Mathematical model formulation of stakeholder management strategies in software engineering projects

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Abstract
Stakeholder management is the process of identifying, analyzing, and engaging people who have either positive or negative influence in a project. The people involved in any project are called stakeholders and all projects have stakeholders irrespective of the size. Managing these stakeholders is a major function of project managers especially the most important ones because their action will determine whether the project is successful or not. Literatures have outlined different strategies of managing stakeholders which lies around stakeholder identification. This paper formulated mathematical model to determine the most important variable in managing stakeholders. In conclusion, the carrying capacity of a project should be considered alongside other stakeholder management strategies like active listening to bring the project to a successful completion.

Keywords: *Mathematical model, Stakeholder management, Software engineering projects, Networking, Active listening*

Introduction

The term stakeholder has gained prominence in strategic studies more than in any other disciplines where research has contributed extensively to its knowledge. Ackerman and Eden [1] have been discussing stakeholder model in organizations and analyse the organizational performance to determine its future directions. According to the PMI [2], project stakeholders are defined as individual, group, or organization who may affect, be affected by, or perceive itself to be affected by a decision, activity, or outcome of a project. They may be actively involved in the project or have interests that may be positively or negatively affected by the performance or completed project. Software engineering project involves actors who cannot be ignored. These are people who design, build, use, and are responsible for managing the systems [3].

According to Takim [4], project management focus has budged to the management of complex interaction and interrelationships existing among the parties involved in the project to determine its overall successful completion. As such, stakeholder management is perceived as a significant strategy for achieving success in software engineering projects. Also, project success has been associated with effective stakeholder management [5], [6], [7], [8]. Even previous researches [9] and [10] have attributed project failures to either lack of or inadequate stakeholder management during the project development.

Modern software engineering projects are increasingly complex and affects broader spectrum of stakeholders depending on the effect and coverage of the system [11]. According to [12] and [13] managing stakeholders will stay highly theoretical unless the project managers also think about how to practice and incorporate the strategies needed to make their stakeholder management successful. It is based on this postulation that the following proxies were identified as the stakeholders' management strategies: Conflict resolution dexterity, Communication and feedback, Active listening, Networking, Rapport trade-off analysis, Social and professional relationship, Neutral emotion [12]. Eskerod et al [14] also presented different strategies in their work but this work will consider the work of Cadle and Yeates [12]. If project stakeholders are selected using networking, the right people will be involved in the project and also if they actively listen to each other, all other outlined [12] strategies will be taken care of.

Software projects will be successful if the number of projects organization is executing at a given time is within their capacity [13]. This may be true assuming the project organization has enough resources to handle all the projects been developed at that time. These resources may be in terms of time, manpower, money or materials [3]. Suppose a project organization is working on two or more software projects at the same time, and there are different stakeholders involved in these projects, the organization can succeed in managing the stakeholders for a successful project if it has enough resources to handle each project [4].

Based on this premise, this study considered active listening and networking as the most important strategies in stakeholder management and developed a mathematical model to investigate whether using networking to select project stakeholders and actively listening to their concerns and requirements during project development will improve project performance more than using any other stakeholder strategy.

Related Literatures

Seboni and Tutesigensi [15] saw mathematical modeling as a part of mathematical logic that uses mathematical statements to solve real life problems. These problems are modeled into mathematical equations known as mathematical modeling. Every system can accurately be modeled mathematically irrespective of how complex the system might be. According to [16], mathematical modeling can improve the ability to predict, simulate, or understand real-world systems such as project. A model helps to explain a system and to study the effects of different components, and to make predictions about behavior [15]. Models behave like communicators to others by giving information and impact in varying conditions. Mathematical models are made-up of relationships and variables which researchers use to analyze controllable or optimized system [16]. Mathematical models use sets of variables to describe a system and a set of equations that establish relationships between the variables as well as mathematical concepts and language to describe a system [15].

Voropajev and Gelrud [16] opined that it involves the knowledge one possessed in mathematics and the system and creates solution to the real-world problems using that knowledge. It has gained prominence in easing financial review and has been used in various decision-making situations [15].

