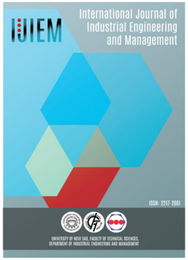
ISSN 2683-345X



journal homepage: http://ijiemjournal.uns.ac.rs/

International Journal of Industrial Engineering and Management

Volume 11 / No 4 / December 2020 / 253 - 262

Original research article

Application of system dynamics in the assessment of project portfolio performance

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ABSTRACT

Effective assessment of a Project Portfolio Performance (PPP) has been widely claimed to hold great promise for the effective management of organizations. The current literature is confined to assessing a PPP either statically or by taking a separate view of each project within a portfolio. Advocated here is the development of a dynamic assessment model that assists with the understanding of the overall performance of a portfolio at any given point in time. In this context, this paper proposes a System Dynamics (SD) modeling approach by creating a link between a portfolio and its constituent projects. The proposed SD model attempts to answer a question of particular interest: "How changes in the state of projects within a portfolio affect the overall performance of the project portfolio over time?". Within this framework, a new index as a function of various factors that affect a project portfolio is developed. Using 60 projects under the engineering and construction portfolio, this paper measures the overall performance of the portfolio over time in response to changes in the performance of its projects. As expected, the level of PPM maturity has a direct impact on the performance of the portfolio. On the one hand, the implementation of effective resource management as well as designing a sound measurement system lead to the improvement of the overall status of the portfolio performance. On the other hand, shifting priorities due to the lack of a coherent business strategy as well as resistance to changes because of internal politics and/or insufficient information result in the delay and cost overrun in projects, thereby decelerating the improvement in the status of the projects within a portfolio.

ARTICLE INFO

Article history:

Received October 8, 2020
Revised December 11, 2020
Accepted December 14, 2020
Published online December 24, 2020

Keywords:
Project portfolio;
System dynamics;
Stock and flow diagram

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1. Introduction

How do organizations monitor Project Portfolio Performance (PPP) in light of the strategic objectives? This question has preoccupied researchers and practitioners in project-based organizations as many companies manage multiple sets of projects simultaneously. In the world of Project Portfolio Management (PPM), two key managerial tasks after selection and prioritization of projects are: 1) assessing the current performance of a portfolio [1], and 2) forecasting the future performance of a portfolio based on its current status. Assessing and controlling the performance of an organization not only facilitates the achievement of the strategic goal [2] but also supports the management system of an organization [3]. Despite the importance of measuring and forecasting the performance of project portfolios, there is a paucity of research on this subject. A few existing quantitative studies are confined to measuring a PPP either statically or by taking a separate view of each project within a portfolio. Limited efforts have facilitated a holistic and dynamic understanding of the overall performance of a portfolio. In fact, the extant literature yields insufficient information about the current and future status of a project portfolio as a whole.

Published by the University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia.

DOI: http://doi.org/10.24867/IJIEM-2020-4-269

Further, the existing literature provides a snapshot of the current status of a portfolio at a given point in time and, therefore, is not able to forecast the future status of the portfolio. To remedy these weaknesses, this article offers a new framework for the assessment of a PPP by the development of a System Dynamics (SD) modeling approach. The approach creates a link between a portfolio and its constituent projects. This link attempts to answer a question of particular interest: "How changes in the state of projects within a portfolio affect the overall performance of the project portfolio over time?"

This research makes the following contributions. We apply, for the first time, the SD modeling technique to the PPM domain, which helps to measure the extent to which projects contribute to the success or failure of the project portfolio as well as the business results of the organization [4]. Furthermore, as highlighted by Saeed et al. [5] and pointed out by Dooley et al. [6], projects should be considered as part of an integrated portfolio rather than a separated collection. The model, developed herein, integrates planned objectives of projects and portfolio performance evaluation.

The remainder of this paper is structured as follows. The following section presents a synopsis of the SD modeling approach as well as the building blocks of this approach. Section 3 reviews the extant literature on the assessment of PPP followed by reviewing the application of SD in the project management domain. Section 4 develops an SD model and proposes a dynamic index to measure the performance of a project portfolio, taken as a whole. Simulation analysis is performed and the discussion of results is provided in Section 5. The practical implications of the proposed model will be presented in Section 6. The article is concluded in Section 7.

