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EFFECTIVE WORKFORCE LIFECYCLE MANAGEMENT VIA SYSTEM DYNAMICS MODELING AND SIMULATION

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ABSTRACT

Efficiently planning and managing workforce is a challenge imposed on many companies, especially for those in the service industry. The target of an effective workforce management is to recruit, develop and deploy the right people at the right places at the right times to fulfill both organizational and individual objectives. In this paper, we propose a novel concept of “workforce supply chain” to address the workforce management issue by considering both the demand side issue, i.e., project management, and the supply side issue, i.e., the human resource management. We then use System Dynamics modeling technique to capture the causality relationships and feedback loops in the workforce supply chain with the merit of system thinking. The evaluation of System Dynamics-based simulation exposes dynamic behavior and workforce management system and shows how adaptive control can be applied to such system.

1 INTRODUCTION

The IT industry is venturing into new areas of the globalization. Today’s economy requires IT professionals possessing right skills in various parts of the globe to be allocated into right opportunities. Such allocation is not a trivial matter since the areas providing right people transcends the boundaries of traditional IT Enterprise. It also needs to combine cultural and technological requirements in global, market driven resource allocation of workforce, while providing sustainable value by integrating ecosystems of partners. To become successful in current competitive environment, an enterprise has to make sure that its workforce management practice is marketplace-driven, culturally aware, boundary-free, globally accessible. The talents are expected to be more self-managing and available through non-traditional channels such as professional communities and social networks. Three major concerns for the service business are: high labor cost, over-run risk, and rapid skill transformation. Labor cost is the dominating cost in service organizations given the nature of service businesses. Service labor cost is increasing for every segment in the service sector. The more IT companies is geared for more service revenue, the more attention they have to pay into workforce management. In addition to the costing concern, the competitive edge of a service organization depends highly upon the effectiveness of managing high-skill talents in desired domains. In order to achieve a sustainable profit growth, an enterprise needs to control the increasing labor cost efficiently, and in the same time, strives more effective workforce management.

Workforce management is the strategic alignment of an organization’s human capital with its business direction. It is a methodical process of analyzing the current workforce, determining future workforce needs, identifying the gap between the present and future, and implementing solutions so that the organization can accomplish its mission, goals, and objectives. Workforce management includes elements such as strategic planning (by both the organization and its partners), workload projections, legislative forecasts, turnover analyses, and budget projections. Workforce management affects the full life cycle and range of human resources activities including recruitment/selection, classification and compensation, training and development, performance management, and retention. There are a lot of efforts in both academia and industry addressing workforce management issues, but traditionally, people either only study human resource problems, or focus merely on project management activities. Not much attention has been paid to consider the issues on both supply side and demand side holistically. Another problem is that existing research has focused on a static view of project management, especially concerning the impacts of process structure, while the dynamic features such as feedback, delays and nonlinear relationships, are less considered.

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In this paper, we will explore the workforce management issues for service-oriented business organizations. Based on the traditional concepts embodies in the manufacturing supply chain, we propose the idea of "workforce supply chain" for the purpose of addressing the issues on both the demand side, i.e., project management, and the supply side, i.e., the human resource management. Then we will present how we can employ the concepts and mechanisms of the modeling and simulation techniques based on System Dynamics to control and optimize workforce. The process of System Dynamic modeling has enabled us to capture causality relationships among data and feedback loops in the domain where the application is meant to be systematically developed with the merit of system thinking. And the evaluation of System Dynamics-based simulation would expose the dynamic behavior and adaptive control of workforce management system. In other words, System Dynamic model gives us the "physics" of the target business processes and enabling systems. Designers are able to understand the system through the design process itself via System Dynamics modeling and simulation.

The remainder of this paper is structured as follows. First, literature review on workforce management and related System Dynamics applications is presented in Section 2. In Section 3, the concept of workforce supply chain is proposed, and a comparison with product supply chain is conducted. A System Dynamics model of the workforce management system under the workforce supply chain concept is built in Section 4. Section 5 performs several simulation runs and the corresponding results are analyzed and discussed. Finally, in Section 6, we conclude this paper with closing remarks.

