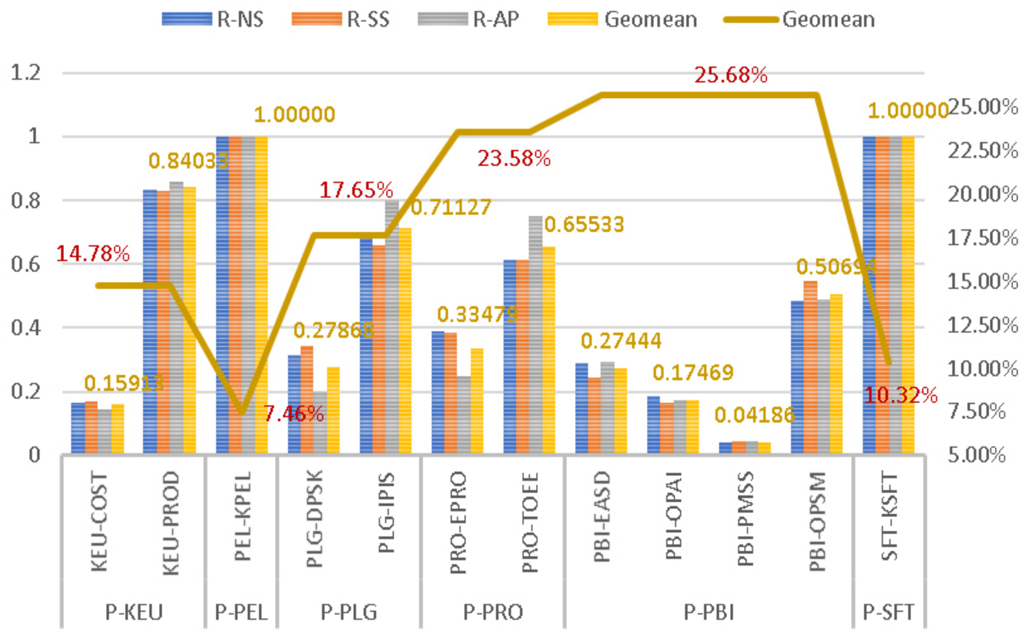

Figure 3. Priority in the perspectives cluster

From the perspective of the internal business process cluster (P-PBI), based on the results of the combined (geomean) analysis data synthesis, it shows that the implementation of a maintenance management system (PBI-OPSM) occupies the first priority position with a weight of 50.69%. The second priority of the combined analysis is the effectiveness of resource allocation (PBI-EASD) with a weight of 27.44%, which is followed by the application of analysis and improvement for the maintenance system (PBI-OPAI) with a priority weight of 17.47%. In comparison, the application of material supply management and spare parts occupy the last priority position of the key success factors of the internal business process with a priority weight of 4.19%.

In the production perspective cluster, the first priority is to increase the total overall equipment effectiveness (PRO-TOEE) with a weight of 65.53%. The second priority is to increase production effectiveness (PRO-EPRO) with a priority weight of 33.48%. The first priority for the learning and growth process cluster is to invest in the improvement program (PLG-IPIS) with 71.13%. The second priority is to increase company support for employee development (PLG-DPSK) with a priority weight of 27.87%. As for the financial perspective, the focus is to improve production performance (KEU-PROD) with a weight of 84.03%, and the second priority is to control cost performance (KEU-PROD) with a priority weight of 15.91%.

Sustainable Safe Production Performance Management Model

Based on the analysis results from experts, the weighted sustainable safe production performance management model can be explained as shown in Figure 4. Sustainable Safe Production has three objectives that have the same priority, namely achieving production targets (SSP-PTP), safe and healthy mining process (SSP-PAS), and achievement of operational cost-effectiveness (SSP-EBO). The achievement of these three goals is supported by six perspectives in the Sustainable Safe Production performance management model, namely the financial perspective (P-KEU), customers perspective (P-PEL), production perspective (P-PRO), safety perspective (P-SFT), internal business processes (P-PBI), as well as a learning and growth process perspective (P-PLG).

