ACTIVITY-BASED STRATEGIC WORK PLANNING AND CREW MANAGEMENT IN CONSTRUCTION: UTILIZATION OF CREWS WITH MULTIPLE SKILL LEVELS

Sungjoo Hwang[1], Moonseo Park[2], Hyun-Soo Lee[3], SangHyun Lee[4], and Hyunsoo Kim[5]

[1] Ph.D. Student, Department of Architecture and Architectural Engineering, Seoul National University, Korea
[2] Professor, Department of Architecture and Architectural Engineering, Seoul National University, Korea
[3] Professor, Department of Architecture and Architectural Engineering, Seoul National University, Korea
[4] Assistant Professor, Department of Civil and Environmental Engineering, University of Michigan, U.S.
[5] Ph.D. Student, Department of Architecture and Architectural Engineering, Seoul National University, Korea
Send correspondence to nkkt14@snu.ac.kr

ABSTRACT: Although many research efforts have been conducted to address the effect of crew members' work skills (e.g., technical and planning skills) on work performance (e.g., work duration and quality) in construction projects, the relationship between skill and performance has generated a great deal of controversy in the field of management (Inkpen and Crossan 1995). This controversy can lead to under- or over-estimations of the overall project schedule, and can make it difficult for project managers to implement appropriate managerial policies for enhancing project performance. To address this issue, the following aspects need to be considered: (a) work performances are determined not only by individual-level work skill but also by the group-level work skill affected by work team members, each member's role, and any working behavior pattern; (b) work planning has significant effects on to what extent work skill enhances performance; and (c) different types of activities in construction require different types of work, skill, and team composition. This research, therefore, develops a system dynamics (SD) model to analyze the effects of both individual- and group-level (i.e., multi-level) skill on performances by utilizing the advantages of SD in capturing a feedback process and state changes, especially in human factors (e.g., attitude, ability, and behavior). The model incorporates: (a) a multi-level skill evolution and relevant behavior development mechanism within a work group; (b) the interaction among work planning, a crew's skill-learning, skill manifestation, and performances; and (c) the different work characteristics of each activity. This model can be utilized to implement appropriate work planning (e.g., work scope and work schedule) and crew management policies (e.g., work team composition and decision of each worker's role) with an awareness of crew's skill and work performance. Understanding the different characteristics of each activity can also support project managers in applying strategic work planning and crew management for a corresponding activity, which may enhance each activity's performance, as well as the overall project performance.

Keywords: Work Planning; Human Resource Management; Organizational Learning; Skill-learning; System Dynamics

1. INTRODUCTION

The construction industry is labor intensive and workers are the major players executing the industry's processes and activities [1]. Construction work has also been organized on a craft basis, where crafts are organized according to specific skill categories of crews [2]. Due to the significance of construction crews in the carrying out of construction work, it is obvious that crew members' work skills (e.g., technical and planning skill) and its improvement can enhance overall project performance (e.g., work duration and quality). Although many research efforts have been conducted to address the effect of a crew's skill and its development on performance in construction projects, the relationship between skill and performance has generated a great deal of controversy in the field of management [3].

As Grugulis and Stoyanova [4] mention, there are analytical difficulties in defining the linkage between skill and performance: (a) both skill and performance are difficult to define, evaluate and measure due to their complexity; and (b) the existing empirical evidence is rather limited and not coherent. As mentioned, there are difficulties in analyzing how skill is manifested in performance; many researchers have thus tried to account for the linkage between skill and performance in order to enhance project performance. This body of research includes an investigation of the types of skill required for carrying out construction work [5] [6] [7] [8], an investigation of crew's skill-learning and evolution [9] [10] [11] [12], and an analysis of how a crew's skill is manifested in performance [2].

Although existing researches provided a theoretical background for defining the linkage between skill and performance, and although it accounted for the gap between a crew's skill and performance, they have not yet achieved a holistic understanding of the complex interaction between a crew's skill and performance. To better understand these interactions, the following aspects need to be considered: (a) work performance is affected not only by each member's skill but also by the composition of work team members (e.g., the number of skilled and unskilled crews), and by each member's work role in performing team-based construction work (i.e., group-level skill) [3] [11]; (b) work planning (e.g., work scope, work schedule, work member composition, and work role assignment) has significant effects on what extent the work skill enhances project performance [8]; and (c) skill can be improved as repetitive work progresses, and is manifested differently according to different work characteristics (e.g., work complexity, required skill level, and required types of skill) [2]. The inappropriate understanding of skill and performance without a consideration of the above aspects can lead to under- or over-estimations of overall project schedule, and can make it difficult for project managers to implement appropriate managerial policies for enhancing project performance.