2 LITERATURE REVIEW

Workforce management is to manage the workforce supply chain, and coordinate the demand and supply of "human resource". From the demand side, the coming projects may generate demand of related workfoce, while from the supply side, the hiring activities could supplement required workforce, and the training and promoting mechanism could guarantee the improvement of workforce themselves. Therefore, workforce management should conside all the problems and coordinate both the supply side and the demand side. However, in literature the research around workforce management seems fall to two seperated catogories, i.e., human resource management and project management.

From the reseach method point of view, workforce management problems are often considered by qualitative approaches traditionaly (Dellacca and Justice 2007, Malone 2001, Malone 2004). However, mathematical models have been playing crucial roles in workforce management during the last several decades, from the use of linear programming in staff scheduling (Haxmeier 1991) to the application of queueing techniques in workforce configuration (Kevin et al. 2002). There is a rich variety of publications on Operations Research (OR) applications in workforce management using various models, collected in books and published proceedings (Bryant and Niehaus 1978, Haxmeier 1991, Jessop 1966, Kevin et al. 2002, Lu et al. 2006, Ward et al. 1994). Wang (2005) classified the OR techniques applied in workforce management into four major categories, i.e., models based on Markov chain, computer simulation, optimization and System Dynamics. These techniques are aimed at different aspects of workforce planning processes. Markov chain, computer simulation and System Dynamics are structured to predict what will happen to the system if present policies continue, while optimization techniques are designed to find which kind of policies should be adopted for given goals. All these techniques face a number of potential limitations (Wang 2005). Among the four classes of techniques, System Dynamics is the one specifically suitable for the study of dynamic behaviors where effects of feedback and nonlinearity are vital.

System Dynamics, first born with the name "Industrial Dynamics" by Jay Forrester in 1961, originated from the theory of non-linear dynamics and feedback control of mathematics, physics and engineering (Forrester 1961). System Dynamics is a method for developing management "flight simulator" to help people learn about dynamic complexity and understand the sources of resistance to design more effective policies (Sterman 2000). The method allows to study and manage complex feedback systems by creating models representing real world system. An efficient human resource or intellectual capital investment strategy demand a good understanding of the dynamics of recruitment and training issues (Hafeez et al. 2004). System Dynamics is widely used to explore dynamics of human resource management and project management.

2.1 System Dynamics in Human Resource Management

Forrester (1961) pioneered the work of using System Dynamics to study the policies of labor source and control labor change. The model was related to the classic manufacturing supply chain model. Sterman (2000) put forward the study to promotion chain and labor force management study, and considered factors such as the learning curve, mentoring and on-job training. He then proposed the concept of labor supply chain, and studied the behaviors including hiring and learning. The inventory model was used as the reference to build the labor supply chain model. Coyle (1996) explored a typical problem existing in consulting firms, i.e., how to recruit the right numbers of trainees and consultants upon the market potential.

These models are mostly highly simpified, and education-oriented.

Winch (1999) used System Dynamics to introduce a skill inventory model to manage the skill of key staff in times of fundamental change. Hafeez and Abdelmeguid (2003) developed a skill pool model to help understand the dynamics of skill acquisition and retention, particularly during times when a company is going through some major change. Hafeez et al. (2004) further used System Dynamics as a tool to model and analyze the human resource planning problems assciated with staff recruitment, staff surpluses and staff shortages. The model is mapped onto an overseas petrochemical company's staff recruitment and attritions and subsequently tested using real data. The System Dynamics modelling could help the decision maker to devise medium to long term efficient human resource planning strategies. Wang (2005) summarized and demonstrated the prospect of modelling training forces via System Dynamics by a causal-loop analysis of the military officer system and a simulation model based on a stock-flow diagram for a one-rank officer training system.

2.2 System Dynamics in Project Management

Static features and impacts of projects have been extensively studied and applied to project management practices, tools and techniques such as the Work Breakdown Structure, the Critical Path Method (CPM) and PERT (Program Evaluation and Review Technique) have dominated for decades (Halpin and Woodhead 1980). In contrast, project managers do not effectively understand or utilize the dynamic features of project structures (Rodrigues and Bowers 1996). These dynamic features include feedbacks, time delays, and nonlinear causal relationships among project components. These features combine to cause project systems to behave in complex ways which are difficult to understand, predict, and manage.