2. A synopsis of SD modeling

In the early 1960s, the idea of modeling the dynamic interactions between the elements of a complex system as well as visualizing the evolution of a system over time, which came to be known as the SD modeling approach, appeared in the book, Industrial Dynamics, authored by Jay W. Forrester [7]. SD modeling approach is based on the idea that the structure of a system and the relationships between its elements governs its behaviour [8]. It observes the behaviour of the system over an interval of time and has the ability to predict the behaviour of the system beyond the symptom of a problem [9]. An SD model contains the following key variables.

2.1 Stock

A stock is represented by a rectangle and characterizes the state of a system. It accumulates or depletes over time. The value of a stock at any given time t, $S(t)$, can be obtained by using the following mathematical expression

$$S(t) = \int_{t_0}^{t} [I(t) - O(t)]dt + S_0 \tag{1}$$

where $I(t)$ and $O(t)$ denote the value of inflow and outflow, respectively, at any given time between the initial time t_0 and the current time t; and S_0 represents the initial value of the stock at time t_0.

2.2 Flow

Flow is the rate of change in stock. It demonstrates the rate of increase or decrease in stock. A pipe with an arrow and a valve represents a flow. A flow is classified as either inflow or outflow. Inflow and outflow change the level of stock over time. Inflow has a positive effect on the stock, whereas outflow negatively affects the stock.

2.3 Feedback loops

A feedback loop is a mechanism through which a system runs itself. Variables in a feedback loop are connected by causal links. Feedback loops either reinforce, which is called a reinforcing loop or oppose the original change, which is known as a balancing loop.

2.4 Causal loop diagram

A causal loop diagram is a conceptual model of the system, which is created by visualizing the relationships between interactive variables of the system [10]. A causal loop diagram is constructed to provide qualitative information prior to building quantitative modeling.

2.5 Stock and flow diagram

A Stock and Flow Diagram (SFD) differentiates between variables (stock and flow), and represents the underlying structure of a system. An SFD is a quantifiable representation of the system performance. It contains four key elements: stock, pipe, valves, and control arrows.

3. Literature review

3.1. Project portfolio performance

Though sparse, a number of assessment methods have been developed in the field of PPM in recent years. For example, Müler et al. [11] suggested a shared information approach to establish an information flow from projects to portfolio level as a successful approach for the assessment of PPP. Lacerda et al. [12] developed a performance measurement framework in PPM by evaluating the success of a project in a portfolio, taking into account different criteria and stakeholders' viewpoints. Young and Conboy [13] developed a qualitative competency standard to assess portfolio management capability in organizations. Purnus and Bodea [14] performed a PPP analysis by defining a set of evaluation criteria for construction projects. Danesh et al [15] adopted the Analytic Hierarchy Process (AHP) for ranking projects in a portfolio. Reginaldo [16] employed a multi-criteria decision support tool for evaluating the performance of a portfolio of projects. Padovani and Carvalho [17] studied the relationships between PPM and project performance by developing a structural model on PPM.

The research cited above mainly provides the qualitative perception of the PPP. Further, the few quantitative methods attempt to measure the performance of each project individually. This study is aimed to sidestep these shortcomings by proposing a quantitative model that takes a holistic approach to assess the PPP as a whole.

3.2. Application of SD in Project Management

Since the invention of the SD modeling approach, it has been widely used in different areas of project management as diverse as software development projects, construction projects, infrastructure networks, and manufacturing development projects [18]. For example, Lyneis et al. [19] attempted to sidestep the shortcomings of the mental models in dealing with project complexity by using an SD approach for strategic project management. Love et al. [20] constructed the causal loop diagram to visualize interdependencies and underlying dynamics between key contributors to rework in complex oil and gas projects. Sheffield et al. [21] applied a system thinking approach to three phases of projects including the concept, implementation and evaluation phases, aimed at providing benefits in framing and solving problems associated with project complexity. Van Oorschot et al. [22] used an SD technique to explore decision traps in new complex product development projects which are subject to multiple information filters. De Marco et al. [23] adopted an SD contingency management model in order to simulate the decision-making scenarios under different complex design-build project conditions. A cost contingency management plan for managing the contingency budget during the project lifecycle was developed in this work by building an SD model. Khan et al. [24] discussed the potential of using SD in order to improve the management of the complexity of information flow in small and medium-sized enterprises. The authors presented a holistic view of a complex problem by focusing on the relationships and interconnectivity in the whole system rather than constituent parts. Li et al. [25] performed SD simulation analysis to evaluate the effect of various risks on the scheduling of prefabrication housing construction projects. Zhong et al. [26] assessed the impact of uncertainties on project performance by constructing an SD model. Ansari [27] simulated change management policies in megaprojects by adopting the SD modeling approach. Mortazavi et al. [28] applied the SD modeling approach to evaluate and prioritize risks in construction projects. Shafieezadeh et al. [29] developed an SD model to capture the hierarchical and dynamic complexities of the project.