To enhance project performance, project managers tend to make continuous efforts, including the practice of employee recruitment strategies to hire skilled crews [13], and the offering of training and education programs for developing crews' skills [8]. However, these policies are difficult to apply due to the shortage of skilled crews in the construction labor market [8], as well as the interdisciplinary and temporary team environments in which allotting money to training costs for temporary workers can be inefficient [14]. Because the project manager is not provided with sufficient resources to implement the project [5], strategic work planning and crew management can be effective in fully using an existing crew's skill to enhance project performance with a comprehensive understanding of how skill evolves and is manifested in work performance within different work.

This research, therefore, develops a system dynamics (SD) model to understand the relationship between a crew's skill and performance in repetitive construction work by utilizing the advantages of SD in capturing a feedback process and state changes, especially in human factors (e.g., attitude, ability, and behavior). The model incorporates: (a) a skill evolution and working behavior development (i.e., skill manifestation in work outcome of crews) of crews within a work group; (b) the interaction among work planning, crew's outcomes, and project performance; and (c) the different work characteristics of each activity. With an awareness of skill and performance dynamics, as well as of different work characteristics, this model can be utilized to implement managerial policies to fully use a crew's skill within the context of insufficient resources.

The paper begins with the study of existing theories including: work skill, the skill-learning and manifestation process, and the linkage between a crew's skill and performance. Based on the theoretical background, the SD policy model is developed. The suggested model is then tested with analyses of the simulation results. Finally, the hybrid model concepts for incorporating detailed work characteristics are presented as focuses for future research.

2. THEORETICAL BACKGROUND

2.1 Work Skill

The role of a crew's skill is particularly significant in craft-based construction work. It is generally asserted that utilization of crew's skill is the way to achieve high profits and high performance organizationally [4] [15]. According to Odusami [6], a crew's skill is defined as an ability that can be developed and that is manifested in performance. It can be also referred to as an ability to translate knowledge of work into action. Many researchers have tried to define and categorize a crew's skill that is required for carrying out assigned work [6] [8] [16].

The aforementioned research provides that a crew's skill can be categorized by its type, including (a) technical skill; (b) conceptual skill (i.e., work planning skill); and (c) human skill. Technical skill can be referred to as an understanding of and proficiency in a specific kind of activity, particularly one involving methods, processes, procedures, or techniques [5] [16]. Conceptual skill can be described as the ability of a group leader (e.g., manager or foreman who generally possesses a higher level of technical skill) to coordinate and integrate all of the activities and interests of the organization toward a common objective [6]. Finally, human skill is the executive ability of a leader to work effectively as a group member and to build cooperative effort within the team he/she leads [6].

In construction projects, different kinds of skills are required of each participant. For example, a manager needs to possess technical skills, conceptual skills, and human skills in order to understand the integration of technical features of a project, solve a common cause of implementation problems, and coordinate and motivate the work teams [5] [6]. Construction crews mostly require technical skills because they perform repetitive work. Despite the characteristic of construction work being manually performed, the two types of construction crews—skilled crews (i.e., foremen of work groups) and unskilled crews (i.e., temporary laborers who perform tasks requiring only manual labor rather than high-level skills)—require different types of skill [2]. Skilled crews require not only high-level technical skills for performing more complex work, but also to some degree they require conceptual skills for understanding work characteristics and coordinating work groups. Unskilled crews require low-level technical skills, needed only for manually performing tasks.

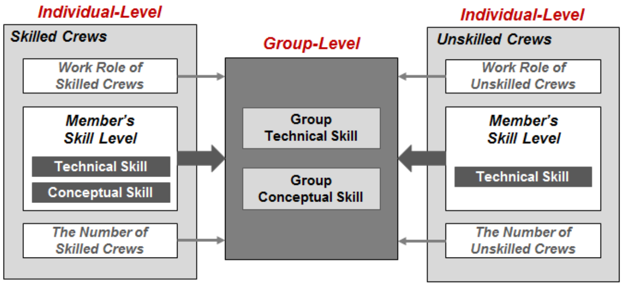

Fig. 1. Workers Skill in Construction Projects

Although an individual-level skill of both skilled and unskilled crews is a main contributor to performing group work, the gap exists between individual-level and group-level skills. This gap exists because group-level work skill is determined not only by each member's skill but also by the work team member composition (i.e., the number of both skilled and unskilled crews in a work group), as well as each member's work role (i.e., the assigned role or tasks of both skilled and unskilled crews in performing group work). The composition of work team members and their work roles are mainly composed by a manager at an early stage of construction projects. [2]. Fig. 1 shows the categorization and determination of crews' multi-level skills (both individual- and group-level) based on the theories dealing with work skill.