System Dynamics models provide a useful tool for a more systematic management of these dynamic issues. There have been a number of applications of System Dynamics in project management. Sterman (1992) used System Dynamics modeling for management of large scale engineering and construction projects. Rodrigues and Williams (1998) assessed the impacts of client behaviors on project performance, including schedule restrictions on milestones, high demand on progress reports, delays in approving documents, and changes to work scope throughout the lifecycle.

With comparison, we conclude that traditional models support the project manager in the detailed operational problems within the process, but System Dynamics models provide more strategic insights and understanding about the effectiveness of different managerial policies. These two approaches provide complementary support to project management; this suggests it could be of major value to integrate the best of both worlds.

In summary, the current research on workforce management fails to provide a systematic view for researchers to explore the overall picture of all workforce management activities. System Dynamics is a useful tool to get the insight of the operational mechanism in the workforce management system. Traditional project management studies only one single project at one time, while for workforce management, we study the problems at the program level which considers multiple projects simultaneously.

3 WORKFORCE LIFECYCLE MANAGEMENT

In order to achieve the competitive advantage, the enterprise needs to keep necessary skilled workforce, and to update its infrastructure and to implement new initiatives. At the same time, enterprise needs to keep cost low and achieve maximal profit margin. Therefore, workforce should be managed strategically hand by hand along with the business operations by evaluating the efficiency of workforce supply chain.

3.1 Workforce Supply Chain Structure

On the demand side, new and existing projects constantly request new resources. In fact, when enterprise conducts business transformation to re-engineer business processes and to improve efficiency of its business operations, senior managers come with multiple initiatives that fit into enterprise strategic objectives. For instance, IBM proposed enhancing on-demand capability across the IBM organization in 2002. Then there are multiple proposals being submitted related to such an initiative. After evaluation (portfolio optimization based certain objective), certain proposals are chosen for execution and become real projects. We are interested in planning and scheduling projects based on the situation on the side of human resources. There are three factors in each project considered here: project lead time, required skill set, and project duration. Project lead time is the difference between the project start time and current time. Project duration is the horizon between project start and finish. The required skill set specifies which kinds of skill and knowledge the project participants should have to accomplish the tasks of the project. It is obvious that 1) these parameters are heterogeneous and different from one project to another; 2) in many cases, their values could not be pre-determined and be dynamically changeable. Specifically, the execution of some project might depend on successful completion of other projects; 3) the duration of a project could be prolonged due to unpredictable events and resource constraints; and 4) the required skill set could be changed as the project is progressed and re-defined.

On the supply side, project managers have to ensure they will have enough available personals with right skills. Several factors need to be considered in this regard. First, job market might be tight and the certain skills in market becomes shortage. Even it is possible to get desired resources, the hiring cost could be higher than normal and might take a longer time to fill the positions. Such situation or similar ones imply uncertain hiring leading time. Second, employees may leave due to various reasons: retirement, job change etc. The employment duration with an employer is also uncertain. Finally, employer may choose to change the composition of skill pool due to business needs. Of course, its efficiency is determined by re-training lead time and in turn such a lead time might vary for different skill and for person with different disciplines.