The financial perspective (P-KEU), which summarizes the economic consequences, contributes to the model by 9.723%, with the production performance factor (KEU-PROD) as the main success factor from a financial perspective. The financial perspective is influenced by three other perspectives below, namely the customer perspective (P-PEL), the production perspective (P-PRO), and the safety perspective (P-SFT). The effect of the production perspective is also seen in Figure 4, which has the most significant influence (15.539%) in achieving the target from a financial perspective, more important than the customer perspective (4.911%) and safety perspective (6.788%). The key factor for total overall equipment effectiveness (PRO-TOEE), which is a measure of the achievement of the overall effectiveness available in the productive maintenance model, which shows the performance of a production machine system or equipment, is a significant factor in achieving targets from a production perspective. This also explains that the reliability and performance of automation systems and production machines, such as remote rock breakers, remote chutes, remote trucks, and other supporting technologies in underground mines, significantly contribute to achieving production.

The internal business process perspective (P-PBI) aims to identify which internal processes are essential in supporting the achievement of the three other perspectives above, namely the customer perspective (P-PEL), the production perspective (P-PRO), and the safety perspective (P-SFT). In Sustainable Safe Production performance management model, it can be seen that two of the four key factors in internal business processes have a significant contribution. The first factor is how to optimize the implementation of the maintenance management system (PBI-OPSM) for the machine and equipment systems in the DMLZ underground mine. The second factor is about how internal resources include 5M, namely the ability of human resources (man), capability financial (money), allocation of time (minutes), resource methods (methods), as well as various technology and machine resources (machine) can be allocated effectively (PBI-EASD).