2.2 Skill-learning

Skill-learning development is the realization of improved production performance for subsequent cycles, such as repetitive construction processes leading to increased knowledge about the task being performed and increased familiarity with the jobsite [11]. In other words, learning increases crew's capacity to take effective action [12] [17].

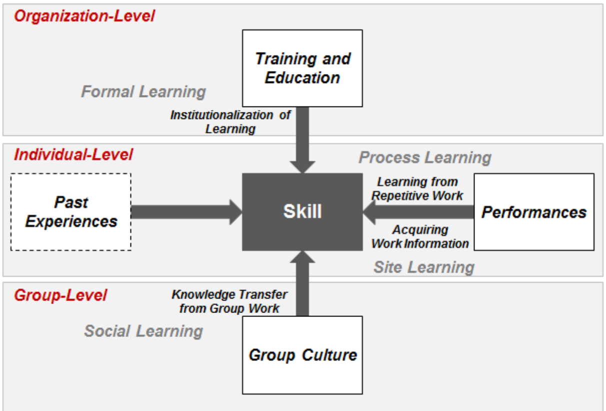

Fig. 2. Skill Development Process

According to Marquardt [18], the learning system of an organization consists of three dimensions, made up of individual-, group-, and organization-level learning. Individual-level learning includes: (a) process learning from past and current experiences by performing repetitive work that leads to increased knowledge and proficiency, and (b) site learning from acquiring work and site information [9] [11]. Group-level learning means that the transferring of experiences between individuals depends on many formal and informal cultural and organizational issues [12]. Group work, which requires collaboration among individuals, has a particularly significant effect on experience transfer. Finally, training and education at the organization- or corporation-level can be effective for developing crews' skills. In construction projects that rely on an interdependent and temporary (e.g. moving from site to site) workforce, however, training and education can a waste of funds due to construction crews' short length of service. Fig. 2 describes the skill-learning process within the construction organizations.

2.3 Skill Manifestation

Skill improvement of construction crews does not always result in a significant improvement for the overall work performance [11]. Although the accumulated skills of labor can decrease the time it takes to achieve an assigned task, workers' behavior—particularly the total working hours affected by the time workers waste (e.g., rest during business hours)—can have significant effect on work performance [4]. In other words, work performance is determined by not only as unit productivity affected by a crew's skill but also as a crew's net working hours.

To address this issue, Vroom [19] provided a comprehensive theory of an individual crew's performance, called the expectancy theory. This theory gives an idea of behavior in which a worker doesn't try to make any additional efforts without appropriate motivation, even if he/she can achieve the assigned tasks before the deadline. In other words, improved skill can be manifested in performance improvement with appropriate work schedule and motivation. Fig. 3 describes the process of how a crew's skill is manifested with managerial policies, including work scheduling and motivation.

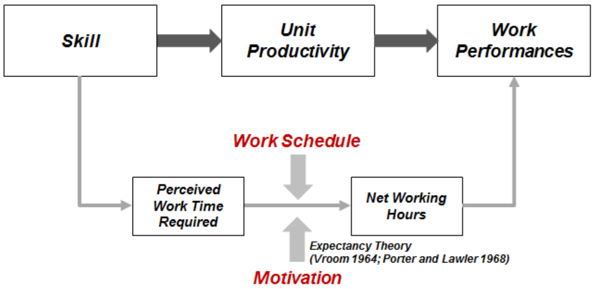

Fig. 3. Skill Manifestation Process

2.4 Construction Work Characteristics

A construction project includes numerous types of work. Thus, construction crews with varying types of skill—which may not be interchangeable—are required in these projects [20]. In different kinds of construction work, there are substantial differences in how a skill is manifested in performance, and to what extent the improved skill is effective in enhancing these performance.

Maloney and McFillen [2] thus suggested a job-characteristics model to understand how construction work performance is determined according to different types of work. Based on this model, this research defines the core characteristics of construction work in order to apply these characteristics to an understanding of the linkage between skill and performance, as follows:

(a) Work complexity: The degree of the amount of proper work information for carrying out the work (e.g., form work has a higher level of work complexity than masonry work).
(b) Required skill level: The degree to which a job requires crews to have a high-level work skill in order to carry out the work (e.g., plastering work

has a higher required skill level than masonry work) [7].

