Mathematical Methods for Controlling the Performance of an Industrial Park

Esther S. M. Nababan, Agus Salim Harahap and Normalina Napitupulu
Department of Mathematics, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan, Indonesia

Keywords: Carrying Capacity, Control, Robust, Environmental Performance, Performance Measurement.

Abstract: Robust reliable performance metrics enable a management to identify and address deficiencies and control factors to improve performance of any system. The complexity of modern operating environments presents real challenges to developing equitable and accurate performance metrics. This paper presents literature review and analysis of how mathematical methods utilized and functioned to develop a control factor or dynamic constraint in endeavoring to increase environmental performance of eco-industrial parks. Constrained minimax optimization model is developed to maximize economic gain while minimizing waste in a region within the border where dynamic carrying capacity is maintained stable. Carrying capacity is added in as control factor to increase environmental performance within a boundary or area within which balance of carrying capacity is maintained, in order to increase environmental performance without reducing quality of environment.

1 INTRODUCTION

Controlling is a central notion in several academic disciplines, but the concept has been almost exclusively subject specific. One of the most essential qualities required in a managing the system or organization is that the manager of the organization should command the respect of its' team. This allows the manager to direct and control all activities and the actions of the elements in the system. Managers at all levels of management need to perform controlling function to keep control over activities in their areas. (McPhail et al., 2018; Siahaan, 2011)

Therefore, controlling is very much important in any system or organization. Controlling can be defined as that function of management which helps to seek planned results from the subordinates, managers and at all levels of an organization. The controlling function helps in measuring the progress towards the organizational goals & brings any deviations, and indicates corrective action. Thus, an overall sense, the controlling function helps and guides the organizational goals for achieving long-term goals in future.

It is an important function because it helps to check the errors, helps in taking the correct actions so that there is a minimum deviation from standards and, in achieving the stated goals of the organization in the desired manner. According to modern concepts, control is a foreseeing action. Whereas the earlier concept of control was used only when errors were detected. Therefore, controlling function should not be misunderstood as the last function of management. It is a function that brings back the management cycle back to the planning function. Thus, the controlling function act as a tool that helps in finding out that how actual performance deviates from standards and also finds the cause of deviations & attempts which are necessary to take corrective actions based upon the same. A good control system helps an organization in accomplishing organizational goals, judging accuracy of Standard, making efficient use of resources, improving employee motivation, ensuring order & discipline, and facilitating coordination in action.

1.1 Controlling the Performance of Industrial Park

In the industrial park, controlling the land as the most important natural resource is conducted in order to make optimum utilization of the natural resources since at the certain point human beings have caused a lot of damages to the land resources. About 95% of our basic needs –food, clothing, shelter come from land. Hence conservation of land

S. M. Nababan, E., Salim Harahap, A. and Napitupulu, N.
Mathematical Methods for Controlling the Performance of an Industrial Park.
DOI: 10.5220/0010138300002775
In *Proceedings of the 1st International MIPAnet Conference on Science and Mathematics (IMC-SciMath 2019)*, pages 178-184
ISBN: 978-989-758-556-2

resources and development of land is extremely crucial to the future generations can survive. There are different land planning and conservation measures that can be taken to protect this natural resource such as :

a. Planting shelter belts for plants
b. Controlling over-grazing in open pastures
c. Stabilizing sand dunes
d. Proper management of wastelands
e. Controlling mining activities
f. Proper disposal of industrial waste
g. Reducing land and water degradation in industrial areas.

Of many outcome targets of controlling, stability is the most important outcome of controlling.

Some of them are constancy, persistence, resilience, elasticity, amplitude, cyclical stability, trajectory stability, global stability, local stability, and alternate stable states (Nababan, 2014). There are 3 basic concept of stability known in general which are constancy, robustness and, resilience. However, stability relates to transitions between states. Robustness can be shown as a limiting case of resilience, and neither constancy nor resilience can be defined in terms of other. Hence, there are two basic concepts of stability, both of which are used in both the social and the natural sciences (Nababan et al., 2017).

A performance measurement control system is designed to help organizations improve performance issues. Every process of a business' operations is studied through this system to improve the performance. When all activities have improved performance, the organization's profitability should increase.