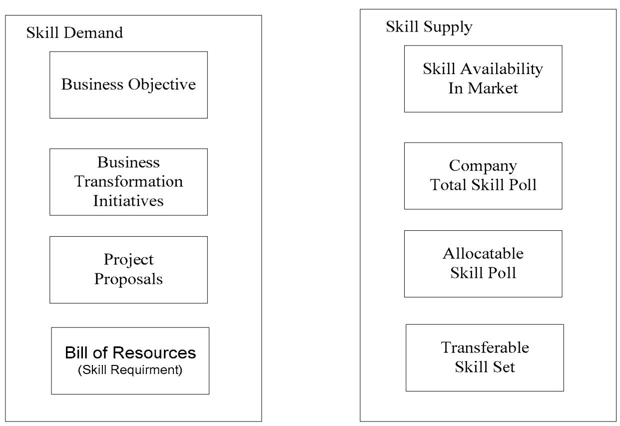

Figure 1: Workforce skill supply and demand

Both similarities and differences exist between product supply chain and workforce supply chain. In product supply chain, a product is developed to meet customer demand. In its upstream, suppliers provide parts and components, then manufacturers make the final product. For workforce supply chain based on our described scenario, the proposed initiatives and projects define the demand for skill requirement and hiring personal resemble part acquisition from suppliers. Comparing with parts that are consumable resource (gone after using like parts and money), human resources are renewable and resources avail themselves again after the completion of committed projects. The second difference is that human resources possess the capabilities of learning and re-learning . As a result, a personnel can be promoted from low-level position to high level position while new skills can be developed through training programs. Machine used to make products is renewable to some extent and could be used for making different products in the same category. However, they are not intelligent enough to improve themselves like human via learning. In the ideal situation of no job quit and stable develop, even no hiring activities are actually required since resources can renew themselves and skills are rebalanced through learning.

3.2 Operational Challenges

Considering demand and supply uncertainty in the workforce supply chain, we'd like to know what policy we can have to optimize the workforce supply chain performance. Keeping high level of skill pool might smooth project flow and keep its business running in continuous fashion, however, the cost may be unbearable for most projects with limited budgets. On the other hand, low level of skill pool will reduce project execution speed and lose opportunity to improve performance. As a result, the corporate needs to keep the balance of technological edge and low project cost in the viewpoint of workforce management. Commonly project manager ask the questions like: How many skilled personals does corporate need to hire? When does corporate to increase its skilled pool? From operational perspective, it is required to capture all relevant factors in the system, to have sound mathematical model based on impact analysis and to evaluate different decision rules and to implement adaptive control policies.

System Dynamics models expose the dynamic characteristics of a project pr a set of projects. Important variables are captured in the modeling process. When they vary along time line, the system behavior would change. To respond to such changes, we need to thoroughly understand quantified impacts of the changes of leading indicators (variables). Good policies can be used to positively influence and guide the change process. In the system we examine, there are the following variables with time dimension: project lead time, project duration, retraining lead time, hiring lead time, averaging employment duration. In an ideal world, a system would run on constant states with no changes. But in a real world, all variables manifest stochastic behavior and change all the time. For example, the project lead time can be highly associated with the project start time. Another example, the variable "project duration" may depend on "project scope" and "resource usability". Re-training lead time might depend on sophisticated level of skill and hiring lead time depends on market situation processing and education. The average employment duration may depend on economic and competitive environment. To account all uncertainties, project managers have to 1) plan and schedule re-training and hiring activities based on demand forecast and guarantee the continuity of business; and 2) reduce fluctuation and stabilize the process in a long run. For the first aspect, the optimization might be proper based on optimizing an objective. But it might not give best solution from the second aspect. System Dynamics simulation would help to evaluate the strategy from this aspect.

4 SYSTEM DYNAMICS MODEL

We describe the System Dynamics model in this section. Two parts of the modeling elements exist in this model: one for demand side, and the other for supply side.

We introduce the stock (project) flow diagram for the demand side first. It consists of two stocks: “Proposed Project” (PP) and “Ongoing Project” (OP). The inflow for “Proposed Project” is an input for the system. It will be chosen based on the incoming flow pattern that will be used for real simulation runs. The outflow “Executing Rate” (ER) is determined by matching available resource pool with requested required resource and using “Project Lead Time” (PLT). At the same time, the “Executing Rate” is also the inflow for the stock “Ongoing Project” and increases its quantity. The outflow “Project Finish Rate” (PFR) of “Ongoing Project” depends on the “Project Duration” (PD). In order to model the different skill set requirement, we array variables in the demand side with “category”. Project in different category has different percentage weight in all considered skills. The “Bill of Resource” (BOR) matrix indicates the relationship between categories and skills.