(c) Skill variety: The degree to which a job requires a variety of different skills and to what extent a certain skill is required in carrying out the work (e.g., curtain wall work has a higher level of skill variety than plastering work) [2] [20].

(d) Autonomy: The degree of independences when each crew performs an assigned work. It can be referred to as a countercurrent of how collaborative work is important for performing tasks (e.g., masonry work has a higher level of autonomy than curtain wall work) [2].

Although work characteristics can be difficult to quantitatively define, a comparison of work characteristics among many types of construction work have a demonstrable advantage in understanding the different linkages between skill and performance according to different work types. This research develops a policy model based on the above work characteristics.

3. RESEARCH METHODOLOGY

The afore-mentioned research can provide meaningful explanations of how and to what extent skill is developed and is manifested in performance. Nonetheless, these potential and traditional approaches to theory development are limited in their ability to analyze multiple interdependent processes operating simultaneously. Because the compositive interactions between skill and performance typically produce nonlinear system behavior with feedback, empirical and theoretical analysis has limited value [21].

In this regard, computer simulation techniques can articulate the complex behavior of interest over time. Especially, an SD simulation model provides an analytic solution for complex, nonlinear, and dynamic systems by focusing on interactions among variables and understanding their structures [22]. SD is based on the theory-based cause-and-effect relationship among variables and the stock and flow diagram. SD can be applied to model the behavior of a system as a whole, due to its ability to capture feedback processes and state changes, especially of human factors (e.g., attitude, ability, and behavior) [21] [23]. Much research has thus tried to analyze organizational issues by utilizing SD simulation, including knowledge transfer [12], worker's skill evolution [20], and performance enhancement in construction projects [24] [25].

These simulation approaches that include SD partially overcome the empirical problem of data availability in existing econometric models. This partial success is due to SD modeling's advantages, including: control (unobserved heterogeneity and unwanted influences are eliminated), less constraint on sample size, the ability to manage greater complexity in experimental design, and the ability to precisely track the behavioral steps and feedback process leading to the outcomes of interest [21]. The SD modeling thus provides a comprehensive solution and a systematic approach for analyzing the relationship between a crew's skill and project performance, as well as skill-learning and manifestation process.

4. SD MODEL DEVELOPMENT

4.1 Model Framework

This research constructs an SD model based on investigated theories with regard to a crew's skill determinant and development process, skill manifestation process, and the linkage between skill and performance. The model framework, as described in Fig. 4, shows skill and performance dynamics with a consideration of work characteristics and managerial decisions. A high technical skill—both individual and group level—results in a high productivity and low work errors by being improved from experiences. A high work planning skill (i.e., conceptual skill) can yield low rework generation with an appropriate planning by acquiring work information as work progresses [5]. As mentioned above, while an individual technical skill determines group skill, group skill can also affect individual skill-learning due to knowledge and experience transfer among work teams.

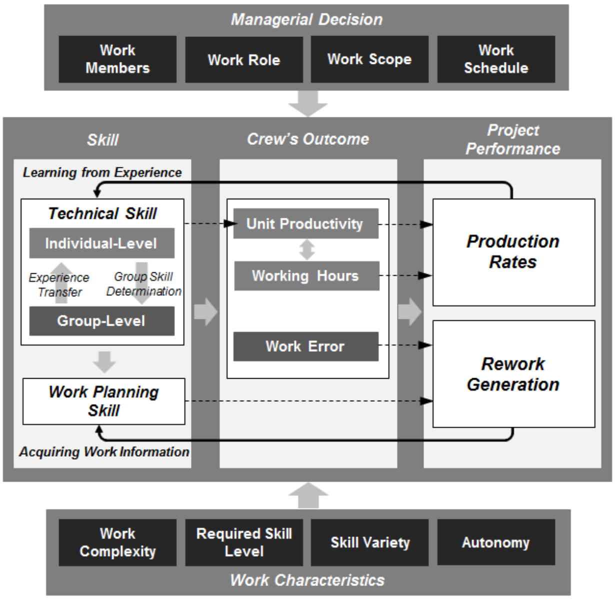

Fig. 4. Model Framework

On the other hand, although a crew's improved skill leads to enhanced productivity, it can be unlinked to performance increases (e.g., work production rates) due to changes in crew's working behavior (e.g., net working hours) without appropriate work schedule or motivation policies. During the process where skill is manifested in performances, work characteristics (e.g., work complexity, required skill level, required skill variety, and work autonomy) and managerial decisions (e.g., work member composition, work role assignment, work scope decision, and work scheduling) can have significant effects on crew's skill manifestation process.