1.2 Perfomance Measurement Control System

Like many scientific concepts, fully adequate definitions of some ecological concepts have not yet been formulated. Performance measurement control systems contain several key principles: All work activity must be measured; if an activity cannot be measured, its processes cannot be improved; all measured work should have a predetermined outcome regarding performance. All work activity must be measured; if an activity cannot be measured, its processes cannot be improved; all measured work should have a predetermined outcome regarding performance. Analysts (managers) determine what the outcome of each particular activity should be. If an activity cannot be measured, the organization tries to eliminate it. After each activity is measured, it is compared to the desired results. If the activity is not performing up to the desired outcome, changes to the activity are implemented to improve performance. Evaluation in general is a part of all organizations. For evaluations to be effective, the criteria to be used for evaluation must be planned carefully and thoroughly. Understanding the objectives of the program and the effectiveness of the activities carried out by the company, output efficiency is a major component of the criteria for evaluation (Siahaan, 2011).

To evaluate the performance of an organization, there must be something to compare the actual performance. Before evaluation criteria can be developed, the goals of the organization must be clear, especially for those who are evaluating. The next stage is to determine whether the activity is sufficient to meet the objectives of the organization. The first stage of the evaluation criteria is an investigation of the company's core operations. These activities must be evaluated to determine whether they are carried out correctly or not. If there are deficiencies, management can take strategic steps to bridge the gap to improve the entire process.

The last part of the evaluation criteria is determining how well the activity helps the manager achieve his goals, whether the company achieves its objectives based on the way the activities are regulated by the company, followed by determining evaluation criteria is to prepare a measurement tool to measure the efficiency of an organization's output. This tool will consist of evaluation techniques that measure whether a company uses its resources wisely and in a cost effective manner and whether objectives are met on schedule. This measurement can help management design alternative solutions to make company operations more efficient.

Another important part of the evaluation criteria is studying the impact of the company. Another important step is evaluating sustainability. This criterion is used to determine how changes in the competitive landscape, regulatory environment, economic conditions, customer preferences, and the labor market affect a company's ability to sustain sales and profit growth. There are several applications of control theory for a system. To improve environmental performance, managers must set specific goals that will improve environmental performance.

In terms of human resource management, the three types of control systems, namely behavioral control, output control and input control can be used to analyse employee behaviour and performance (Margalef, 1969).

More advanced and more critical applications of control concern large and complex systems the very existence of which depends on coordinated operation using numerous individual control devices (usually directed by a computer). The launch of a spaceship, the 24-hour operation of a power plant, oil refinery, or chemical factory, and air traffic control near a large airport are examples. An essential aspect of these systems is that human participation in the control task, although theoretically possible, would be wholly impractical; it is the feasibility of applying automatic control that has given birth to these systems. Conceptual representation of conditions affecting ranking stability shows that A high stability in ranking indicates that two metrics will rank the decision alternatives the same, whereas a low stability indicates that two metrics will rank the decision alternatives differently (McPhail et al., 2018).

A range of theories and methods is developed for improving productivity in every industrial activity without damaging the quality of the environment. A quality of the environment can be achieved by maintaining the ecological stability of the environment. Each industrial activity must be carried out within the stable region of ecological carrying capacity. A community's resilience stability is determined by how fast the variable of the interest returns to its pre-perturbed stable equilibrium.

1.3 Robustness Metric Calculation

Robustness is generally calculated for a given decision alternative x_i across a given set of future scenarios $S = \{s_1, s_2, \ldots, s_n\}$ using a particular performance metric $f(\cdot)$.

Consequently, the calculation of robustness using a particular metric corresponds to the transformation of the performance of a set of decision alternatives over different scenarios $f(x_i, S) = \{f(x_i, s_1), f(x_i, s_2), \ldots, f(x_i, s_n)\}$ to the robustness $R(x_i, S)$ of these decision alternatives over this set of scenarios. Although different robustness metrics achieve this transformation in different ways, a unifying framework for the calculation of different robustness metrics can be introduced by representing the overall transformation of $f(xi, S)$ into $R(x_i, S)$ by three separate transformations: performance value transformation (Tr.1), scenario subset selection (Tr.2), and robustness metric calculation (Tr.3), as shown in Figure 1. Details of these transformations for a range of commonly used robustness metrics are given in Table 1 and their mathematical implementations are given in Supporting Information S1.