While SD has been successfully applied to various areas of project management, studies on the application of SD to PPM remain scant. In the next section, an attempt is made to explore the potential of using the SD modeling approach in the PPM field.

4. SD model development for the assessment of PPP

4.1 Distribution of projects among the three states

In order to keep track of project-related metrics such as team performance, quality measures, earned value indicators, and so forth, each project is classified into one of the three discrete project states, suggested by Sanchez and Robert [30], as follows: Healthy State, in which the project has met its targets. Alert State where the project has met a proportion of its target and this proportion falls within the project expected variance. Failure State that represents the measurement of the project performance above its accepted variance.

Let HS(t), AS(t), FS(t) , respectively, be the set of projects within a portfolio that are in Healthy State, Alert State, and Failure State at a given time t. Mathematically, these sets can be defined as given below:

$$HS(t) = \{P_i | PV_i(t) \geq 0, i = 1, \ldots, n_{HS}\} \qquad (2)$$

$$AS(t) = \{P_i | -V_{i(a)} \leq PV_i(t) < 0, i = 1, \ldots, n_{AS}\} \qquad (3)$$

$$FS(t) = \{P_i | PV_i(t) < -V_{i(a)}, i = 1, \ldots, n_{FS}\} \qquad (4)$$

where the status of project i is denoted by a variable, P_i, such that P_i is one of the distinct objects that makes up a set described above; n_{HS}, n_{AS}, and n_{FS} are, respectively, the number of projects in Healthy, Alert, and Failure State; $V_{(i(a))}$ denotes the absolute value of the acceptable variance to planned objectives of project i; and $PV_i(t)$ is the variance of project i at time t. $PV_i(t)$ can be expressed by the following equation.

$$PV_i(t) = P_{i(Actual\ Value)}(t) - P_{i(Target\ Value)}(t) \qquad (5)$$

where $P_{i(Actual\ Value)}(t)$ is the actual value for the quantity being measured at time t; and $P_{i(Target\ Value)}(t)$ denotes the planned objectives of project i.

In order to provide better visualization of the distribution of the projects among the three states, Fig.1 depicts a conceptual sketch of project's status over time.

4.2 Creating a Stock and Flow Diagram

The project states developed in the previous step are now transformed to an SFD. An open-source software VENSIM PLE 8.0.7 is employed to illustrate the main cause and effect relationships between the constituent variables of the SD model. The model contains three stock variables, each of which represents the state of the projects at a particular moment in time. The inflow to each stock is the transition rate.

We now associate with each state an interval defined in Eq. 2, 3, and 4 as illustrated in Fig.1. Each project i is then accommodated into one of the sets based on the value of PVi(t). We depict the probability of transition from one state to another state over the simulation time by a State Transition Diagram (STD), shown in Fig.2. This diagram illustrates the three possible states described earlier. Arrows originated from each state and concluded to other states indicate transition probabilities P_{ij}. In the STD, P_{ij} is the probability of project transition from state i to state j, whereas P_{ii} denotes that a project in state i remains in the same state. $P_{ij}=0$ indicates that there is no transition between state i and state j. As can be seen in Fig.2, it is assumed that a project can transi-