The low part models skill set evolution. The most left starts with “Available Skill In Market” (ASM). Its resource comes from graduates from colleges as well as workers quitting from other companies with “Skill Creating Rate” (SCR) which is exogenous for our model. The flow “Hiring Start Rate”, which is outflow for the stock “Available Skill In Market” and inflow for the stock “Hiring In Process”, is determined by “Available Skill In Market” and the decision rule that determines how many needs at the time and will discuss in detail in a moment. The focus stock is “Available Skill Pool” (ASP). The person in this pool is available to be deployed for the coming projects. The quantity of the pool, combining with allocation rule and the “Bill Of Resource”, is used to determine “Execution Rate”. And in turn, its outflow “Utilizing Rate” of the pool is synchronized with “Execution Rate”. By the same token, the stock “Skill in Use” would be synchronized with “Ongoing Project” in the project flow. Since the human is renewable resource, the skill used by “Ongoing Project” will return to the “Available Skill Pool” after projects finish. The flow “Returning Pool Rate” is related to “Project Duration” and the size of “Skill in Use”. Beside the inflow “Returning Pool Rate” for “Available Skill Pool”, there are additional two inflows for it. One is the flow “Hiring Finishing Rate” which comes out from the stock “Hiring In Process” and represents skill acquisition from “Available Skill In Market”. The other comes from the stock “Transferred Skill Pool” which corresponds to personal promotion and job transfer through re-training. Its flow rate is related to “Training Lead Time” and the “Re-training Ratio” in the “Available Skill Pool”. There is another outflow corresponding to people quitting their job due to various reasons. Its rate “Turn Over Rate” is related to “Average Employment Duration”.