Institute of Electrical and Electronics Engineers (IEEE) Standard Glossary [17] defined software engineering as the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software. Also, Sommerville [18] reiterated it as concerned with all aspect of software production that uses sound engineering principles to develop software. It differs from other engineering professions in that developers build an intangible production instead of tangible structure [11]. Software can be categorized as embedded software used in things like medical equipment and airplanes and non-embedded software that covers financial information and those used to run businesses and conduct work activities [12]. The engineering of software has a well-enunciated life cycle beginning with the requirements elicitation, design, coding, validation, documentation, maintenance, and ending with reverse engineering [13].

The idea of stakeholder dated as far as 1960s in pioneer work of Stanford Research Institute known now as SRI. SRI contended that management should understand the concerns of employees, customers, suppliers, lenders, and society and this will enable stakeholders support the developed system. Stakeholder management as a branch of Strategic Management was popularized by Freeman [19] which became the most important input to stakeholder concept where he proposed that effective management of stakeholder relationships prolongs the lifespan of any organization. Since then academic interest has grown enormously on the topic [20]. Identifying and managing stakeholders' needs and expectations effectively will reduce risk, fit mitigation measures, and deliver successful projects [8].

Nowadays everyone knows everyone through social media and people in the same profession collaborate irrespective of their location. The networking approach according to Prell [21] creates a more pro-active strategy in stakeholder management since it incorporates specialist who will contribute to project implementation and commercialization. Networking among stakeholders establishes contacts between project development team and other stakeholders who are interested in participating in a specific software engineering project development [22]. Effective stakeholder management is becoming crucial in this age of social networking and the effect of stakeholders in projects can be complex if the stakeholders are not properly managed and this might result to missing deadlines, political intervention, resource wastage and project abandonment [10]. Networking helps organizations get more proactive standpoint in dealing with their stakeholders [22]. The network approach also helps project managers get more realistic view of the role the various stakeholders play in a project and how they interact with each other [23].

Garciatorres [24] divided communication into two parts: listening and speaking but listening is viewed as more important than speaking to the extent that mammals have two ears and one mouth to enable them listen more than speaking. Active listening involves not only hearing but clearly understanding what the speaker is saying and it requires the attention and interest of the listener at that moment [25]. According to Kliem [26], when project managers failed to ascertain the credibility of what a stakeholder said, the result is erroneous or incomplete requirements and inaccurate product and this causes conflict among project stakeholders. In computer weekly news of January 2011, Goodwin [27] wrote that Gartner report correlated business intelligence project failure to poor communication to the extent that implementing the right requirements became an issue. Active listening is beneficial to project success because stakeholders can understand each other's intentions [25]. It gives the stakeholders a clearer vision of the project progress or any setback that might hinder the project from progressing [27]. Garciatorres [24] saw active listening as the gateway to trust and solid relationship. When the stakeholders know that their ideas and suggestions are taken into consideration, they are encouraged to contribute more to the progress of the project. It also builds relationship among stakeholders because they see the project situation from each other's perspective and this encourages openness.

Model Formulation

Let *N(t)* be the number of successfully executed software projects by project organization at time *(t)* and let *b* and *d* be the average per capita success or failure rate respectively as contributed by active listening and networking strategies. A little change in *bN(t)* on the number of projects successfully executed and *dN(t)* of the number of uncompleted projects. An equation for *N* at time $t + \Delta t$ is then determined to be:

$$N(t + \Delta t) = N(t) + b\Delta t N(t) - d\Delta t N(t) \quad \ldots\ldots (1)$$

This can be rearranged as:

$$N(t + \Delta t) - N(t) = \Delta t(b - d)N(t)$$

Dividing through by Δt, we obtain

$$\frac{N(t+ \Delta t) - N(t)}{\Delta t} = (b - d)N(t)$$

And as $\Delta t \to 0$ we get

$$\frac{dN}{dt} = (b - d)N \quad \ldots\ldots (2)$$

If we let $b - d = r$ then we have

$\frac{dN}{dt} = rN$ ……………………………………………………………………………….. (3)

