Voice Over IP Technology Development in Offshore Industry: System Dynamics Approach

B. Kiyani, R. H. Amiri, S. H. Hosseini, A. Bourouni, and A. Karimi

***Abstract*—**Nowadays, offshore's complicated facilities need their own communications requirements. Nevertheless, developing and real-world applications of new communications technology are faced with tremendous problems for new technology users, developers and implementers. Traditional systems engineering cannot be capable to develop a new technology effectively because it does not consider the dynamics of the process. This paper focuses on the design of a holistic model that represents the dynamics of new communication technology development within offshore industry. The model shows the behavior of technology development efforts. Furthermore, implementing this model, results in new and useful insights about the policy option analysis for developing a new communications technology in offshore industry.

***Keywords*—**Technology development, Offshore industry, System dynamics, Voice Over IP.

I. Introduction

In today's world, as oil and gas exploration, drilling, and production facilities have become increasingly modern, they have their own communication requirements. In fact, the deployment of effective and secure remote communication systems is critical to realize the offshore industry's vision for a truly digital and successful industry. On the other hand, the fact that new communication technologies are always developing is well known and realized not only in offshore industry but also in all industries. Nevertheless, this technology might be everywhere, its development and real-world applications are still faced with tremendous problems for new technology users, developers and implementers.

The introduction of new technologies leads to increase the expenses due to unanticipated system performance degradation, additional downtime, and increased maintenance over a system's life cycle. Within this context, performance refers to the specific measures which are related to the technical capability or operational ability of the technology. Cost overruns are one of the most important control mechanisms in implementation processes, wherein they are traded off against technical performance realizations. The traditional systems engineering implementation process can then be thought of as the main reason for the incapable development of new technologies. In the traditional implementation of the systems engineering process, as far as the management of research and development, emphasis is usually placed on breaking the various activities of the process into discrete and non-dynamic phases that are isolated in structure and function [1]. This is different from how the process really works, wherein the different stages in the technology development process actually communicate to each other in a continuous manner.

This paper presents a system dynamics performance assessment framework model for the development process of Voice over IP (VoIP) technology in Iranian offshore industry. This model helps to identify the performance drivers in the technology development process and to understand the dynamic behavior that characterizes the new technology development process.

The rest of the paper is sets out as follows. The next section considers the previous literature on technology development and system dynamics methodology. Following that, are explanations about the model of VoIP technology development in offshore industry. Finally, the results are depicted and one scenario is analyzed.

II. Developing a New Technology

Oxford dictionary defines the word technology as "the application of scientific knowledge for practical purposes". In the National Aeronautics and Space Administration (NASA) Technology Plan, the concept of "practical application of knowledge to create the capability to do something entirely new or in an entirely new way," is called technology [2]. Christenson [3] argued about the word technology as a process, technique, or methodology- embodied in a product design or in a manufacturing or service process which transforms inputs of labor, capital, information, material, and energy into outputs of greater value.

Technology plays a significant role in economic development as well as providing companies with strategic advantages [4]. Even economists who are skeptical about technology policy, admit that technological progress is a vital

B. Kiyani is with the Iran University of Science and Technology (IUST), Green Research Center, Narmak, 1684613114, Tehran, Iran (e-mail: kiyani@iust.ac.ir).

R. H. Amiri is now with the Department of Industrial Engineering, IUST, Narmak, 1684613114, Tehran, Iran (corresponding author to provide phone: +98-912-535-6487; fax: +98-21-8881-4576; e-mail: amiri_r@ind.iust.ac.ir).

S. H. Hosseini was with Arak University, Arak, Iran. He is now with the Department of Industrial Engineering, IUST, Narmak, 1684613114, Tehran, Iran (e-mail: hoseini@ind.iust.ac.ir).

A. Bourouni is now with the Department of Industrial Engineering, IUST, Narmak, 1684613114, Tehran, Iran (e-mail: bourouni@ind.iust.ac.ir).

A. Karimi is with the Department of Electrical Engineering, IUST, Narmak, 1684613114, Tehran, Iran (e-mail: alikarimi@ee.iust.ac.ir).

source of economic growth and R&D is a vital source of technological progress [5].

Over time as technology changes, companies look for new technologies because they want to reach a higher performance. Based on [6], technological change is a change in one or more of such inputs, processes, techniques, or methodologies that improves the measured levels of performance of a product or process. Christenson [3] argued that the technology S-curve is a useful framework which describes the substitution of new instead of old technologies at the industry level. The technology S-curve has become a centerpiece in thinking about technology strategy. It represents an inductively derived theory of the potential for technological improvement, which suggests that the magnitude of improvement in the performance of a product or process occurring in a given period of time or resulting from a given amount of engineering effort differs as technologies become more mature. The theory which is depicted in Fig. 1, states that in a technology's early stages, the rate of progress in performance is relatively slow. As the technology becomes better understood, controlled, and diffused, the rate of technological improvement increases [6]. But the theory posits that in its mature stages, the technology will asymptotically approach a natural or physical limit, which requires that ever greater periods of time or inputs of engineering effort be expended to achieve increments of performance improvement.

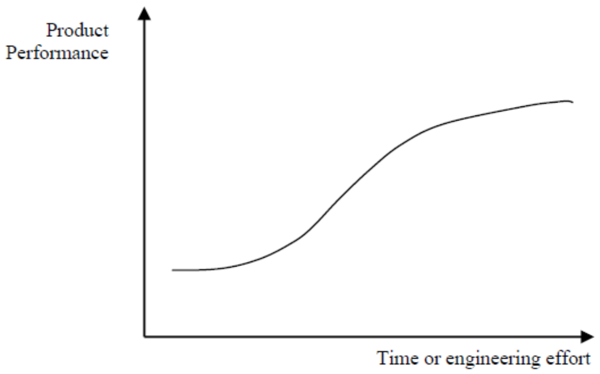

Fig. 1 The Technology S-Curve (Christenson, 1992)

Becker and Speltz [7] and Foster [8] in particular, seem to draw strong prescriptive implications for managers from industry-level observations. Fig. 2 shows the essence of these prescriptions. These authors urge strategists to identify when the S-curve of the technology they currently employ has passed its point of inflection, to identify new approaches that are rising from below at a more productive rate and that may in the future intersect with the current technology, and to launch efforts to acquire or develop the new technology in time to switch to it when its performance surpasses the capabilities of the present technology. In other words, prescriptive S-curve theory would have a firm follow the dotted line in Fig. 2.