The model this research constructs is categorized as: (a) skill determinants and development model, (b) skill manifestation model, and (c) skill and performance dynamics model based on the model framework.

4.2 Skill Determinants and Development

Fig. 5 shows the causal loop diagram which describes crew's skill determinants and development process. In this model, variables with grey background color mean work characteristics, and variables with black background color mean managerial decisions. An individual technical skill of crews can be utilized only when crews perform individual work (i.e., a work which each crew can perform alone without collaborative efforts). The group work, which the most construction work consist of, are affected by group-level technical skill because they are performed by work group which includes both skilled and unskilled crews. A group technical skill thus is determined not only by each individual skill level but also by the composition of group members (A in Fig. 5).

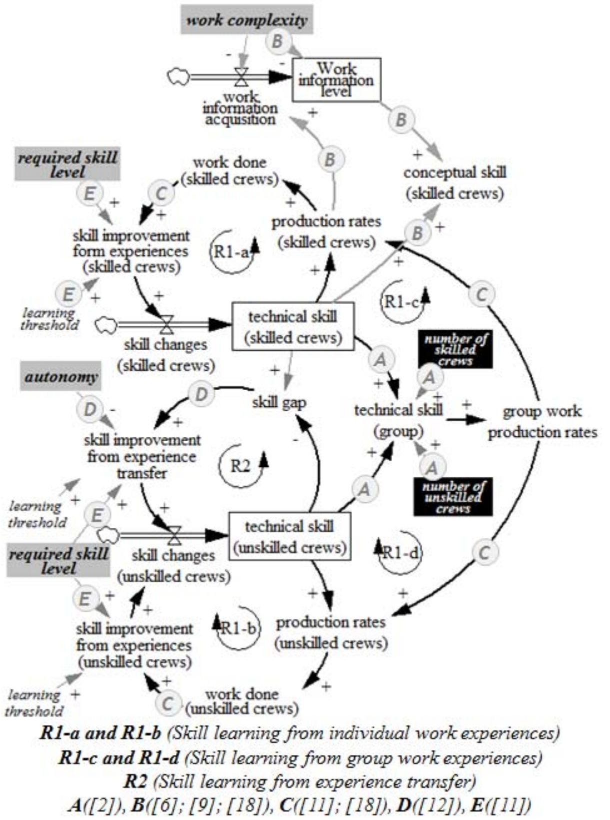

Fig. 5. Causal Loop Diagram: Skill Determinants and Development

A conceptual skill of skilled crews (e.g., foremen of work groups) also has a significant effect on work performance because to some degree, skilled crews contribute to plan the work. While a technical skill of skilled crews is the main contributor of a conceptual skill, work and site information, which are continuously accumulated during projects, also affect this skill in a complex construction environment (B in Fig. 5).

Both skills can be continuously improved from accumulation of work (both individual and group work) experiences as repetitive work progresses (R1-a, R1-b, R1-c, and R1-d loops in Fig. 5) as well as knowledge and experience transfer from skilled crews to unskilled crews by performing collaborative group work (R2 loop in Fig. 5). Transferring of experiences between individuals depends on many formal (e.g., work characteristics with respect to the importance of collaboration) and informal (e.g., a collaborative culture) organizational issues (D in Fig. 5).

Although a crew's skill can be continuously developed during the repetitive work process, there are following restrictions on crew's skill-learning: (a) a required skill level of work; (b) skill-learning threshold (E in Fig. 5). In detail, work characteristics, such as a required skill level, affects the learning rates and the impact of learning on the overall operation [11]. For example, it is difficult to expect an evident skill increase of high-skilled crews when they performs task which require low-skill or are manually performed. Furthermore, the trend of skill improvement would eventually converge to zero if the process were repeated for a sufficient time (i.e., skill-learning threshold) [9].