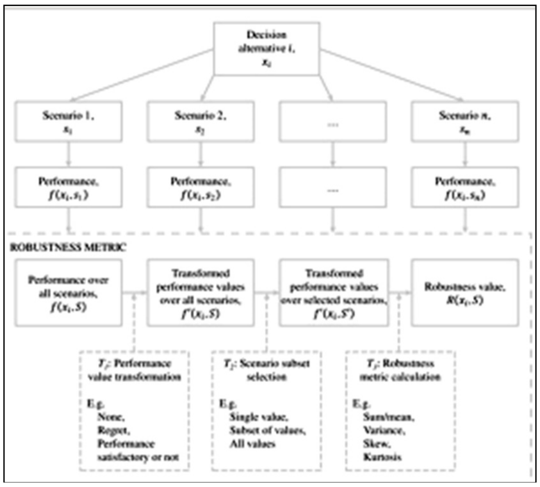

Figure 1: Unifying framework of components and transformations in the calculation of commonly used robustness metrics (Source: McPhail et al., 2018).

The performance value transformation (Tr.1) converts the performance values $f(xi, S)$ into the type of information $f'(x_i, S)$ that is used in the calculation of the robustness metric $R(xi, S)$. For some robustness metrics, the absolute performance values (e.g., cost, reliability) are used, in which case Tr.1 corresponds to the identity transform (i.e., the performance values are not changed). For other robustness metrics, the absolute system performance values are transformed into values that either measure the regret that results from selecting a particular decision alternative rather than the one that performs best had a particular future actually occurred or indicate whether the selection of a decision alternative results in satisfactory system performance or not (i.e., whether required system constraints have been satisfied or not).

The scenario subset selection transformation (Tr. 2) involves determining which values of $f'(x_i, S)$ to use in the robustness metric calculation (Tr. 3) (i.e., $f'(x_i, S') \subseteq f'(x_i, S)$), which is akin to selecting a subset of the available scenarios over which system performance is to be assessed. This reflects a particular degree of risk aversion, where consideration of more extreme scenarios in the calculation of a robustness metric that corresponds to a higher degree of risk aversion and vice versa. The third transformation (Tr. 3) involves the calculation of the actual robustness metric based on transformed system performance values (Tr. 1) for the selected scenarios (Tr. 2), which corresponds to the transformation of $f'(x_i, S')$ to a single robustness value, $R(x_i, S)$. This equates to an identity transform in cases where only a single scenario is selected in Tr. 2, as there is only a single transformed performance value, which automatically becomes the robustness value. However, in cases where there are transformed performance values for multiple scenarios, these have to be transformed into a single value by means of calculating statistical moments of these values, such as the mean, standard deviation, skewness or kurtosis.

In relation to the performance value transformation (Tr.1), which robustness metric is most appropriate depends on whether the performance value in question relates to the satisfaction of a system constraint or not, and is therefore a function of the properties of the system under consideration. For example, if the system is concerned with supplying water to a city, there is generally a hard constraint in terms of supply having to meet or exceeding demand, so that the city does not run out of water (Beh et al., 2017). The system performs satisfactorily if this demand is met and that is the primary concern of the decision-maker. Alternatively, there might be a fixed budget for stream restoration activities, which also provides a constraint. In this case, a solution alternative performs satisfactorily if its cost does not exceed the budget. For the above examples, where performance values correspond to determining whether constraints have been met or not, satisficing metrics, such as Starr's domain criterion, are most appropriate.

In contrast, if the performance value in question relates to optimizing system performance, metrics that use the identity or regret transforms would be most suitable. For example, for the water supply security case mentioned above, the objective might be to identify the cheapest solution alternative that enables supply to satisfy demand. However, there might also be concern in over-investment in expensive water supply infrastructure that is not needed, in which case robustness metrics that apply a regret transformation might be most appropriate, as this would enable the degree of over- investment to be minimized when applied to the cost performance value. For the stream restoration example, however, decision-makers might simply be interested in maximizing ecological response for the given budget. In this case, robustness metrics that use the identity transform might be most appropriate when considering performance values related to ecological response.