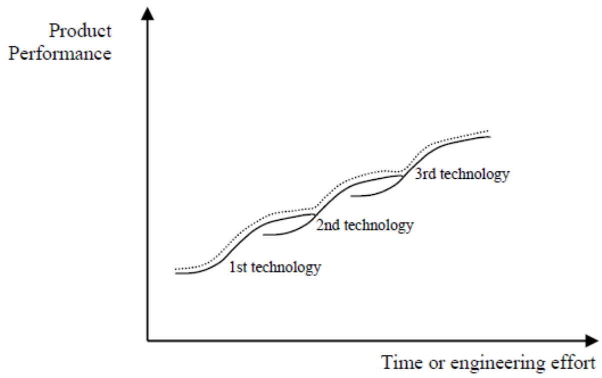

Fig. 2 Prescriptive S-Curve Strategy (Christenson, 1992)

Technology development is the process of creating and managing activities such as experiments, analysis, and prototyping in order to reduce the risk associated with the use of a new technology [9]. In this last decade, the need to understand and manage technology development and deployment has grown critical for firms. Business today is striving to break down functional and global barriers so as to manage technology better. Managers who have been taught by schooling and experience to think of linear solutions to fragmented problems are being asked to cope with complex, interdependent systems [10]. A study of a United States Department of Defense contract for a weapon's development found that there was an 88% growth in cost and a 62% growth in time for the contract's completion which was largely due to insufficient development of technology. The study's overall findings show that commercial and military product development programs which utilize mature technologies typically finish on time and under budget, while programs that begin advanced development with less mature technologies did not meet cost, schedule, and sometimes performance requirements [11]. Technologies that are designed to improve performance, even if designed well, may not produce desired results unless the implementation, that is, the carrying out of all processes related to achieving successful use (e.g., training, financial support, maintenance, simulations, end user participation, etc.) is designed appropriately as well.

Largent and Mavris [9] proposed a model of technology development process which showed in Fig. 3:

Fig. 3 Technology Development Process (Largent and Mavris, 2001)

Largent and Mavris [9] argued that technology development draws from the disciplines of Project Management and Risk Management. Each provides tools and techniques which assist in planning and managing the technology development process. Project management is a very broad discipline that covers both technical and non-technical methods for getting the best results out of a project within set goals for schedule and cost. Cooper and Chapman [12] defined risk as exposure to the possibility of economic or financial, schedule, or technical performance either above or below target values as a consequence of the uncertainty associated with pursuing a particular course of action.

Risk management is usually an iterative process; as the technology develops, updated uncertainty information can be added and the risk reevaluated. Risk management is also more effective early in the life cycle of a program. For technology development, this means applying formal risk management processes as early as possible. Risk management can be considered to have 3 phases: identification (determining where the significant uncertainties lies), assessment (taking the areas of uncertainty and evaluating their effect on the top-level measures), and control (control or reduce that risk) [13].

Therefore, it is important to properly manage a technology development process in order to reduce cost and schedule overrun and to control technical uncertainty and performance.

III. System Dynamics

As one of the first responses to the shortcomings of OR and other management science techniques for complex problems such as large number of variables and nonlinearity, an idea now known as system dynamics (SD) was introduced by J.W Forrester in the 1960s at the Massachusetts Institute of Technology (MIT). With background knowledge of electric circuits, servo-mechanism theory and feedback control theory, he developed a powerful method and a set of tools to modeling and analyzing problems in complicated situations. These models and tools were based on those used by control engineers to analyze the stability of mechanical and electrical control systems that was first suggested by Tustin [14]. SD considers systems as "feedback processes" which can describe specific and orderly structures. In his book *Industrial Dynamics* [15] he showed that how models of the structure of a human system and the policies used to control it could help to more understanding of its operation and future behavior. It is a methodology which is based on the theory of information feedback and control in order to evaluate a real world problem. In SD terms, the complex relationships between variables to predict and control the behavior of a system can be described as levels and rates.

SD prides itself on combining human mind and the power of computers in order to overcome the barrios to learning such as dynamic complexity, limited information of problem situation, confounding variables and ambiguity, bounded rationality, flawed cognitive maps, erroneous inferences about dynamics, and judgmental errors [16].

In this study, the authors accept the system dynamics (SD) methodology and use it to achieve a realistic and reflective system form for a greater understanding of the target system. SD is a three step process: (1) understand the problem situation: in this key step, the purpose is to clearly identify the problem, its factors that most appear to be causing it and the relationships between them, (2) explicit conceptual model and simulation model building: a sign causal diagram is drawn in order to develop the understanding of influences between the variables. Explicit concepts of SD such as flows, levels and auxiliary are used in simulations model building process, (3) simulation and gathering the results: after building the simulations model, it is now possible to analyze different scenarios for different policies.

SD consists of four components: system, feedback, level, and rate. Although there is a wide range of definitions for system, a common view is that a system tends incorporate a set of elements sharing a particular purpose within a defined boundary. Depending on its boundary, a system can be an organization, an environment, an economic entity, an inventory system, etc.

A. Causality and Feedback

The casual relationship depicts that one element affecting another element. A causal-loop diagram (CLD) has been used to model this causality relationship. In order to show the feedback of related elements, CLD requires additional positive (+) and negative (-) polarity. A positive relationship is presented with "+" and a negative one with "-" as in Fig. 4.