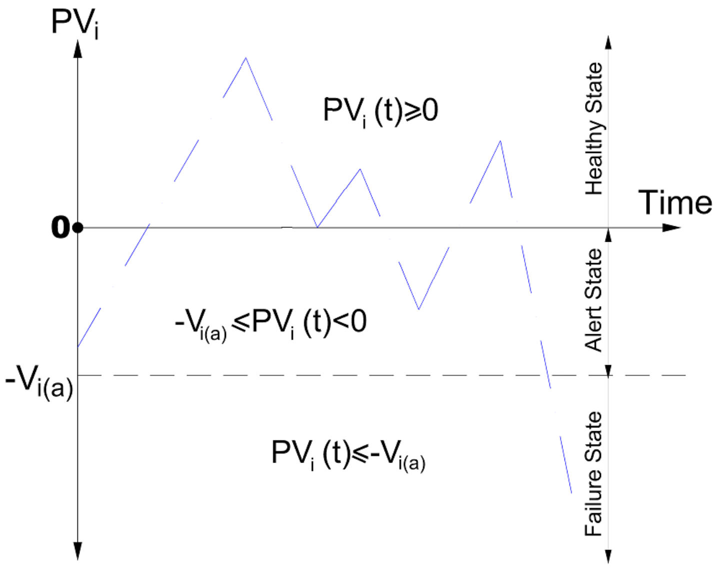

Figure 1. A conceptual sketch of a project status over time

tion from each state only to the next upper or lower state.

4.3 Factors affecting transition probabilities

The factors affecting transition probabilities are derived from Hadjinicolaou and Dumrak (2017). Each factor represents a barrier or a benefit in PPM. These factors, which influence each other as shown in Fig.3, are briefly outlined as follows.

PPM Maturity is concerned with organizational flexibility and resource agility to improve project success within the portfolio [31]. In a nutshell, PPM maturity refers to an advance in PPM capability.

Effective Resource Management refers to handling and balancing scarce resources of an organization based on the corporate strategic objectives [32].

IT infrastructure refers to the availability of systems for planning, coordination, and monitoring of projects [33].

Business Case is a key document of PPM, which plays a central role in decision-making on a project portfolio level.

Shifting in Business Priorities can be caused by factors such as changes of the project manager, sponsor request, and changes in organizational strategy.

Organization Business Strategy refers to the plans that integrate the main goals and polices [34] as well as the actions to achieve the long-term goals of an organization. Project objectives should be aligned with organizational strategy.

Change Resistance is defined as the act of opposing changes in organizations and projects. Managing resistance to change is among the key contributors to the success of a project portfolio.

A Project Progress Measurement System provides a warning when the actual performance is lagging behind the planned performance, which is a necessity for the successful completion of a project.

Insufficient Information in a project hinders the project team to make informed decisions. In fact, information and knowledge are strategic assets for a project portfolio, and the lack of information is often cited as a key reason for project failure.

Internal Politics are behind the scene efforts that can impact a portfolio and its constituent projects. If the destructive aspects of internal politics are not managed, the PPP will be greatly retarded.

Executive Sponsorship is a strategic role that can provide conditions for the successful execution of projects. An executive sponsor champions the project and secures support from cross-functional entities within the portfolio.

4.4 A dynamic project portfolio assessment index

Up to this point, we have created a part of an SFD, in which each project has been placed into a

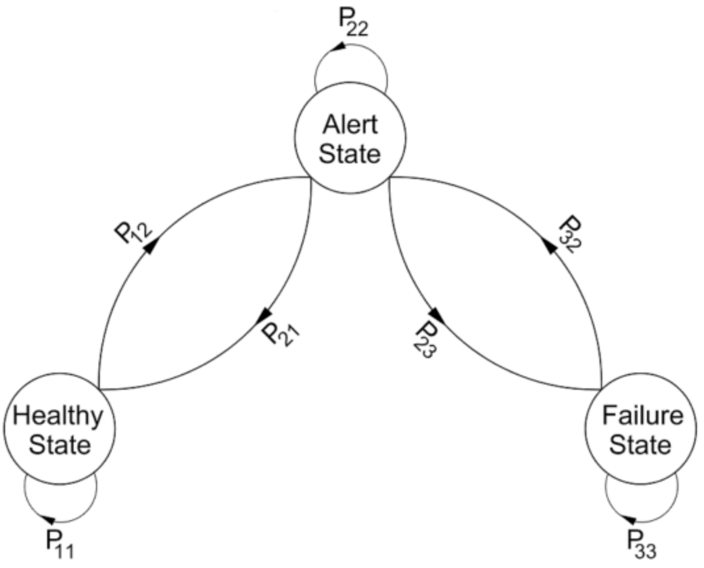

Figure 2. State Transition Diagram for the model

stock variable. It is now possible to develop a dynamic Project Portfolio Assessment (PPA) index that accounts for the overall performance of a portfolio given the performance of its projects. Motivated by Rashedi and Hegazy [35], we define a PPA index, as given below.

$$PPA_{Index} = \frac{\sum_{i=1}^{3}(n_i . i)}{\sum_{i=1}^{3} n_i} \qquad (6)$$

where PPA_{Index} is an index that quantifies the performance of a project portfolio, i represents the project state number, and n_i is the number of components in state i.