Observe that the exponential growth law for population size (rate at which the variables contribute to successful completion of projects) is realistic over a long period of time, that is if the project is one which requires a long period of time to complete. Eventually, since the rate of successful completion of any project will be checked over active listening to project stakeholders and networking among project stakeholders, we assume that there is a definite number of projects which the project organizations can handle at a given time and this is known as the carrying capacity and we shall denote it by *k*. Therefore if project organizations are assigned with projects larger than this size, there will be heightened failure rates. To improve the model in equation (3) we include the carrying capacity and look for a non-linear equation of the form

$\frac{dN}{dt} = rNF(N)$ …………………………………………………………………………….. (4)

Where F(N) provide a model for regulation of the project completion. This function should satisfy

F(0) = 1 (the number of projects completed increases exponentially with success rate r when N is small)

and

F(N) < 0 when *F(N) > k* (the failure rate increases when N is larger than the carrying capacity)

The simplest function F(N) satisfying this condition is linear and is given by

$$F(N) = 1 - \frac{N}{k}$$

This gives us the model

$\frac{dN}{dt} = rN(1 - \frac{N}{k})$ …………………………………………………………………………….. (5)

Suppose the two variables that contributed to the effective completion of software engineering projects are active listening to project stakeholders and networking among project stakeholders, we therefore have two different models for the two variables. These variables contribute differently and have different carrying capacities. If we let N_1 and N_2 be the number of projects completed using the two variables respectively, we have

$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1}{k_1}\right)$ ……………………………………………………………… (6)

$\frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_2}{k_2}\right)$ ……………………………………………………………………… (7)

At equilibrium, $\frac{dN_1}{dt} = 0$ and $\frac{dN_2}{dt} = 0$

$r_1 N_1 \left(1 - \frac{N_1}{k_1}\right) = 0$ ……………………………………………………………………… (8)

$r_2 N_2 \left(1 - \frac{N_2}{k_2}\right) = 0$ ……………………………………………………………… (9)

From (8) $N_1 = 0$ or $r_1 - \frac{N_1 r_1}{k_1} = 0$

$k_1 r_1 = N_1 r_1 = 0$

$\therefore N_1 = k_1$

Also from (9), we obtain $N_2 = 0$ and $r_2k_2 - r_2N_2 = 0$

$\therefore N_2 = k_2$

To investigate the linear stability, we consider small perturbation to the system in the vicinity of the equilibrium point. We expand $\frac{dN_1}{dt}$ and $\frac{dN_2}{dt}$ in Taylor series expansion about N_1 and N_2. That is if we differentiate equation (8) with respect to N_1 and (9) with respect to N_2, we obtain

$F_1^{`}(N_1) = r_1 - \frac{2N_1 r_1}{k_1}$ ……………………………………………………………… (10)

$F_2^{`}(N_2) = r_2 - \frac{2N_2 r_2}{k_2}$……………………………………………………………… (11)

So that

$F_1^{`}(0) = r_1$ ………………………………………………………………..………………… (12)

$F_2^{`}(0) = r_2$ ……………………………………………………………………………… (13)

Also

$$F_1^{`}(k_1) = r_1 - \frac{2k_1 r_1}{k_1}$$

$= r_1 - 2r_1 = - r_1$ ……………………………………………………………… (14)

$$F_2^{`}(k_2) = r_2 - \frac{2k_2 r_2}{k_2}$$

$= r_2 - 2r_2 = - r_2$ ……………………………………………………………………… (15)

We then conclude that $N_1 = 0$ and $N_2 = 0$ are unstable and $N_1 = k_1$ and $N_2 = k_2$ are stable. These are uncoupled equations so that asymptotically $N_1 \rightarrow k_1$ and $N_2 \rightarrow k_2$. If N_1 is much smaller than k_1 and N_2 is much smaller than k_2, then the executable projects will not be more than the carrying capacity and there will be growth in success rate, that is r_1 and r_2. Since we do not know the impact each of the variables creates on one another, we introduce two additional parameters to the model. A reasonable modification that couples the two equations is:

$$\frac{dN_1}{dt} = r_1 N_1 \left(1 - \frac{N_1 + \gamma_{12} N_2}{k_1}\right) \qquad \text{(16)}$$

$$\frac{dN_2}{dt} = r_2 N_2 \left(1 - \frac{N_1 + \gamma_{21} N_1}{k_1}\right) \qquad \text{(17)}$$

Where $\gamma_{12}$and γ_{21} are dimensionless parameters that model the impact of the two variables

Also $k_1, k_2, r_1, r_2, \gamma_{12}, \gamma_{21}$ are positive constants. In particular, given a range of parameter values and initial values for N_1 and N_2 at time $t = 0$, we would typically like to know if the final outcome is one of the following possibilities.