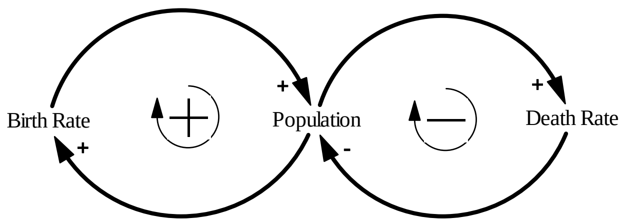

Fig. 4 The diagram of casual relationship

Positive relationship refers to ‘a condition in which a casual element, A, results in a positive influence on B, where the increase of A value responds to the B value with a positive increase' and Negative relationship refers to 'a condition in which a causal element, A, results in a negative influence on B, where the increase of A value responds to the B value with a decrease' [17].

The dynamic behaviour of the system can be caused by a feedback loop, and there are two types of feedback: reinforcing (R) and balancing (B). As shown in Fig. 4, increases in population increases the number of birth, which again increases the overall population. It is a reinforcing loop. To the contrary, the greater the population, the higher the number of deaths, and then the population decrease. It is a balancing loop. In addition, it is not easy to understand the complexity involved with the dynamic changes among elements and the target system in which casual relationships and feedback loops exist.

B. Level and Rate

Although CLD causes in improved communication and comprehensiveness among users, there are two variables required for simulating all elements inside a system, level and rate. The 'level' refers to a given element within a specific time interval, e.g. inventory level on June 2008 or current total students in a university and so on. Meanwhile, the rate reflects the extent of behavior of a system, such as hourly production volume, and daily sales turnover. Specifically, the differences between the level and the rate depend on whether the element contains a time factor.

The level is calculated from the difference between a rate variable that increases the level and a rate variable that reduces the level. A value of level (an accumulated rate) can be identified easily, but a rate is not easy to be identified. The level and the rate can be formulated using the stock-flow diagram (SFD) for a simulation test.

The value of stock at t time would be made by adding the initial stock value $(Stock_{t-dt})$ to the input and output difference during the time, dt: Stock-flow formulas are illustrated as follows:

$$Stock_t = Stock_{t-dt} + dt \cdot \left(Inflow_{t-dt} - Outflow_{t-dt}\right) \quad (1)$$

Or

$$\frac{d(Stock)}{dt} = Inflow_t - Outflow_t \quad (2)$$

The CLD which is depicted in Fig. 4, can be modeled as a Stock-flow diagram (SFD). This SFD is shown in Fig. 5.

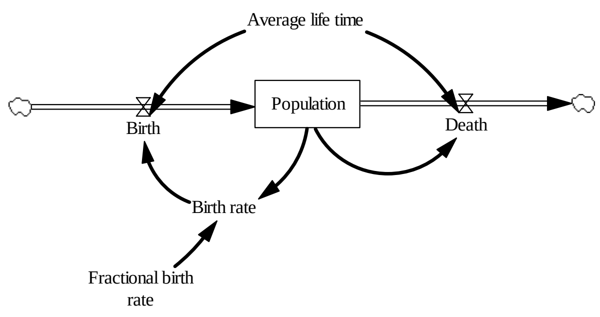

Fig. 5 Stock-flow Diagram

In the example shown in Fig. 4, the variable entitled 'population', is only depicted as the stock (unit: person), while both 'birth' and 'death' (unit: person/ year) are presented as the flows. As shown in the Fig. 5, additional variables for the simulation are also added to SFD. Fractional birth rate describes birth rate per person. For example, a couple which has four children throughout their lifetime and the fractional birth rate can be 2 (unit: dimensionless). If the current number of population is one thousand, the expected numbers of birth on the current population will be one thousand (birth rate = fractional birth rate × population). Meantime, this birth is a long run process throughout one's lifetime, one that belongs to the population stock. Subsequently, yearly birth rate, 'Birth', can be obtained by birth rate/average lifetime. The age distribution of population stock is assumed as a uniform distribution, and the male to female ratio is assumed as one to one. Similarly, yearly death rate, 'Death', can be expressed by an equation, population/average lifetime (expectancy). The birth increases the population, and it also proportionally increases the death. This will lead to the decrease in population, which in turn, decreases birth. Consequently, a non-liner relationship exists among variables, and then the population cannot be calculated through linear equations.

IV. System Dynamics Model of Developing New Technology

As oil and gas exploration, drilling, and production facilities have become increasingly advanced, they would have their communications requirements. In fact, the deployment of effective and secure remote communication systems is critical to realize the offshore industry's vision for a truly digital industry.

When compared to some of the other components in the offshore E&P chain, remote communications expenses can be viewed as quite small. This is so special when considering how the deployment of a relatively inexpensive, redundant communications infrastructure can help avoid the loss of hundreds of millions of dollars per day in excess production and operation costs.

Effective incorporation and implementation of a new communication technology poses a formidable challenge in almost all industries and organizations. On the other hand, costs and schedule overruns are commonplace in these large development projects. Cost overruns are exhibited usually when there is a need to hire and train additional personnel midway through the project. Schedule overruns are experienced when allotted time is not met. However, we proceeded with the assumption that they have persisted in our client's (Iran Offshore Engineering and Construction Company) experiences in spite of reasonable attempts to avoid them. We considered here a large communication technology development project, involving a large number of people, a considerable number of detailed tasks, and a long time frame (90 weeks).

Iranian Offshore Engineering and Construction Company (IOEC) is the first Iranian general contractor to the oil and gas industry, specializing in offshore engineering, procurement, construction, pipe coating, pipe laying, and installation of jackets, TopSites, etc. IOEC designs, procures, builds, installs and services a complete range of offshore surface and partial subsurface infrastructure for the offshore oil and gas industry. With more than 400 employees operating wherever there is offshore oil and gas activity. IOEC is one of the largest truly integrated offshore and subsea pipeline companies in the Middle East.