By substituting the number of projects in each stock into Eq.6, the overall status of a portfolio can be obtained. By definition, $1 \leq PPA_{Index} \leq 3$. The lower extreme value, $PPA_{Index}=1$, represents the case where all projects are in the Failure State, whereas the upper extreme value, $PPA_{Index}=3$, corresponds to the case where all projects are in the Healthy State. Indeed, the higher value of PPA_{Index} indicates the better performance of the portfolio, while the lower value of this index raises a red flag.

The proposed SFD, demonstrating an SD model for measuring PPA, is presented in Fig.3.

5. SD model development and analysis

5.1 Empirical data used for constructing the SD model

The empirical data was collected from 60 projects in Australia to construct the SD Model presented in Fig.3. These projects were initiated under the engineering and construction portfolio in medium-size organizations. An open-ended questionnaire survey was disseminated to the executive management with the focus on PPM implementation, the current status of the projects within the studied portfolio, and influencing factors associated with PPM. The collected survey data was examined to illustrate the connections between influential factors of the projects within the studied portfolio. It was found that PPM Maturity was a focal factor as a result of supportive and obstructive interactions with other factors surrounding the projects. PPM Maturity could be strengthened by having appropriate resource management, measurement systems, change management and executive sponsorship. On the contrary, PPM Maturity could be deteriorated by ineffective business cases, business strategies and change management.

The SD model constructed from the obtained empirical data demonstrates the relationships between PPM Maturity and different states of PPP namely Healthy State, Alert State, and Failure State. It can be seen that PPM Maturity determines a transition from one state to another. The constant transitions between states, therefore, naturally represent

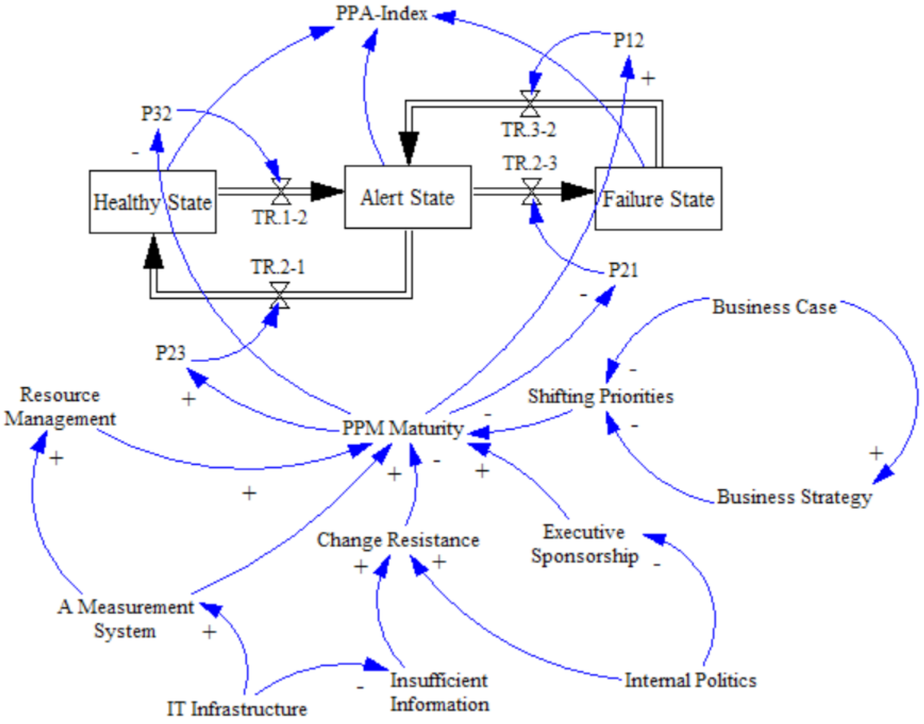

Figure 3. Stock and Flow Diagram for the model

the dynamic trait of the portfolio that can be visualized from the SD model.