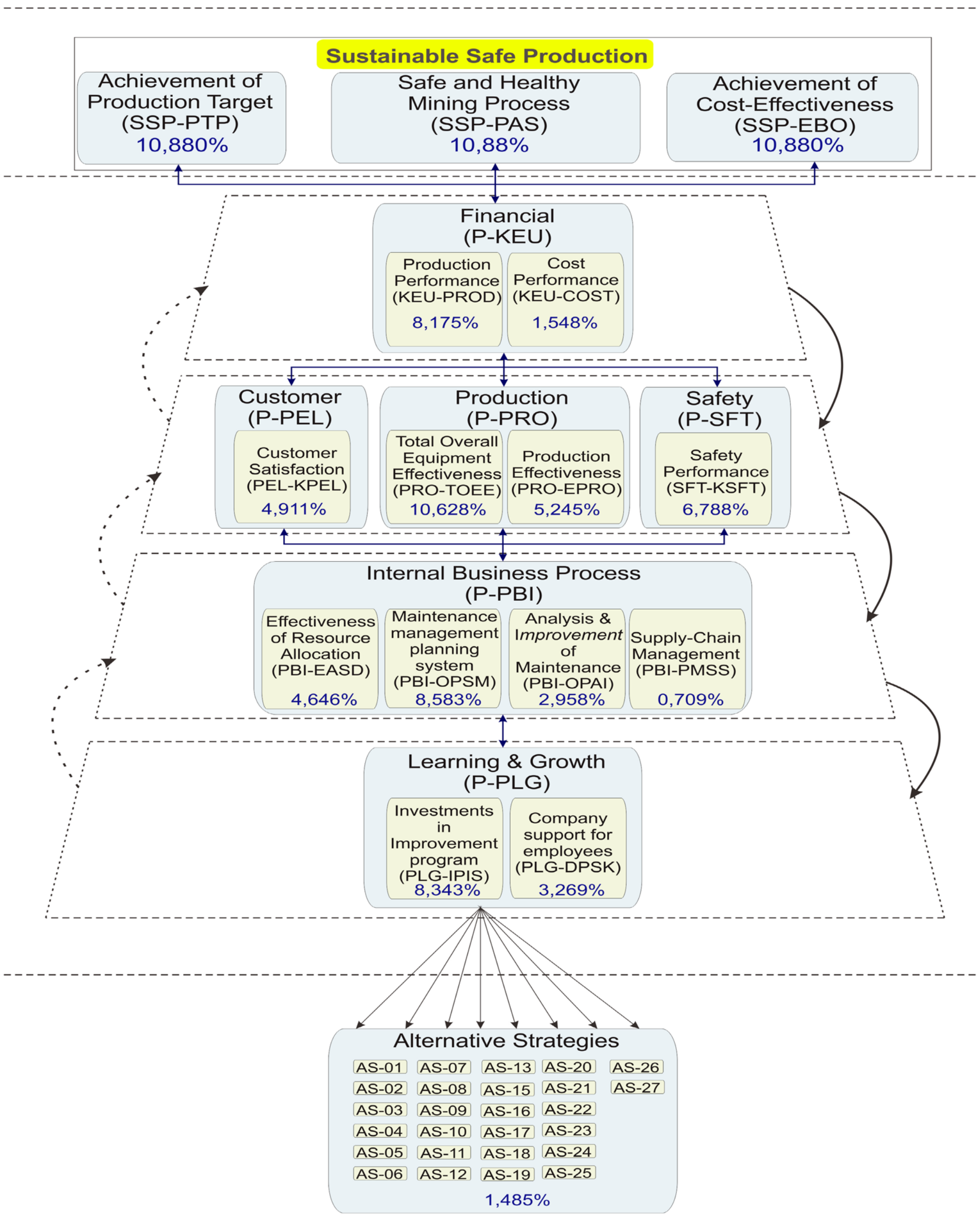

Figure 4. Sustainable safe production performance management model

The learning and growth perspective (P-PLG) provides the infrastructure that supports the achievement of the five perspectives above. Financial, customer, production, safety, and internal business process perspectives can provide an overview of the gaps between the existing capabilities of people, systems, and procedures and what is needed to achieve reliable performance in achieving Sustainable Safe Production. This perspective has two key success factors: the achievement of investment in the safety culture and safety resources development program (PLG-IPIS) and achievements in support for employee development (PLG-DPSK).

The Alternative Strategies

Based on the results of the priority analysis on the alternative strategy cluster, it was found that only 11 alternative strategy choices weighted the average (≥ mean 0,03704), namely 1) increasing production capacity (8.70%); 2) reducing production cuts (7.83%); 3) increasing the achievement of safety (7.02%); 4) investment in safety culture (6.18%); 5) efficient use of resources (6.05%); 6) increasing machine availability (5.98%); 7) investment in safety resources (5.92%); 8) controlling maintenance costs (5.88%), 9) implementing strategy and maintenance management (5.77%), 10) developing skills & competencies (5.75%) and the last alternative strategy chosen was 11) optimizing the use of technology new (5.04%).

Manajerial Implications

From the results of the analysis and discussion in this study, the main implication is that the Sustainable Safe Production performance management can be implemented at PTFI. Implementing the Sustainable Safe Production performance management can be done through the following stages (Figure 5).

The first step is to form a team that will formulate and build a Sustainable Safe Production performance model. The formed planning team then translated the organization's vision & mission into several key factors and strategic alternatives. The key factors that have been analyzed will then be translated into several strategic targets, which will then be developed into plans to be carried out, the time required, and the budget needed to carry them out. The strategic goals that are made must be stated in a specific, measurable, achievable, results-oriented form and have a deadline for achievement. The next step is to build a strategy map by combining and linking strategies and objectives into one strategy map. The strategy map depicts the causal relationship between strategy and goals into six perspectives of Sustainable Safe Production performance management.

The implementation of sustainable safe production performance management cannot be done simultaneously in every organizational unit/department, but must be done in stages. The implementation of Sustainable Safe Production management at PTFI will be implemented in four stages, namely the application at the company level, the application at the departmental level, the application at the individual level, and the implementation of the integrated total Sustainable Safe Production performance model starting from the corporate level to the individual level. In each stage of implementation, the evaluation is continuously and consistently carried out. Evaluation of the implementation of Sustainable Safe Production performance management is carried out by continuously monitoring the outcome of each indicator and performance appraisals based on the strategic map and CSF-KPIs that have been made.