IOEC has successfully expanded its offshore services providing projects with full marine fleet supports for pipe laying, installation, hook-up and commissioning. Today as a Holding Company, IOEC is planning to extend its oil, gas and petrochemical activities to onshore and offshore, upstream as well as downstream activities and operations. IOEC owns over $600 million in assets including fabrication yards, concrete weight coating plant (CWC), pipe laying vessels, various lifting vessels, barges and other relevant equipment.

Over the recent years IOEC has grown considerably. This philosophy set out in this section has been developed to help IOEC maintain its position as a general contractor to the offshore oil and gas industry and to help to attain its aim of becoming "the contractor of choice across the range of products and services that they offer".

In IOEC, telecommunication project started in June 2001 with the scope of telecom building utilities, detail engineering, supply equipment/material, construction and installation, testing, commission and training. Different communication systems were developed such as VHF radio system, paging radio system, marine radio system, and satellite communication. Voice Over IP (VoIP) technology is utilized as an essential for more economic communications between the company’s vessels, offices in Iran and abroad.

A. Conceptualization of Model

There are many methods available to work with a group to elicit the information needed to define the problem dynamically while still keeping the conversation focused firmly on the clients and their problem. Two of the most useful processes are establishing reference modes and explicitly setting the time horizon [16].

Reference modes are patterns of behavior, unfolding over time, which show how the problem arose and how it might evolve in the future. They show what the historical behavior of the key concepts and variables is and what behavior they might be show in the future?

The time horizon should extend far enough back in history to show how the problem emerged and describe its symptoms. It should be extended far enough into the future to capture the delayed and indirect effects of potential policies.

As discussed previously the major problems, which often occur in new technology development projects, are overruns in costs, schedule, and fall in technical performance. Fig. 6 shows the reference modes of new technology development and describes the behavior of the main concepts in these projects.

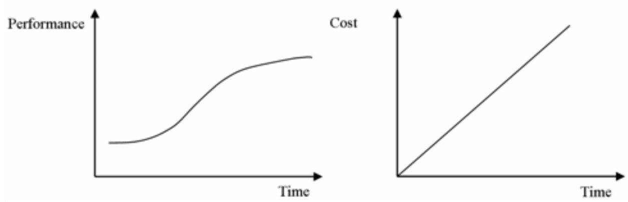

Fig. 6 The reference modes of new technology development projects

As depicted above, it is important to realize and establish a correct time horizon. Therefore, in order to show how the problem emerged and capture the delayed and indirect effects of potential policies, a time horizon of 90 weeks was defined.

Based on Monga [18], a model of developing for a new technology is used and customized by IOEC experts. Fig. 7 represents the casual loop relationships of the VoIP technology development in the Iranian Offshore Engineering and Construction Company.

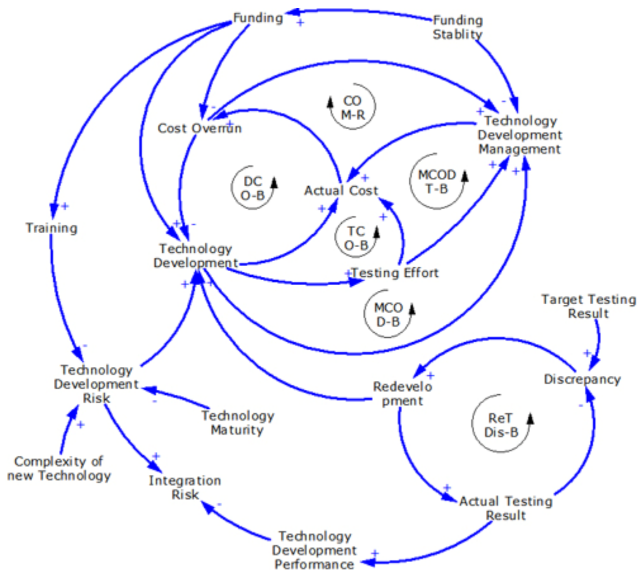

Fig. 7 The casual loop diagram of the VoIP technology development

There are some reinforcing and balancing loops in this diagram. The main causal loop relationships which are identified for this model are as follows:

- Cost Overrun-Management (reinforcing loop)
- Development-Cost Overrun (balancing loop)
- Testing-Cost Overrun (balancing loop)
- Management-Cost Overrun-Development (balancing loop)
- Management-Cost Overrun-Development-Testing (balancing loop)
- Redevelopment-Testing Results-Discrepancy (balancing loop)

The logic of the Cost Overrun-Management loop, named COM-R, is as follows. A rise in Cost Overrun, ceteris paribus, causes a rise in Technology Development Management effort to control it. This rise, ceteris paribus, causes a rise in man-hours required to perform actual effort; therefore it causes a rise in Actual Costs. A rise in the Actual Costs closes the loop and ensures, ceteris paribus, that Cost Overruns will be higher than it otherwise would have been.

The logic of the Development-Cost Overrun loop, named DCO-B, is as follows. A rise in Technology Development Effort, ceteris paribus, causes a rise in Actual Costs, as it because a rise in man-hours required carrying out the efforts. This rise, ceteris paribus, may cause a rise in Cost Overrun which closes the loop and cause a fall in Technology Development efforts since there are money constraints and other constraints.

The logic of the Testing-Cost Overrun, named TCO-B, is as follows. As Technology Development effort increases, Testing Efforts should be conducted to ensure that the performance is at right level. These efforts require man-hours to complete the testing activity. This increase, ceteris paribus, causes a rise in Actual Costs, and this increases Cost Overrun. Therefore, the loop is closed and this Cost Overrun causes a fall in Technology Development.