It is important to note that the factors found in this study could contribute directly to PPM Maturity or act as latent factors that influenced other factors supporting or wearying PPM Maturity. IT infrastructure is an example of the latent factors that contributed to a measurement system. Ineffective IT infrastructure, on the other hand, could result in delivering insufficient information causing resistance to change. Internal politics was another latent factor found to have a positive relationship to change resistance whereas lesser internal politics could gain healthier sponsorship from the executive management.

5.2 The SD model validation

To validate the proposed SD model, we followed the steps suggested by Barlas [36]. By doing so, we developed our SD model based on the participatory system dynamics modelling in which validation was done throughout the model development by a number of project management experts. Additionally, dimensional consistency was checked to ensure that each model equation is dimensionally correct. Finally, we performed the structural test to ascertain that the model structure represents description of the system.

5.3 Discussion of the SD simulation results

We define the variance of project i at time t, denoted by $PV_i(t)$, as:

$$PV_i(t) = [SPI_i(t).CPI_i(t)] - 1 \tag{7}$$

where $SPI_i(t)$ and $CPI_i(t)$ are statistical measures obtained from earned value analysis. $SPI_i(t)$ is the measure of schedule efficiency that evaluates the conformance of the actual progress to the planned progress. $CPI_i(t)$ is the measure of financial effectiveness that evaluates the conformance of the actual work completed to the actual cost incurred.

Mathematically speaking, if $[SPI_i(t).CPI_i(t)]<1$ the project is either over budget, behind schedule, or both, and if $[SPI_i(t).CPI_i(t)]>1$ implies that the project is either under budget, ahead of schedule or both. We define the value of the acceptable variance to the planned objectives of project i, as $V_{(i(a))}=0.10$.

Simulation analysis is now performed to quantify the performance of an illustrative project portfolio. The portfolio consists of 60 projects. The number of projects in each state at the beginning of the simulation period is determined based on the value of $PV_i(t)$. If $PV_i(t)\geq 0$, the project will be stocked in the Health State. In the case of $-0.10\leq PV_i(t)<0$, the project will be counted in the Alert State. If $PV_i(t)<-0.10$, the project will be stocked in the Failure State. Table 1 reports the number of projects in each of these three states.

Table 1. Initial number of projects in each state

State	Project State Number (i)	Number of Projects
Healthy State	3	38
Alert State	2	15
Failure State	1	7

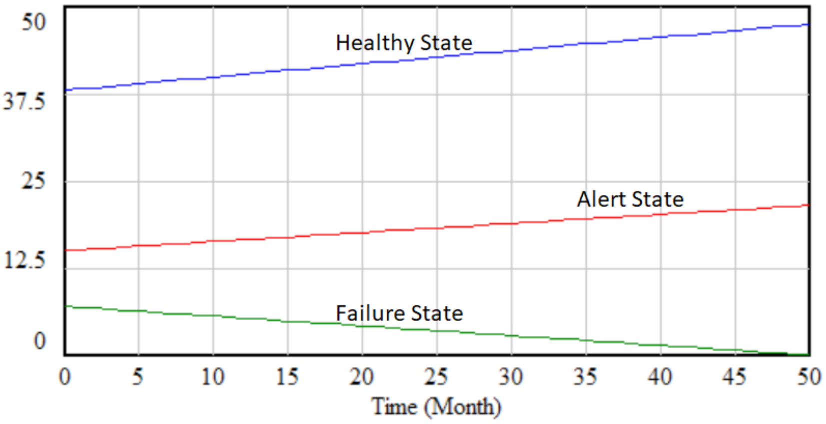

Figure 4. The number of projects in each state over the simulation period

The time horizon for the simulation model is 50 months and the model runs at a monthly time step. The transition probabilities P_{12}, P_{21}, P_{23}, and P_{32} are assumed to be 0.09, 0.10, 0.05, and 0.19, respectively. Simulation results are provided in Fig.4 and Fig.5.