4.3 Skill Manifestation

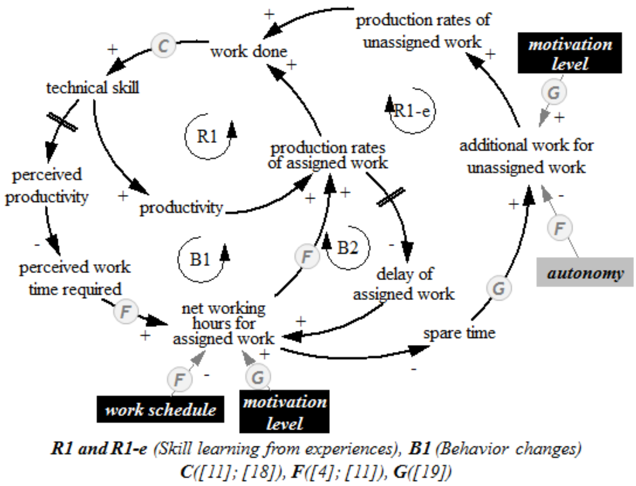

Fig. 6. Causal Loop Diagram: Skill Manifestation

The causal loop diagram with respect to a crew's skill manifestation process which is affected by managerial decisions is represented in Fig. 6. Although skill can be continuously improved during repetitive work process (C and R1 loop in Fig. 6), it is difficult to be linked to enhanced performance without appropriate work schedule and motivation policies. When crews perceive their skill improvement, they set up a new standard of their working behavior (i.e., particularly daily net working hours) based on their perceived productivity and work schedule (F in Fig. 6). This behavior adjustment can offset the possibility of performance enhancement resulted from crew's productivity increases (B1 and B2 loop in Fig. 6). With an appropriate motivation or collaborative team culture, spare times of crews that is generated by improved skill can be utilized for additional works including other members' delayed works (G in Fig. 6).

4.4 The Linkage between Skill and Performances

By utilizing the stock and diagram of SD modeling, this research describes the structure of the linkage between a crew's skill and work performance according to different work characteristics, as shown in Fig. 7.

At first, work to be performed can be categorized as individual and group work according to work characteristics of autonomy (H in Fig. 7). With respect to both individual and group work, a crew's skill—both individual- and group-level—determines productivity which contribute to production rates (I in Fig. 7) and work error probability which affect rework generation (J in Fig. 7). Although a crew's skill affects work performance, work characteristics—including a required skill level (K in Fig. 7) and a required skill variety (L in Fig. 7) as well as the composition of group members (M in Fig. 7) —have significant effects on how a crew's skill is utilized in different kinds of work. In other words, the knowledge, attitudes, or abilities of crews needed for a certain job can be understood and manifested only within particular working context [7]. For example, high-skill of crews in a masonry work has a limitation on considerable productivity improvement because a masonry work consists of monotonous work (i.e., a low required skill level).

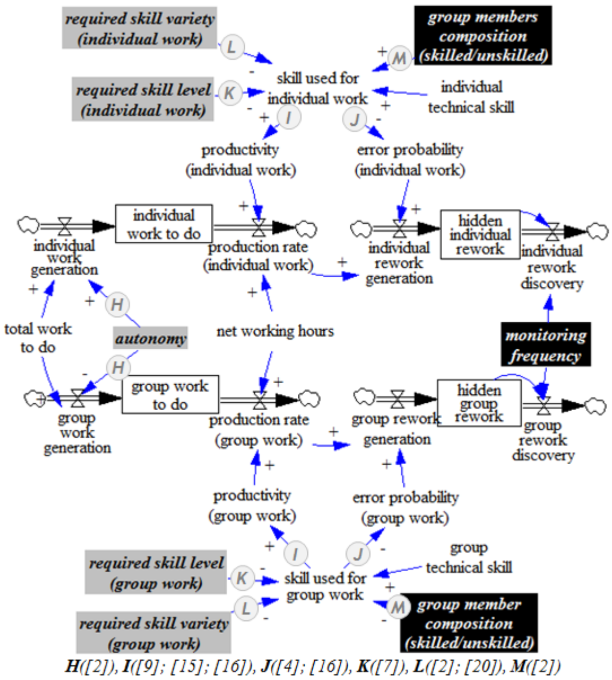

Fig. 7. Structure of the Linkage between Skill and Performances

5. MODEL BEHAVIOR TEST

Based on the causal loop diagrams presented above, this research constructs a simulation model for conducting experiments to analyze the effects of diverse managerial policy scenarios. This model may have limitations regarding point estimations due to the difficulties in measuring and quantifying inherent and behavioral factors of crews. It can be still useful for conducting comparative analysis among diverse managerial decisions, however, since SD simulation can better capture the impact of changes in the structure of variables with an understanding of complex interactions among variables in system. To analyze the changes in variables, particularly skill and performance, therefore, the developed model simulates the differences between variables and their changes, and then compares these shifts with a base case when managerial policies are applied to different types of work. The whole policy model, including the descriptions of model structures and equations, can be found in the author's research website (http://blog.naver.com/nkkt14).