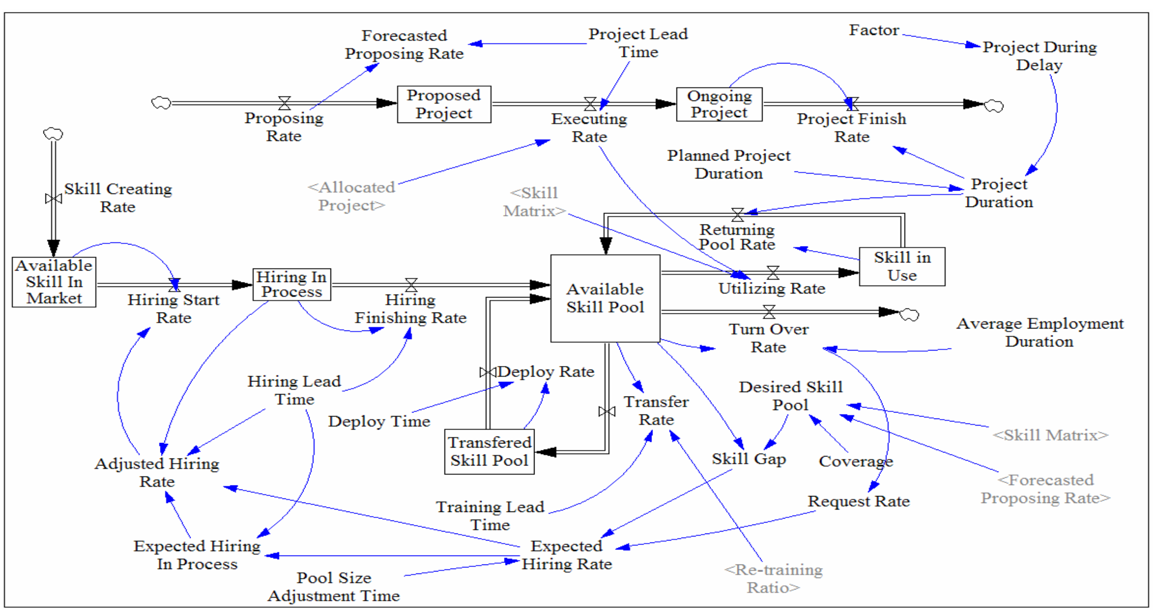

Figure 2: System Dynamics model

Now we go back to the decision rule on “how many people we should hire for each period”. We capture three feedback loops in the model. First of all, the “Request Rate”, a forecast based on “Turn Over Rate”, gives rough idea on how many skills are needed. In fact, in an ideal case that the proposed projects come in a constant speed and finish on time, that “Request Rate” would be the hiring rate. However, there are a lot of uncertainties involved, like "Project Lead Time", "Project Duration", "Hiring Lead Time" and "Training Lead Time", the imbalance between demand and supply occurs all the time. The second feedback loop is to correct the rate based on the appeared "Skill Gap". Based on the "Forecasted Proposing Rate" from "Proposing Rate", a coverage policy (resource for how many days should be covered) gives a size of "Desired Skill Poll". If the size of "Available Skill Pool" is different from the desired one, the "Skill Gap" would be nonzero. The new rate "Expected Hiring Rate" is generated from the "Request Rate" plus the "Skill Gap" adjustment. The final step is to cooperate with the quantity in the stock "Hiring In Process" and the training in process of "Transferred Skill Pool". The "Expected Hiring In Process" is estimated based on "Hiring Lead Time". Then the gap is formulated into the "Hiring Start Rate".

The second decision rule considered is how to handle skill evolution. People promotion is related to skill enhancement and responsibility widen. The other is related to horizontal transfer. Some skill has shortage and some has excessive supply. Company might initiate to change their organization structure to move people around. Also some employee might initiate changes based on current situation of company and personal development consideration. In either case, there is a learning curve associated to new skills with different training lead time. The decision to move people around is based on the internal imbalance between demand and supply as well as the market shortage, hiring cost vs. training cost. In the model, the decision rule for skill transformation is based on imbalance minimization. Mathematically, we minimize the following function.

$$f(T) = \sum_k \left(S_k - D_k - T_k\right)^2 \text{ with constraint } \sum_k T_k = 0$$

Where S is for supply, D is for demand, and T is for transferring amount among skills. When T_k is positive, the value of T_k represents transfer-out amount. On the other hand, its negative value represents transfer-in amount. And the constraint $\sum_k T_k = 0$ specifies the balance between transfer-in and transfer-out skills. The problem achieves its minimal value when

$$T_i = S_i - D_i - \frac{1}{N}\sum_k \left(S_k - D_k\right) \ ,$$

where N is the number of considered skills.

5 SIMULATION RESULTS AND DISCUSSIONS

We only present simulation for limited scenarios here. Simulation results for other scenarios will be investigated in the coming paper. The results validate the model and demonstrate dynamic nature of the system.

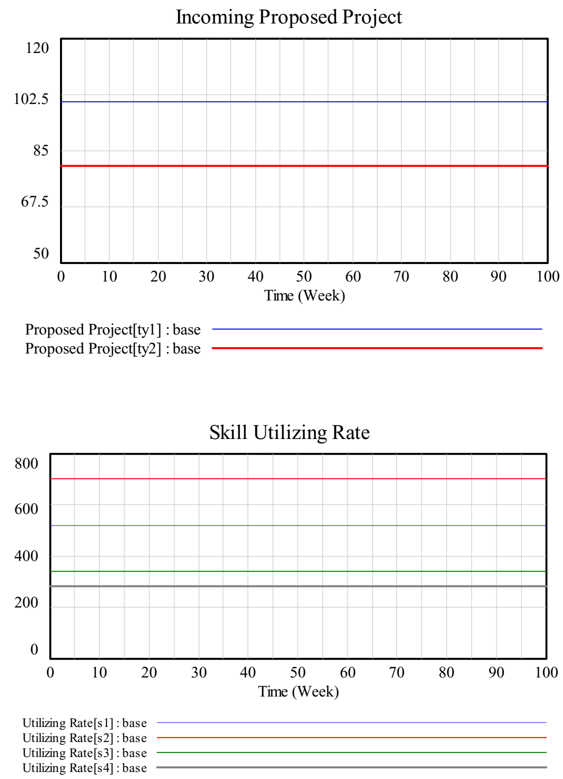

Figure 3: Steady state solution

Figure 3 shows that, under perfect condition where all leading times are kept constants, the system does have a fixed point and the problem has steady state solution along time-dimension. The top one shows that proposed projects come in at constant rate; the type 1 projects is 80 and the type 2 project is 100. Assume the following the bill of resource: the type 1 has skill distribution (4, 5, 3, 1) and the type 2 has skill requirement (2, 3, 1 ,2). Skill count per period is transformed into (520, 700, 340, 280) as shown in the bottom. Since resource returns the available skill pool, the hiring rate for each skill also keeps constant and equals to the attrition rate of each skill.