The logic of the Management-Cost Overrun-Development, named MCOD-B, is as follows. A rise in Technology Development effort, ceteris paribus, causes a rise in Technology Development Management effort to manage the process of technology development activities. These efforts require man-hour to perform it; hence, it, ceteris paribus, causes a rise in Actual Costs and then Cost Overrun. A rise in Cost Overrun closes the loop and ensures, ceteris paribus, that Technology Development efforts will be lower than they otherwise would have been.

The logic of the Management-Cost Overrun-Development-Testing, named MCODT-B, is as follows. As Technology Development effort increases, Testing efforts increase too. This increase, ceteris paribus, causes a rise in Technology Development Management effort to manage the process of testing activities. This increase, after cause an increase in Actual Costs leads to an increase in Cost Overrun which closes the loop and causes a fall in Technology Development efforts.

The logic of the Redevelopment-Testing Results-Discrepancy, named ReTDis-B, is as follows. An increase in Redevelopment activities, ceteris paribus, causes an increase in actual state of the system, that is, the testing results get better and closer to the target testing results. A rise in Actual Testing Results, ceteris paribus, causes a fall in Discrepancy between Actual Testing Results and Target Testing Results which closes the loop via decreasing the Redevelopment rate.

B. Formulating of New Technology Development Model

The next steps are creating a formal and quantitative model of the system, analyzing the sensitivity of the parameters, and then doing some policy experiments. Therefore, a simulation model with complete equations, parameters, and initial conditions should exists in order to direct real world experiments with different parameter values and initial conditions, which often impractical and infeasible in real world due to a number of reasons. Fig. 8 shows the Stock-Flow diagram of the model. Equations are given in Appendix.

In the next section, the results of the simulation is explained and situations under some scenarios are analyzed.

V. Results

The simulation was run with the following parameters:

A. Simulation Control Parameters

The final time for the simulation is 90 weeks. The implementation of the model was for a specific technology (Voice over IP communication) whereby a time horizon of 90 weeks was used based on inputs from IOEC experts. The initial time for the simulation is week=0, and the time step is 0.25.

B. User Defined Parameters

Table I depicts user defined parameter names, their related description, and values based on the data provided by IOEC experts.