Improvements to the management system, processes, and implementation of Sustainable Safe Production performance management need to be carried out continuously. So that it can identify opportunities or improve weaknesses and shortcomings found during the evaluation process to find and get the "best form" of the improvements produced so that they can provide the best solution for existing problems, the results will continue to persist and even develop for the better.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The Total Overall Equipment Effectiveness (TOEE) factor is a key success factor in achieving productivity at the DMLZ mine. TOEE is a measure of the achievement of overall effectiveness available in a productive maintenance model which shows the performance of a production machine system or equipment. Performance management of Sustainable Safe Production can be used as a performance measurement model at the DMLZ mine which can assist management in setting goals not only at the highest level, but also to ensure that company goals and strategies have been translated correctly into alternative sub-strategies at the strategic level. lower company scope. In an effort to increase productivity at the DMLZ mine, it can be done by implementing 11 alternative main priority strategies. Implementation of strategies to increase production capacity

Recommendations

This research is still focused on performance measurement in the UG Mine Automation department at the DMLZ underground mine. For the next research, the writer suggests expanding the scope to a broader scope to get a complete picture of the Sustainable Safe Production performance management model. Some of the key success factors (CSF) and alternative strategies that have less significant weight in this study can be simplified to focus on the significant factors that affect the Sustainable Safe Production management model. In subsequent studies, the author also recommends including key success factors related to environmental factors and community development which are still limited in the scope of this study.

REFERENCES

Alsyouf I. 2006. Measuring maintenance performance using a balanced scorecard approach. *Journal of Quality in Maintenance Engineering* 12(2):133-149.

Andrade Arteaga C, Rodríguez-Rodríguez R, Alfaro-Saiz JJ, Verdecho MJ. 2020. An anp-balanced scorecard methodology to quantify the impact of tqm elements on organisational strategic sustainable development: Application to an oil firm. *Sustainability* 12(15):6207.

Ardi R, Zulkarnain Z, Sudarwanto B, Ambarwati L. 2019. Development of Performance Measurement Model using Balance Scorecard Method and Analytic Network Process in Construction Consultant Services Industry. In: Proceedings of the 2019 5th International Conference on Industrial and Business Engineering. pp:148-152.

Ascarya. 2005. *Analytic Network Process (ANP): Pendekatan Baru Studi Kualitatif*. Jakarta: Pusat Pendidikan dan Studi Kebanksentralan Bank Indonesia.

Assauri S. 2018. *Manajemen Produksi dan Operasi.* Jakarta: Fakultas Ekonomi Universitas Indonesia.

Chen FH, Hsu TS, Tzeng GH. 2011. A balanced scorecard approach to establish a performance evaluation and relationship model for hot spring hotels based on a hybrid MCDM model combining DEMATEL and ANP. *International Journal of Hospitality Management* 30(4):908-932.

Darestani SA, Shamami NH. 2019. Performance evaluation of lean production based on balanced score card method using ANP and SIR: A case from Iranian home appliance industry. *Opsearch* 56(3):717-738.

Domanović V, Jakšić M, Mimović P. 2014. Balanced scorecard and analytic network process in performance measurement and strategy evaluation: A case study. *TEME: Casopis Za Društvene Nauke* 38(4).

Gram M. 2013. A systematic methodology to reduce losses in production with the balanced scorecard approach. *Manufacturing Science and Technology* 1(1):12-22.

Griffin RW, Ebert RJ. 2006. *Business, International Edition*. New Jersey: Pearson Education Limited.

Günter R. 1978. *General technology: a systems theory of technology.* Deutschland: KIT Scientific Publishing.

Gutenberg E. 1983. *Fundamentals of Business Economics: Production.* New York: Springer.

Hashemi SH, Karimi A, Tavana M. 2015. An integrated green supplier selection approach with analytic network process and improved Grey relational analysis. *International Journal of Production Economics* 159:178-191

Hu Y, Xiao S, Wen J, Li J. 2019. An ANP-multi-criteria-based methodology to construct maintenance networks for agricultural machinery cluster in a balanced scorecard context. *Computers and Electronics in Agriculture* 158:1-10.

Ishikawa K. 1985. What Is Total Quality Control? The Japanese Way. New Jersey: Prentice Hall.

Janeš A, Kadoić N, Begičević Ređep N. 2017. The ANP Representation of the BSC. In: Proceedings of 28th International Conference Central European Conference on Information and Intelligent Systems. pp: 28:309-315.

Kaplan RS, Atkinson AA. 1989. *Advanced Management Accounting.* New Jersey: Prentice-Hall Inc.