In relation to scenario subset selection (Tr.2), which robustness metric is most appropriate depends on a combination of the likely impact of system failure and the degree of risk aversion of the decision-maker. In general, if the consequences of system failure are more severe, the degree of risk-aversion adopted would be higher, resulting in the selection of robustness metrics that consider scenarios that are likely to have a more deleterious impact on system performance. For example, in the water supply security case, it is likely that robustness metrics that consider more extreme scenarios would be considered, as a city running out of water would most likely have severe consequences. In contrast, as the potential negative impacts for the stream restoration example are arguably less severe, robustness metrics that use a wider range or less severe scenarios might be considered. However, this also depends on the values and degree of risk aversion of the decision maker. As far as the robustness value calculation (Tr. 3) goes, this is only applicable to metrics that consider more than one scenario, as discussed previously, and relates to the way performance values over the different scenarios are summarized. For example, if there is interest in the average performance of the system under consideration over the different scenarios selected in Tr.2, such as the average cost for the water supply security example or the average ecological response for the stream restoration example, a robustness metric that sums or calculates the mean of these values should be considered. However, decision-makers might also be interested in (1) the variability of system performance (e.g., cost, ecological response) over the selected scenarios, in which case robustness metrics based on variance should be used, (2) the degree to which the relative performance of different decision alternatives is different under more extreme scenarios, in which case robustness metrics based on skewness should be used, and/or (3) the degree of consistency in the performance of different decision alternatives over the scenarios considered, in which case robustness metrics based on kurtosis should be used. As these metrics are used to make decisions on outcomes, it is important to obtain greater insight into the conditions under which different robustness metrics result in different decisions.

It is important to note that the relative ranking of two decision alternatives (x_1 and x_2), when assessed using two robustness metrics (R_a and R_b), will be the same, or stable, if the following three conditions hold:

$$R_a(x_1) > R_a(x_2) \text{ and } R_b(x_1) > R_b(x_2), \qquad (1)$$

or $R_a(x_1) < R_a(x_2)$ and $R_b(x_1) < R_b(x_2)$, (2)
or $R_a(x_1) = R_a(x_2)$ and $R_b(x_1) = R_b(x_2)$, (3)
$R_a(x_1) > R_a(x_2)$ and $R_b(x_1) < R_b(x_2)$, (4)
or $R_a(x_1) < R_a(x_2)$ and $R_b(x_1) > R_b(x_2)$. (5)

The relative rankings will be different or "flipped" if the following two conditions hold: Consequently, relative differences in robustness values obtained when different robustness metrics are used are a function of (1) the differences in the transformations (i.e., performance value transformation (Tr.1), scenario subset selection (Tr.2), robustness metric calculation (Tr.3)) used in the calculation of Ra and Rb and (2) differences in the relative performance of decision alternatives x_1 and x_2 over the different scenarios considered. In general, ranking stability is greater if there is greater similarity in the three transformations for R_a and R_b and if there is greater consistency in the relative performance of x_1 and x_2 for the scenarios considered in the calculation of Ra and R_b, as shown in the conceptual representation in Figure 4. In fact, if the relative performance of two decision alternatives is the same under all scenarios, the relative ranking of these decision alternatives is stable, irrespective of which robustness metric is used.

2 ECOLOGICAL STABILITY AS A CONTROL

Ecological Indicator is a measure, or a collection of measures, that describes the condition of an ecosystem or one of its critical components. Ecological indicators are used to communicate information about ecosystems and the impact human activity has on ecosystems to groups such as the public or government policy makers.

Some theories define that good ecological indicators should:

- reflect something basic and fundamental to the long-term economic, social or environmental health of a community over generations.
- be understood and accepted by the community as a valid sign of sustainability or symptom of distress
- have interest and appeal for use by local media in monitoring, reporting and analysing general trends toward or away from sustainable community practices; and
- be statistically and practically measurable in a geographical area, preferably comparable to other cities/communities, and yield valid data.

The basic principles of developing indicators are: use existing data, re-evaluate underlying assumptions, integrate long-term focus with short-term change, relate indicators to individual and vested stakeholders, identify the direction of sustainability, present indicators as a whole system and determine linkages. It is also important to use a simple and easy to understand format for presenting data so that decision makers or other stakeholders can base on the existing data to seek further information that addresses issues of primary concerns in the community.