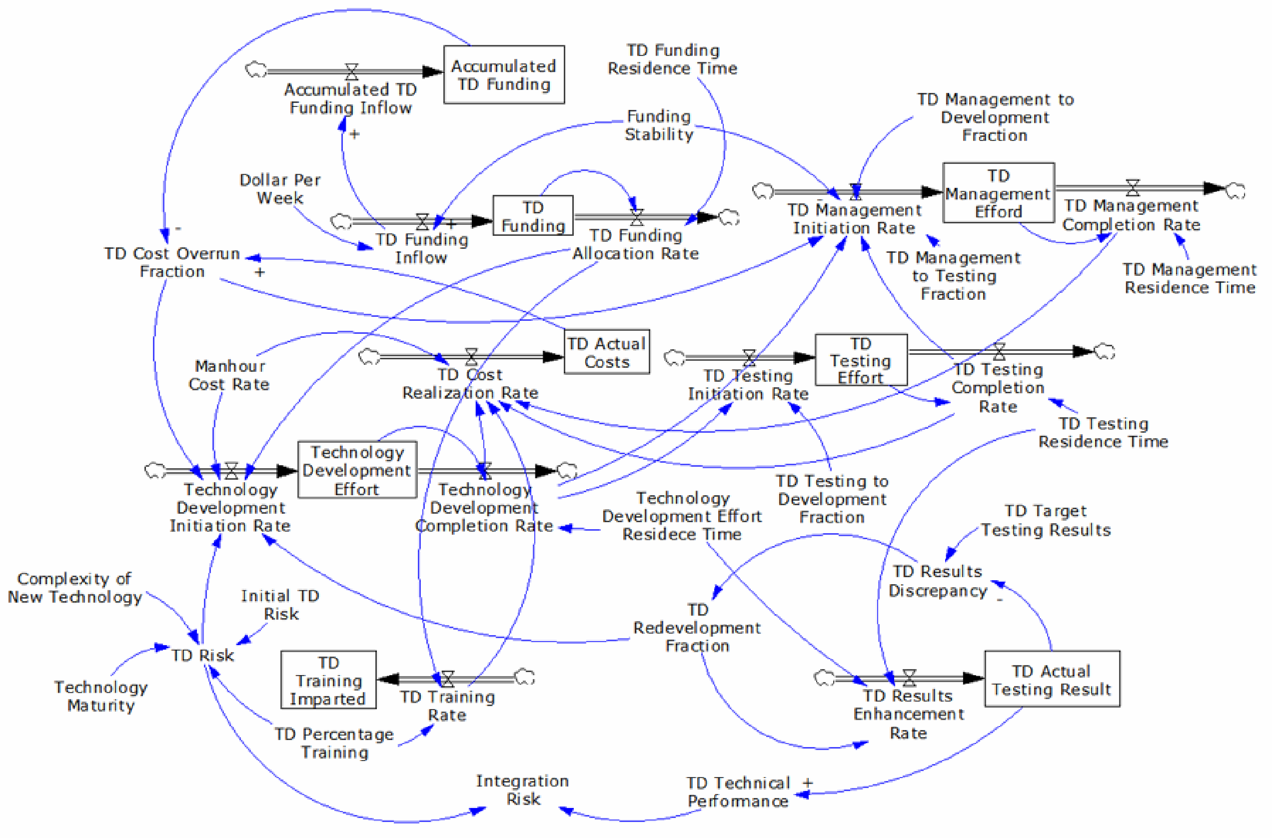

Fig. 8 The stock flow diagram (SFD) of the new VoIP technology development

TABLE I
USER DEFINED SIMULATION PARAMETERS

Parameter name	Value	Description
TD Management to Development Fraction	0.25	This represents the average effort (in man-hours) spent in management activities as a fraction of the effort (in man-hours) spent in technology development activities.
TD Testing to Development Fraction	1/3	This represents the average effort (in man-hours) spent in testing activities as a fraction of the effort (in man-hours) spent in technology development activities.
TD Management Residence Time	0.5 week	This represents the average delay for management activities.
TD Management to Testing Fraction	0.35	This represents the average effort (in man-hours) spent in management activities as a fraction of the effort (in man-hours) spent in testing activities.
Initial TD Risk	7.5 (High Risk)	The initial risk for this industry is high because based on IOEC experts
TD Percentage Training	0.75 %	This represents the percentage of total available funds spent for training activities
TD Funding Residence Time	1.5 week	This represents the average delay of funds in the subsystem.
Technology Development Effort Residence Time	4 weeks	This represents the average technology development time.
TD Testing Residence Time	1 weeks	This represents the average testing time.
Complexity of New Technology	4.5 (High Complexity)	Based on inputs from IOEC experts.
Funding Stability	6.87 (High)	Based on inputs from IOEC experts about this technology.
Man-hour Cost Rate	21.5 dollars/Man-hour	IOEC experts provided the information that the average cost of labor was 35 dollars/man-hour
Technology Maturity	3 (medium)	This technology has medium maturity

C. Simulation Results

The model is implemented based on its parameters, and the following resulted graphs show the dynamic behavior of the system.

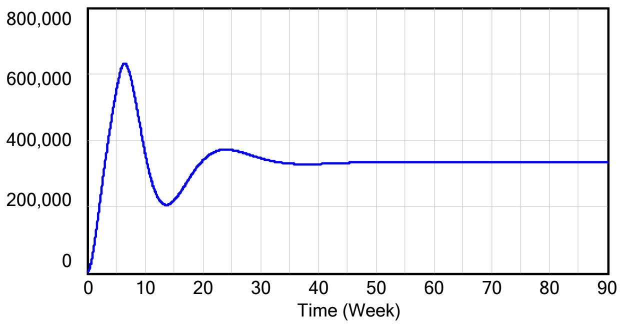

Fig. 9 Technology development effort

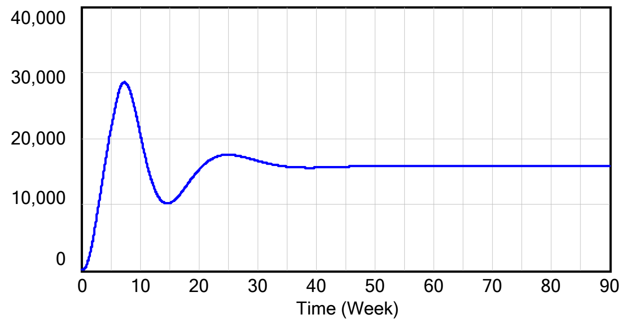

Fig. 10 Technology development management effort

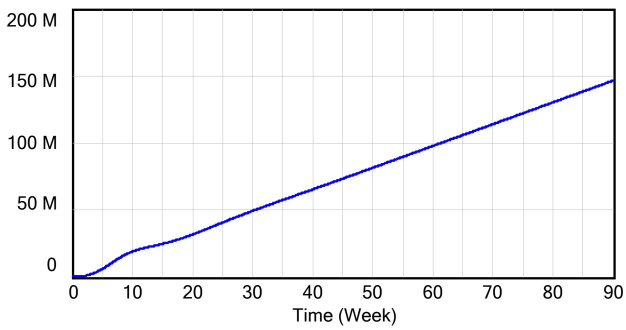

Fig. 11 Technology development actual costs

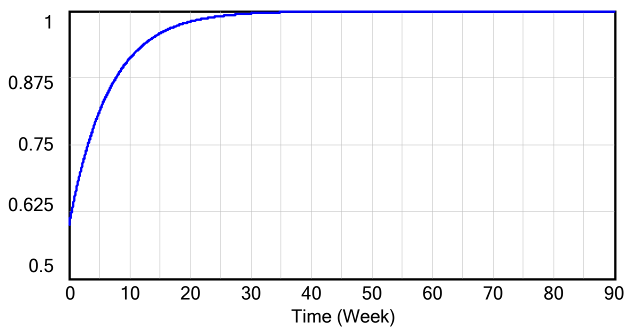

Fig. 12 Technology development technical performance

Fig. 9 and Fig. 10 show the behavior of Technology development effort and Technology development management effort over time. They have a damped oscillation behavior and finally reach an equilibrium. According to figures, as management effort changes over time, technology development effort changes likewise. Fig. 11 and Fig. 12 also show the dynamic behavior of Technology development actual costs and Technology development technical performance, which are similar to the reference modes mentioned in section IV.

Since circumstances change over time, models should be simulated under different conditions. Thus, we show the results of simulation under different scenarios. When the initial value of Accumulated TD Funding, Funding Stability, and the Complexity of New Technology change, the behavior of model would be important, as these changes might occur in IOEC projects (based on experts' opinions).

We change the initial value of Accumulated TD Funding from \$0 to \$10000000, Funding Stability from 6.87 to 8.75, and the Complexity of New Technology from 4.5 to 6.5. That is, the initial value of Accumulated TD Funding, Funding Stability, and the Complexity of New Technology are increased. Following figures show the simulation results under this scenario.