1. Both variables does not contribute to the successful completion of projects
2. Both variables contribute to the successful completion of projects

After non-dimensionalization, we have

$$\rho_1 = \rho_1(1 - \rho_1 - \phi_{12}\rho_2) \stackrel{\text{def}}{=} f_1(\rho_1, \rho_2) \qquad \text{(18)}$$

$$\rho_2 = \alpha\rho_2(1 - \rho_2 - \phi_{21}\rho_1) \stackrel{\text{def}}{=} f_2(\rho_1, \rho_2) \qquad \text{(19)}$$

Where $\alpha = {}^{r_2}/_{r_1}$

The possible fixed point is

1) $(\rho_1^*, \rho_2^*) = (0,0)$
2) $(\rho_1^*, \rho_2^*) = (1,1)$

We investigate the linear stability by considering small perturbation to the system in the vicinity of the steady state(ρ_1^*, ρ_2^*). Expanding ρ_1 and ρ_2 in Taylor series expansion about ρ_1^* and ρ_2^* then retaining only the linear terms we have

$$\frac{d\rho_1}{dt} = [1 - 2\rho_1^* - \phi_{12}\rho_2^*]\rho_1 + [-\phi_{12}\rho_1^*]\rho_2 \qquad \text{(20)}$$

$$\frac{d\rho_2}{dt} = [-\alpha\phi_{21}\rho_2^*]\rho_1 + [\alpha(1 - 2\rho_2^* - \phi_{21}\rho_1^*)]\rho_2 \qquad \text{(21)}$$

This can further be represented thus

$$\begin{bmatrix}\frac{d\rho_1}{dt}\\ \frac{d\rho_2}{dt}\end{bmatrix} = \tau\begin{bmatrix}\rho_1\\ \rho_2\end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

It is straightforward application of phase plane techniques to investigate the nature of these equilibrium points

1) Steady state $(\rho_1^*, \rho_2^*) = (0,0)$

$$\tau - \lambda I = \begin{bmatrix}1-\lambda & 0\\ 0 & \alpha-\lambda\end{bmatrix}$$
$$|\sigma - \lambda I| = 0$$
$$\Rightarrow (1-\lambda)(\alpha-\lambda) - (0,0) = 0$$
$$\Rightarrow 1-\lambda_1 = 0 \ or \ \alpha - \lambda_2 = 0$$
$$\therefore \lambda_1 = 1 \ or \ \lambda_2 = \alpha \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

Therefore (0,0) is unstable equilibrium point

2) Steady state$(\rho_1^*, \rho_2^*) = (1,1)$

$$\tau - \lambda I = \begin{bmatrix}-1-\phi_{12}-\lambda & -\phi_{12}\\ -\alpha\phi_{21} & -\alpha(1-\phi_{21})-\lambda\end{bmatrix}$$
$$|\sigma - \lambda I| = 0$$
$$(-1-\phi_{12}-\lambda)(-\alpha-\alpha\phi_{21}-\lambda) - \alpha\phi_{12}\phi_{21} = 0$$
$$\alpha + \alpha\phi_{21} + \lambda + \alpha\phi_{12} + \alpha\phi_{12}\phi_{21} + \phi_{12}\lambda + \alpha\lambda + \alpha\phi_{21}\lambda + \lambda^2 - \alpha\phi_{12}\phi_{21} = 0$$
$$\alpha + \alpha\phi_{21} + \alpha\phi_{12} + \alpha\phi_{12}\phi_{21} - \alpha\phi_{12}\phi_{21} + \lambda + \phi_{12}\lambda + \alpha\lambda + \alpha\phi_{21}\lambda + \lambda^2 = 0$$
$$\lambda^2 + (1 + \phi_{12} + \alpha + \alpha\phi_{21})\lambda + \alpha(1 + \phi_{12} + \phi_{21}) = 0$$