Table 1. Model Test Scenario

	Skill Level (Skilled Crews)	Skill Level (Unskilled Crews)	Average Required Skill of Work	Learning Effects
Graph 1 *(Base Case)*	0.6	0.2	0.4	X
Graph 2	0.6	0.2	0.4	O
Graph 3	0.6	0.2	0.5	X
Graph 4	0.6	0.2	0.5	O

Using the scenarios described on Table 1, this research conducts a behavior test of the developed policy model to confirm that to what extent the simulation results exactly correspond with existing theories on skill determinant and, skill-learning and skill manifestation in work performance. In detail, the purposes of this behavior test are twofold: (a) to identify to what extent the skill-learning can be effective to enhance performances in different work; and (b) to understand how differently skill are manifested in work performance in different work environments.

This research set four types of scenarios including: (a) the first case of conducting the work which has normal-level of difficulty without a consideration of skill-learning effects, which is a base case (Graph 1 in Fig. 8-10); (b) the second case of conducting the work which has normal-level of difficulty with a consideration of skill-learning effects (Graph 2 in Fig. 8-10); (c) the third case of conducting the work which has difficult-level of difficulty without a consideration of skill-learning effects (Graph 3 in Fig. 8-10); and (d) the fourth case of conducting the work which has high-level of difficulty with a consideration of skill-learning effects (Graph 4 in Fig. 8-10).

As shown in Fig. 8 which displays simulation results of work duration, the skill-learning of crews result in remarkable improvement in work performance, particularly work schedule in difficult-level of work (i.e., skill-learning effects on work duration of a Graph 4 compared to Graph 3 in Fig. 8), while crew's skill-learning has no evidence on improvement in work performances in normal-level of work (i.e., skill-learning effects on work duration of a Graph 2 compared to Graph 1 in Fig. 8). In normal-level of work, even a slight improvement in work productivity of crews by skill-learning effects (i.e., skill-learning effects on work productivity of a Graph 2 compared to Graph 1 in Fig. 9) can be offset by a crew's behavior change (i.e., reduced net working hours of crews by their improved skill perception as shown in Graph 2 of Fig. 10), rather manifested in work performances. The skill-learning effects on performances, however, can be significant in difficult-level of work because skill improvement crews can yield not only high productivity (i.e., skill-learning effect on work productivity of Graph 4 compared to graph 3 in Fig. 9) but also low level of work errors, which can result in a decrease of rework from crew's work error. It thus requires less net working hours due to less rework generation (Graph 4 in Fig. 10).

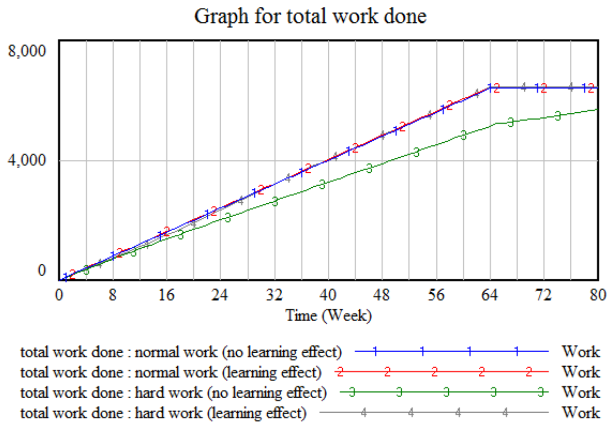

Fig 8. Model Test: Work Duration according to Different Skill-learning Effects and Work Characteristics

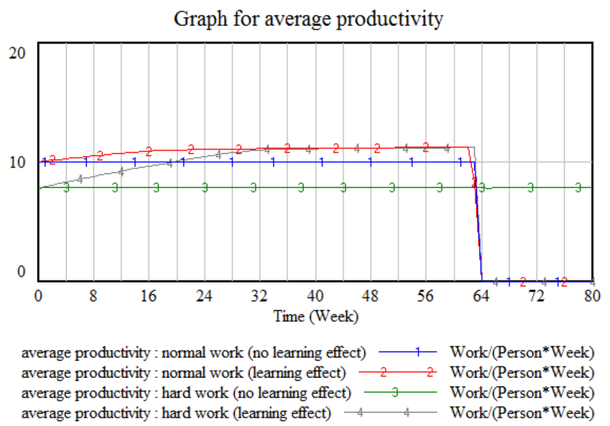

Fig. 9. Model Test: Work Productivity according to Different Skill-learning Effects and Work Characteristics