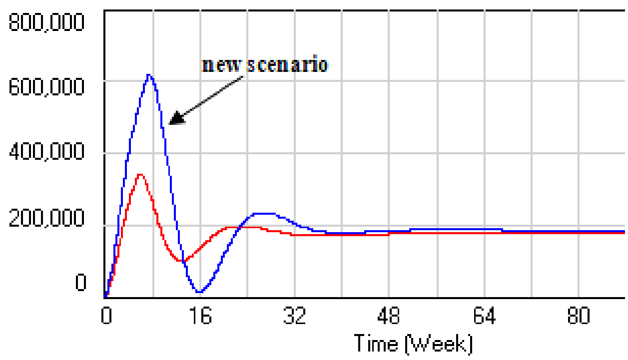

Fig. 13 Technology development effort

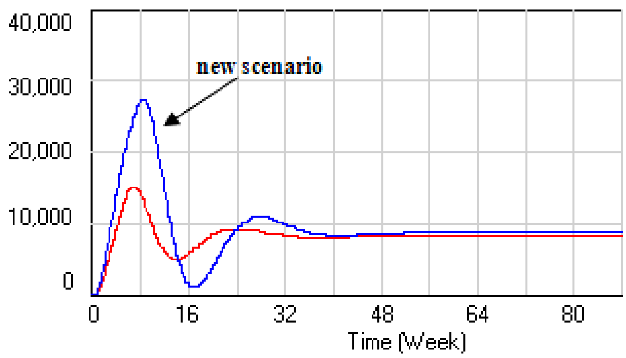

Fig. 14 Technology development management effort

Under this scenario, the behavior of some levels changed. For example, Technology development effort oscillate more in compare to the previous situation. This increase in oscilation domain can be explained as follows. When the initial value of the Technology development funding encreases, Technology development initiation rate increases more that previous. Moreover, an increase in Funding stability causes in more Technology development funding which have the same impact on the behavior. On the other hand, an incease in Complexity of new technology also increases the Technology development initiation rate. These increses cause a higher increase in Technology development effort. Similarly, more decreases in Tecnology development effort have the same logic.

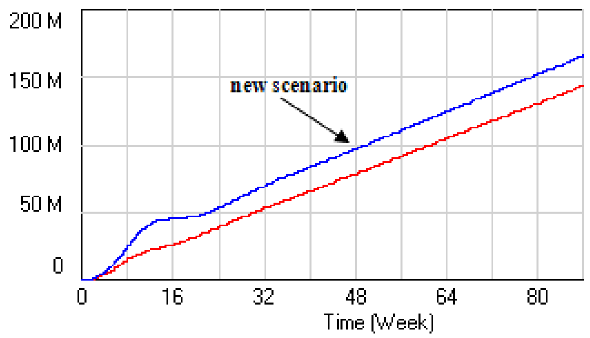

Fig. 15 Technology development actual costs

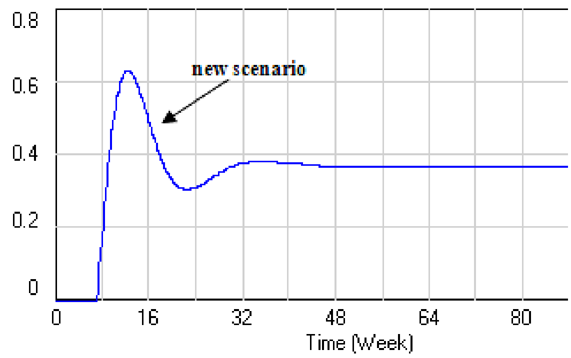

Fig. 16 Technology development cost overrun fraction

Figs. 15 and 16 depict the changes in the behavior of Technology development actual costs and Technology development cost overrun fraction. In this scenario we encounter Cost Overrun because of increases in the domain of oscilliation which was explained above.

VI. Conclusion

The System Dynamics Technology Development model was simulated for a specific VoIP technology whereby IOEC experts provided the user-input parameters. The results are briefly discussed and the behavior of the model was analyzed under a specific scenario. The simulation was run for 90 weeks. The model showed the behavior of technology development effort and other important levels. Implementing this model, resulted in new and useful insights about the future of possible policies for developing a new communications technology in offshore industry. This model also makes the policy option analysis possible for IOEC top management experts.

Hopefully the information provided in this paper could be a useful initial clue to the offshore professionals who are looking for ways to make leverage points to be considered for the better practices of technology development. However, it has to be admitted that the model is yet to be refined and expanded in greater detail by identifying more variables and factors and analyzing their related data in a more rational manner.

Appendix

System dynamics model equations:

1) Accumulated TD Funding= INTEG (Accumulated TD Funding Inflow, 5e-005)
   Units: dollars
2) Accumulated TD Funding Inflow = TD Funding Inflow
   Units: dollars/Week
3) Complexity of New Technology = 4.5
   Units: Dmnl
4) Dollar Per Week= 50
   Units: dollars/Week
5) FINAL TIME = 90
   Units: Week
   The final time for the simulation.
6) Funding Stability = 6.87
   Units: Dmnl
7) Initial TD Risk = 7.5
   Units: Dmnl
8) INITIAL TIME = 0
   Units: Week
   The initial time for the simulation.
9) Integration Risk = TD Risk * (1 - TD Technical Performance)
   Units: Dmnl
10) Manhour Cost Rate = 21.5
    Units: dollars/man hour
11) TD Actual Costs= INTEG (TD Cost Realization Rate, 0.1)
    Units: dollars
12) TD Actual Testing Result = INTEG (TD Results Enhancement Rate, 0.6)
    Units: Dmnl
13) TD Cost Overrun Fraction=MAX (((TD Actual Costs - Accumulated TD Funding) / Accumulated TD Funding) ,0)
    Units: Dmnl
14) TD Cost Realization Rate = (Technology Development Completion Rate + TD Management Completion Rate + TD Testing Completion Rate)* Manhour Cost Rate + TD Training Rate
    Units: dollars/Week
15) TD Funding= INTEG (+TD Funding Inflow - TD Funding Allocation Rate, 0.1)
    Units: dollars