How does the system respond for sudden changes? We introduce additional 20 demand in the system for type 1 project at time period 30 as shown in the top of Figure 4. Since we introduces smooth for the project backlog, the skill usage has certain transition period and then stabilizes to a new level for each skill.

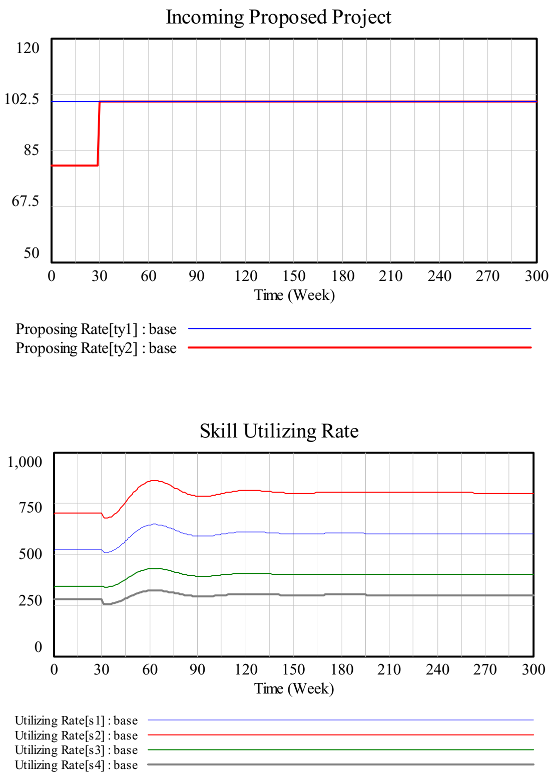

Figure 4: Skill usage change under demand jump

Figure 5: Hiring rate change

Figure 5 shows the corresponding hiring rate change based on decision rule 1 mentioned in the last section. The change magnitude 20 is translated into skill adjustment (80, 100, 60, 20) through the bill of resource. It is obvious from Figure 5 that the magnitude of hiring rate change is much bigger then the translated adjustment. This fact is associated with the bullwhip effect mentioned in the typical supply chain operation. The smoothed project backlog reduces the magnitude of adjustment in certain extent already. We also can see that the curve stabilizes to the level corresponding to new attrition rate. Compared with single skill case, it takes a longer time to stabilize to new level. In fact, the change we introduced for type 1 project is not translated to proportional changes for each skill. It takes a while to square skill adjustment.

6 CONCLUSIONS AND FUTURE WORK

We build a System Dynamics model for workforce supply chain. Take service business as example, we face the challenge of balancing the demand - incoming project, and supply - company's skill pool acquisition and attrition. Different types of project would be associated with different sets of skill requirement. That is modeled through the bill of resource matrix. Based on different characteristics of skill supply chain, we include skill reusable loop and skill transferable loop. We take the System Dynamics model as a test bed to examine theoretically informed and postulated relationship in workforce supply chain management. For instance, we capture a simple rule - minimizing the imbalance between demand and supply to determine the transferring amount among skills, determine hiring rate based on attrition rate, the gap between the accumulative project backlog and available skills as well as market restriction. We demonstrate the system response to sudden demand change. It is exposed that bullwhip effect happens along its upstream and a longer time to return a new steady state might relate to the non squared adjustment.

Since System Dynamics is a deductive approach, it is free to expose any reasonable hypotheses and to discover drivers that change system behavior. In future, we plan to enrich the model to include other decision rules into the system: 1) Allocating skills based on demand should be flexible in order to allow people working under intensifying environment (it happens all times in reality). So that the projects could start even under staffing situation. But that would associate fatigue development, motivation and affect attrition rate. 2) Skill transfer should take transferability into consideration. A transition matrix can be added to specify the transferring direction. The skill set is more general here and is classified based on category, experience level as well as geographic control. 3) In the case of having surplus skill, employers usually release persons. The release rate could be added to the model to reflect reality. 4) The cost information is added to the model: the unit cost for hiring, training, using, penalty cost for backlog and holding cost for extra skill pool. So that we can evaluate different decision rules and management strategies based on cost and benefit and constantly optimize the business performance.

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