There are the number of options for formulating a complex definition of ecological stability. Adopting ecological stability defined as the ability of an ecosystem to resist changes in the presence of perturbations, in the context of stability on industrial parks, perturbations consists of social, economic, environmental and political influence on the management of industrial park (May, 1973).

Assume X_1 = social perturbation ; X_2 = economic perturbation ; X_3 = environmental perturbation , and X_4 = political perturbation. All vectors are confined within some closed arbitrary boundary.

Probability $$\sum_{i=1}^{4} P(X_i) = 1 \quad (6)$$

Each variables can either be independently affects the stability of industrial park, or have simpal causal relationship or dependence among each vectors as well as sub vectors.

By adopting Rutledge's concepts about ecological stability, to develop an index for the stability a model diagram can be developed to describe the dependence on time for each perturbation component. All the compartment model diagram has a dependence on time. Hence, each main component is represented at two arbitrary times t_1 and t_2.

Let Q_i be the initial conditions of the industrial park at time t_1. P_j is the conditions of the industrial parks at time t_2, f_{ij} is the percentage of the total perturbation flow through the i^{th} component that passes to the j_{th} component between times t_1 and t_2.

The Q_i and P_i refer to component of perturbation X_i occurs at different times with any difference in these components and subcomponents therein accounted by f_{ij}. The relationship between these variables is provided by the equation :

$$P_j = \sum_{i=1}^{4} f_{ij} Q_i \quad (7)$$

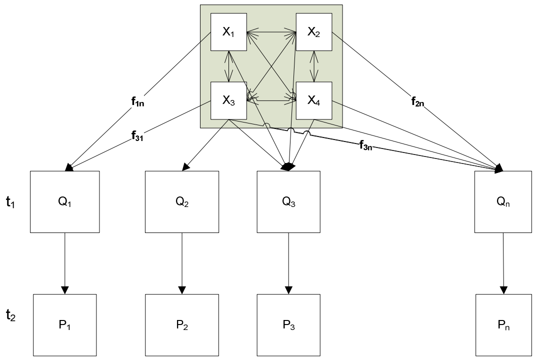

Figure 2: Diagram of main components from the original conditions to perturbed conditions.

Perturbation flow in an industrial park ecosystem is a fuction of time. It can occur either in a pathways between entities or in a resources point itself affected by internal or external perturbation. The variables X_i can be defined to be of discrete or continue in nature which represent perturbation flows over some arbitrary time period.

Let a_k be the passage of a given increment of perturbation through the k^{th} component at time t_1 and the b_j represent the passage of a given increment of perturbation through the j^{th} component at time t_2. The diversity of the ecosystem in terms of its throughput is given by :

$$D = -\sum_{i=1}^{4} P(a_k)\log P(a_k) \tag{8}$$

Where the event a_k is defined as the passage of a given increment of perturbation through the k^{th} component and $P(Q_k)$ is the probability that event a_k occured. The diversity is a function of time, since the perturbation flow in an ecosystem is a function of time. Hence, the time dependent nature is obtainded by defining the appropriate events of perturbation occurence as functions of time.

is the logarithm of the ratio of a posteriori to a priori probabilities (Gallagher, 1986).

$$I(a_k;b_j) = \log\frac{P(a_k/b_k)}{P(a_k)} \tag{9}$$

Uncertainty as measured by equation (4) is equivalent to the uncertainty resolved about the occurence of perturbation event b_j by the occurence of perturbation event a_k (Gallagher, 1986) and is given by :

$$I(a_k;b_j) = \log\frac{f_{kj}}{P_j} \tag{10}$$

Since the complexity of the symbiotic chain reflects the opportunities for choice of pathways, a measure of choice is an appropriate index for symbiotic chain and hence for ecological stability. If one of the components is perturbed, the extent to which it is affected may serve as an index of its ecological stability. As perturbation occurance is a function of time, equlibrium will dinamically change depend on time as well. Continuous perturbation may lead to the occurance of phase distribution equilibrium.