16) TD Funding Allocation Rate = TD Funding/TD Funding Residence Time
Units: dollars/Week
17) TD Funding Inflow = 25000/(0.0056 * Funding Stability^2 - 0.0944 * Funding Stability + 1.3889) * Dollar Per Week
Units: dollars/Week
18) TD Funding Residence Time = 1.5
Units: Week
19) TD Management Completion Rate = TD Management Effort/TD Management Residence Time
Units: man hours/Week
20) TD Management Effort= INTEG (+TD Management Initiation Rate - TD Management Completion Rate, 0.1)
Units: man hours
21) TD Management Initiation Rate = (Technology Development Completion Rate * TD Management to Development Fraction + TD Testing Completion Rate * TD Management to Testing Fraction) * (1+0.1 * TD Cost Overrun Fraction) * (0.0056 * Funding Stability^2 - 0.0944 * Funding Stability + 1.3889)
Units: man hours/Week
22) TD Management Residence Time = 0.5
Units: Dmnl
23) TD Management to Development Fraction = 0.25
Units: Dmnl
24) TD Management to Testing Fraction = 0.35
Units: Dmnl
25) TD Percentage Training = 0.0075
Units: Dmnl
26) TD Redevelopment Fraction= 0.3 - 0.3 * (1-SQRT ((TD Results Discrepancy)^2 / 0.16))
Units: Dmnl
27) TD Results Discrepancy = TD Target Testing Results - TD Actual Testing Result
Units: Dmnl
28) TD Results Enhancement Rate = TD Redevelopment Fraction/(TD Testing Residence Time + Technology Development Effort Residence Time)
Units: 1/Week
29) TD Risk= (Initial TD Risk - (20+5 * (Initial TD Risk-2)/1.5) * TD Percentage Training) * (0.7 + 0.1 * Complexity of New Technology) * (1.3-0.1 * Technology Maturity)
Units: Dmnl
30) TD Target Testing Results = 1
Units: Dmnl
31) TD Technical Performance = TD Actual Testing Result
Units: Dmnl
32) TD Testing Completion Rate = TD Testing Effort/ TD Testing Residence Time
Units: man hours/Week
33) TD Testing Effort = INTEG (+TD Testing Initiation Rate - TD Testing Completion Rate, 0.1)
Units: man hours
34) TD Testing Initiation Rate = Technology Development Completion Rate * TD Testing to Development Fraction
Units: man hours/Week
35) TD Testing Residence Time = 1
Units: Week
36) TD Testing to Development Fraction = 1/3
Units: Dmnl
37) TD Training Imparted = INTEG (TD Training Rate, 0.1)
Units: dollars
38) TD Training Rate= TD Funding Allocation Rate * TD Percentage Training
Units: dollars/Week
39) Technology Development Completion Rate = Technology Development Effort/ Technology Development Effort Residence Time
Units: man hours/Week
40) Technology Development Effort = INTEG (+Technology Development Initiation Rate - Technology Development Completion Rate, 100)
Units: man hours
41) Technology Development Effort Residence Time = 4
Units: Dmnl
42) Technology Development Initiation Rate = TD Funding Allocation Rate/Manhour Cost Rate * 0.75 * (1 + TD Redevelopment Fraction) * (1 - 2 * TD Cost Overrun Fraction) * (5 - 4 * SQRT(1 - ((TD Risk - 1)^2)/81))
Units: man hours/Week
43) Technology Maturity = 3
Units: Dmnl
44) TIME STEP = 0.25
The time step for the simulation.

ACKNOWLEDGMENT

This project was funded by the Iranian Offshore Engineering and Construction company (IOEC). Their contribution is gratefully acknowledged. The authors also would like to express their appreciation for the assistance provided by Persia Telecom Company.

REFERENCES

[1] E. B. Roberts, *The Dynamics of Research and Development*. New York: Harper & Row, 1964.
[2] NASA Technology Plan, 1998-2001, http://technologyplan.nasa.gov
[3] C. M. Christenson, *Exploring the Limits of the Technology S-curve*. Production and Operations Management, Vol. 1, No. 4, 1992.
[4] R.M. Price, *Technology and Strategic Advantage*. California Management Review Vol. 38, No. 3, pp. 38–56, 1996.
[5] L. R. Cohen and R. G. Noll, *The Technology Pork Barrel*. Washington, D.C.: Brookings, 1991, ch. 1, p.11.
[6] D. Sahal, *Patterns of Technological Innovation*. London: Addison-Wesley, 1981.

[7] R. H. Becker, L. M. Speltz, *Putting the S-Curve Concept to Work*. Research Management, Vol. 26, September-October, pp. 31-33, 1983.

[8] R. Foster, *Innovation: The Attacker's Advantage*. Summit Books, New York.

[9] M. C. Largent, D. N. Mavris, *Formulation of A Process for the Planning and Management of Technology Development*. American Institute for Aeronautics and Astronautics, 2001.

[10] D. Leonard-Barton, *Management of Technology and Moose on Tables*. Organization Science, Vol. 3, No. 4, November 1992.

[11] United States General Accounting Office, *Best Practices: Better Management of Technology Development Can Improve Weapon System Outcomes*. GAO/NSAID-99-162, July 1999.

[12] D. F. Cooper, C. B. Chapman, *Risk Analysis for Large Projects*. Chichester, England: John Wiley and Sons Ltd., 1987.

[13] J. V. Michaels, *Technical Risk Management*. Upper Saddle River, NJ: Prentice Hall, 1996.

[14] E. Tustin, *The Mechanism of Economic Systems*. Cambridge, MA: Harvard University Press, 1953.

[15] J. W. Forrester, *Industrial Dynamics*. Cambridge, MA: MIT Press, 1961.

[16] J. D. Sterman, *Busyness Dynamics – systems thinking and modeling for a complex world*. John Wiley, 2000.

[17] G. Richardson, *Problems with causal-loop diagrams*. System Dynamics Review, Vol. 2, No. 2, pp. 158–170, 1986.

[18] P. Monga, *A System Dynamics Model of the Development of New Technologies for Ship Systems*. Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of Master of Science, 2001.