Let $\alpha + \alpha\phi_{21} = m$ then we have

$$\lambda^2 + (1 + \phi_{12} + m)\lambda + (\alpha\phi_{12} + m) = 0$$

This is a polynomial of second degree, that is, quadratic equation. Using the formula for factorization of quadratic equation, we have

$$\lambda = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Where $a = 1, b = 1 + \phi_{12} + m,$ and $c = \alpha\phi_{12} + m$

$$\therefore \lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{(1+\phi_{12}+m)^2 - 4 \times 1 \times (\alpha\phi_{12}+m)}}{2 \times 1}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{(1+\phi_{12}+m)^2 - 4\alpha\phi_{12} - 4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{(1+\phi_{12}+m)(1+\phi_{12}+m) - 4\alpha\phi_{12} - 4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1 + \phi_{12} + m + \phi_{12} + \phi_{12}^2 + m\phi_{12} + m + m\phi_{12} + m^2 - 4\alpha\phi_{12} - 4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1+2\phi_{12}+\phi_{12}^2+2m\phi_{12}+2m+m^2-4\alpha\phi_{12}-4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1+2\phi_{12}+\phi_{12}^2+2m\phi_{12}+2m+m^2-4\alpha\phi_{12}-4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1+2\phi_{12}+\phi_{12}^2-4\alpha\phi_{12}+2m\phi_{12}+2m+m^2-4m}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1+\left(\frac{2\phi_{12}+2\phi_{12}^2}{4\alpha\phi_{12}}-1\right)+\left(\frac{2m\phi_{12}+m^2}{2m}-1\right)}}{2}$$

$$\lambda = \frac{-(1+\phi_{12}+m) \pm \sqrt{1+\left(\frac{1+\phi_{12}}{2\alpha}-1\right)+\left(\frac{2\phi_{12}+m}{2}-1\right)}}{2}$$

Therefore

$$\lambda_1 = -{}^1/_2\left[(1+\phi_{12}+m)+\sqrt{1+\left(\frac{1+\phi_{12}}{2\alpha}-1\right)+\left(\frac{2\phi_{12}+m}{2}-1\right)}\right]$$

or

$$\lambda_2 = -{}^1/_2\left[(1+\phi_{12}+m)-\sqrt{1+\left(\frac{1+\phi_{12}}{2\alpha}-1\right)+\left(\frac{2\phi_{12}+m}{2}-1\right)}\right]$$

If $\frac{1+\phi_{12}}{2\alpha} \geq 1$ and $\frac{2\phi_{12}+m}{2} \geq 1$then the steady state $(\rho_1^*, \rho_2^*) = (1,1)$is asymptotically stable

Also If$\frac{1+\phi_{12}}{2\alpha} < 1$, $\frac{2\phi_{12}+m}{2} < 1$ and$\left[\left(\frac{1+\phi_{12}}{2\alpha}-1\right)+\left(\frac{2\phi_{12}+m}{2}-1\right)\right] < 1$ then the steady state will be asymptotically stable

But If$\frac{1+\phi_{12}}{2\alpha} < 1$, $\frac{2\phi_{12}+m}{2} < 1$ and$\left[\left(\frac{1+\phi_{12}}{2\alpha}-1\right)+\left(\frac{2\phi_{12}+m}{2}-1\right)\right] > 1$ then the steady state will be unstable

The steady state is asymptotically unstable means that project organizations are assigned with projects that is larger than their carrying capacity which is included on the model to determine whether a project is successful or failure using active listening and networking as the most important strategies in the stakeholder management, while when the steady state is asymptotically stable, it means otherwise.

Conclusion

The study succeeded in showing how stakeholder management strategies can be used as practical directions for effective software engineering project. This model concur with our assumption that active listening to project stakeholders and networking among project stakeholders are strong determinants of project performance when stakeholder management is employed during software project development. We conclude that project organization should observe the following:

1. The carrying capacity in a project should be perfectly defined
2. They should not operate beyond the carrying capacity of the variables if they want to record more success.

In other words using networking to select project stakeholders and active listening to project stakeholders' needs and concerns will work well as stakeholder management strategies provided the organizational carrying capacity is considered.

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