For every perturbation passing through a component in an ecosystem, a probability assignment can be made to its destination or source. Given a specific perturbation has passed through the k^{th} component, $P(Q_j/P_k)$ is the probability that the increment of perturbation will affect or taken up by the j^{th} componen, $P(Q_j/P_k)$ is the probability that the perturbation passed from the k^{th} component to the j^{th} component. The occurence of perturbation b_j changes the probability of the occurence of perturbation a_k from the a proiri probability, $P(Q_k)$ to the a posteriori probability $P(Q_k/P_j)$.

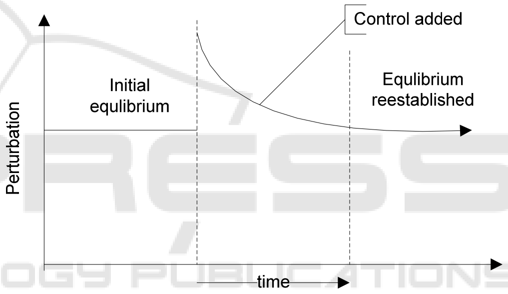

Figure 3: A control is added to get equilibrium reestablished.

A quantitative measure of the uncertainty about the occurence of perturbation events. Phase distribution equilibrium occurs when the perturbation event occurs continuously.

Continuous perturbation may occured by temperature, energy flow, and chemical reactions. Equilibrium change dinamically continuous. In such case, equilibrium constant can is calculated on each defined phase. Phase can either be time period, or symbiotical phase.

One of the many ways to get the community equilibrium reestablished is to add control. If control is added while the system is at equilibrium, the system must respond to counteract the control. The system must consume the control and produce products until a new equilibrium is established.

3 CONCLUSION

Ecological stability of industrial parks can be used as a control developed based on choice of pathways for symbiotic structure. Ecological stability is one of the many indicators that affect the environmental performance of industrial estates. This ecological stability can be functioned as an environmental performance control system, including the industrial estate system. The robust method is used to determine whether a decision alternative performs satisfactorily under different scenarios, and are commonly referred to as satisficing metrics.

In robust optimization, the set of uncertainties for parameters determines a very important role. To date there are no clear provisions on how to determine the set of uncertainties correctly. Robust optimization is to reduce optimal portfolio sensitivity due to uncertainty in estimating mean vectors and variance-covariance matrices.

Relationships among ecological stability, diversity and complexity consistent with observed behavior during succession arise naturally in the development of the stability index. Theoretical community ecology can provide a much needed resource even when it does not give definitive answers about what to do in particular cases but only explores possibilities. There are a variety of stability concepts and ecologists have begun to systematically explore and use them to remove various confusions concerning the complexity-stability hypotheses.

REFERENCES

Beh, E. H. Y., Zheng, F., Dandy, G. C., Maier, H. R., & Kapelan, Z. (2017). Robust Optimization of Water Infrastructure Planning under Deep Uncertainty using Metamodels. *Environmental Modelling & Software*, *93*, 92–105. https://doi.org/https://doi.org/10.1016/j.envsoft.2017.03.013

Gallagher, S. (1986). Body Image and Body Schema. *Journal of Mind and Behavior*, *7*, 541–554.

Margalef, R. (1969). *Diversity and Stability in Ecological Systems, G. M. Woodwell and H. H. Smith, eds.*

May, R. (1973). *Stability and Complexity in Model Ecosystems*. Princeton University Press.

McPhail, C., Maier, H. R., Kwakkel, J. H., Giuliani, M., Castelleti, A., & Westra, S. (2018). Robustness Metrics: How Are They Calculated, When Should They Be Used and Why Do They Give Different Results? *Resilient Decision-Making for a Riskier World*, *6*(2), 169–191. https://doi.org/https://doi.org/10.1002/2017EF000649

Nababan, E. (2014). Ecological Stability of Industrial Park. *The 4th ASEAN Environmental Engineering Conference Proceeding*.

Nababan, E., Delvian, D., & Siahaan, N. M. (2017). Environmental Performance Indicators of Oleo-Chemical Based Industrial Park in Indonesia: The Conceptual Model. *International Journal of Applied Engineering Research*, *12*(21), 11614–11623.

Siahaan, N. (2011). Controlling Residential Supporting Environment System to Reduce CO2 Emissions in Urban Housing. *Proceeding of the 4th ASEAN Civil Engineering Conference*.