As can be seen in Fig.4, the Healthy and Alert States show upward linear trends, while the Failure State demonstrates a downward linear trend. The number of projects in the Healthy State, n_{HS}, increases from 38 to 47 over 50 months. In the Alert States, the number of projects, n_{AS}, steadily increases from 15 to 21 at the end of the simulation time horizon (month 50). The Failure State experiences a diminishing trend. This turns to leave no project at this state after 50 months. As expected, the level of PPM maturity has a direct impact on the performance of the portfolio. This is consistent with the results of the survey. As stated by 60 project managers, the implementation of effective resource management has led to the improvement of the overall status of the portfolio performance. Furthermore, designing a sound measurement system, which assists in determining how well the project plan is executed, has resulted in a higher level of PPM maturity. Conversely, shifting priorities due to the lack of a coherent business strategy as well as resistance to changes because of internal politics and/or insufficient information have led to delay and cost overrun in projects, thereby decelerating the improvement in the status of the projects within the portfolio.

The PPA index is graphed in Fig.5. The graph demonstrates a slight improving trend for PPP. The change appears linear in the sense that PPA_{Index} increases from 2.52 to 2.69. This can be ascribed to the higher values of transition probabilities from a lower state to the higher one (P_{32} and P_{21}) compared to the transition probabilities in the opposite direction (P_{12} and P_{23}).

6. Managerial implications

The proposed SD model provides three types of practical implications. First, it helps a portfolio manager to determine how a portfolio is likely to perform over time. As pointed out by Danesh et al. [37], PPM is a dynamic decision process within which the projects' statuses are constantly changing. The proposed SD model facilitates a better understanding of how PPP changes over time. As put forward by Hadjinicolaou and Dumrak [38], the availability of a model that provides real-time project performance data enables key actors in PPM to make adjustment decisions such as resource allocation, de-prioritizing and accelerating projects. Second, PPA index developed in this work not only can provide insight into the current status of a portfolio but also allows for measuring the extent of improvement in the performance of a portfolio after the implementation of PPM. This, in turn, will lead to the improvement of PPM maturity. Third, project portfolio managers may take advantage of the SD model proposed in this work to evaluate the overall performance of a portfolio under different scenarios by conducting what-if analysis. In other words, what-if scenario analysis aided by the present SD model can be used to measure the extent to which a change in the status of a particular project might affect the status of the project portfolio as a whole. This helps organizations to identify critical projects within a portfolio and, subsequently, gives an indication as to which projects require more resources in order to reduce risks to PPM success [39].

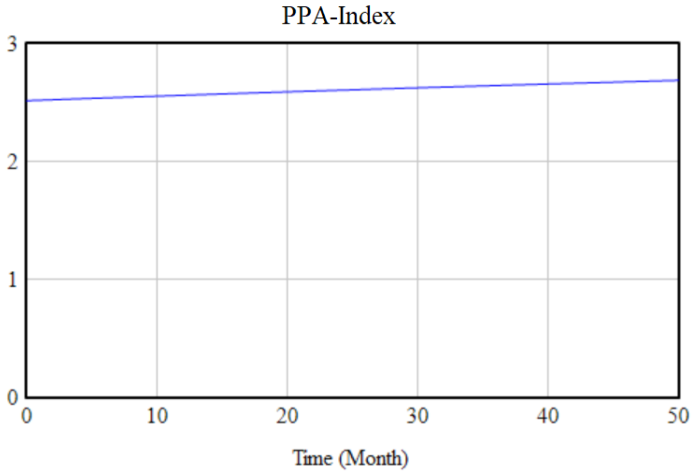

Figure 5. The number of projects in each state over the simulation period

7. Conclusion

The literature underpinning the question “How do organizations monitor PPP in light of the strategic objectives?” offers little help. This study has attempted to address this question by linking a portfolio with its constituent projects. This has been assisted by the development of an SD model that has proven to be very effective to quantify the overall performance of the portfolio in response to changes in the performance of its projects. Within this framework, a new index for the assessment of PPP, as a function of various factors that affect a project portfolio, has been developed. Using 60 projects under the engineering and construction portfolio, this paper has quantified the overall performance of the portfolio over time in response to changes in the performance of its projects.

This study has some limitations that should be addressed in future research. First, despite using empirical data to identify the constituent variables of the model, the illustrative values have been specifically determined for the performance assessment of the projects within the studied portfolio. Future research is required to validate the proposed model by collecting real-world data for the performance assessment of projects. Second, the model presented herein takes a new angle on the assessment of PPP by taking into account the dynamics of factors affecting PPP. However, more barriers and benefits, than presented in this work, affect the performance of a project portfolio. Future work can also build upon our current model by incorporating more factors that affect PPP.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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