Kaplan RS, Norton DP. 2001. Transforming the balanced scorecard from performance measurement to strategic management: Part II. *Accounting Horizons* 15(2):147-160.

Lesourd JB. 1985. Energy and resources as production factors in process industries. *Energy Economics* 7(3):138-144.

Leung LC, Lam KC, Cao D. 2006. Implementing the balanced scorecard using the analytic hierarchy process & the analytic network process. *Journal of the Operational Research Society* 57(6):682-691.

Lincoln YS, Guba EG. 1985. Establishing trustworthiness. *Naturalistic Inquiry* 289(331):289-327.

Luis S, Biromo PA. 2008. *Step by Step in Cascading Balanced Scorecard.* Jakarta: PT Gramedia Pustaka Utama.

Mathison S. 1988. Why triangulate?. *Educational Researcher 1*7(2):13-17.

Modak M, Ghosh KK, Pathak K. 2019. A BSC-ANP approach to organizational outsourcing decision support-A case study. *Journal of Business Research* 103:432-447.

Nebl T. 2018. The potential factor of production resource. *Production Management* 239-358.

Nieto A. 2011. Key deposit indicators (KDI) and key mining method indicators (KMI) in underground mining method selection. *Transactions of the American Institute of Mining and Metallurgical Engineers* 328:381-396.

Öztayşi B, Sari İ.U. 2012. Performance measurement of a manufacturing company using fuzzy analytical network process. *International Journal of Applied Management Science* 4(4):439-459.

Parida A, Kumar U. 2009. *Maintenance Productivity and Performance Measurement: Handbook of Maintenance Management and Engineering.* London: Springer.

Parida A, Åhrén T, Kumar U. 2003. Integrating Maintenance Performance with Corporate Balanced Scorecard. In: International Congress on Condition Monitoring and Diagnostic Engineering Management; Sweden, 27-29 Aug 2003. Sweden: Växjö Universitet. pp 53-59.

Ravi V, Shankar R, Tiwari MK. 2005. Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach. *Computers & Industrial Engineering* 48(2):327-356.

Rybak A, Rybak A. 2016. Possible strategies for hard coal mining in Poland as a result of production function analysis. *Resources Policy* 50:27-33.

Saaty TL. 1994. Highlights and critical points in the theory and application of the analytic hierarchy process. *European Journal of Operational Research* 74(3):426-447.

Saaty TL. 1999. Fundamentals of The Analytic Network Process. In: Proceedings Of The 5th International Symposium on The Analytic Hierarchy Process. pp 12-14.

Saaty TL. 2004. Decision making—the analytic hierarchy and network processes (AHP/ANP). *Journal of Systems Science and Systems Engineering* 13(1):1-35.

Stainback S, Stainback W. 1988. *Understanding & Conducting Qualitative Research.* Dubuque Iowa: Kendall.

Sugiyono. 2019. *Metode Penelitian Kuantitatif Kualitatif dan R&D.* Jakarta: Alfabeta.

Thakkar J, Deshmukh SG, Gupta AD, Shankar R. 2007. Development of a balanced scorecard: an integrated approach of interpretive structural modeling (ISM) and analytic network process (ANP). I*nternational Journal of Productivity and Performance Management.*

Tjader Y, Shang J, Vargas L, May J. 2009. Integrating the analytic network process and the balanced scorecard for strategic it outsourcing decision making [paper]. Pittsburgh: University of Pittsburgh.

Tseng ML. 2010. Implementation and performance evaluation using the fuzzy network balanced scorecard. *Computers & Education* 55(1):88-201.

Yang Y, Yang SL, Yang, J. 2013. A BSC-ANP model for evaluation of strategic fit of new product development projects. In: 25th Chinese Control and Decision Conference (CCDC). pp 1643-1647.

Yu X, Wang F. 2007. A method of performance evaluation based on ANP and BSC. *Asian Social Science* 3(11):43-47.

Yüksel İ, Dağdeviren M. 2010. Using the fuzzy analytic network process (ANP) for Balanced Scorecard (BSC): A case study for a manufacturing firm. *Expert Systems with Applications* 37(2):1270-1278.