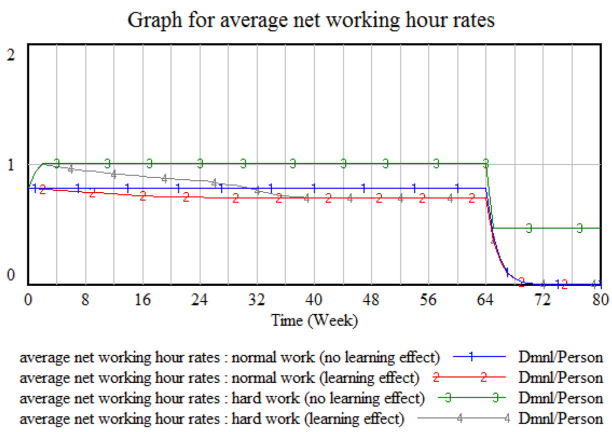

Fig. 10. Model Test: Work hour Rates according to Different Skill-learning Effects and Work Characteristics

Furthermore, it is hard to expect more considerable skill improvement in normal-level of work, than in difficult-level of work which has much room for skill improvement. In other words, there are more chances to continuously improve crew's skill (Graph 4 in Fig. 9) because difficult-level of work has more knowledge and information to be acquired during work process resulted from its work complexity.

From the results of the behavior test, as shown above, it is confirmed that model can provide reliable simulation results of how crew's skill is determined, to what extent the skill is improved and manifested in performance. It can be also applied to planning of different kind of construction works by incorporating the effects of different work characteristics and managerial decisions. Although the model can produce simulation results which may reflect existing theories, more quantified data and deterministic equations on a crew's skill and performance will be helpful to produce more reliable and diverse simulation results in the future research. The behavior test that this research conducts will be continuously and diversely conducted to modify and complement the model, which can fortify model's reliability for analyzing managerial policies in different construction works.

6. CONCLUSIONS

To analyze the effects of managerial policies on performance in different types of construction work environment, this research attempted to develop a dynamic and integrated SD policy model that focuses on the construction crew's skill determinants and developments, skill manifestation, and the linkage between skill and performances.

The policy model was developed based on existing theories with respect to crew's skill and construction work performance with an understanding of different characteristics of diverse construction works. Simulation model of this research can be utilized to develop a tool for generating virtual management policy scenarios and implementing strategic policies for a corresponding work including appropriate work planning (e.g., work scope and work schedule) and crew management policies (e.g., work team composition and decision of each worker's role) with an awareness of a crew's skill and work performance. Understanding the different characteristics of each activity can also support project managers in applying strategic work planning and crew management for a corresponding activity to fully use crew's skill, which may enhance each activity's performance, as well as the overall project performances.

Although this research constructed simulation model with operationally defined equations based on the theoretical background and qualitative data, it should be complemented with quantitative data and deterministic equations from existing researches with regard to a crew's skill and work characteristics in the future research.

On the other hand, a SD model does not reflect the physical specifications of the system, particularly the process and operational details of different types of construction work [26], despite its ability to capture feedback process and state changes of crew's skill development and manifestation. In this regard, Peña-Mora et al. [27] and Lee et al. [26] suggested hybrid model between SD and discrete-event simulation (DES) (i.e., an effective tool for construction process analysis which can analyze the process and operational details including resources by its powerful ability to handle complexity and uncertainty [28]), encompassing operational detail of construction work, human factors (e.g., attitude, ability, and behavior of crews), and their feedback with a simulation approach. By utilizing the advantages of this concept, more detailed work characteristics modeled by DES can be considered to analyze the complex effects of skill on performance in different construction work context. Modeling detailed construction work using DES also help SD model to be simplified by making it only focus on feedback process and state changes of a crew's skill.

REFERENCES

[1] Maloney, W. F. (1983). "Productivity Improvement: The Influence of Labor" *Journal of Management in Engineering*, ASCE, 13(3), 49-56.

[2] Maloney, W. F., and McFillen, J. M. (1995). "Job Characteristics: Union-Nonunion Differences" *Journal of Construction Engineering and Management*, ASCE, 121(1), 43-54.

[3] Inkpen, A. C., and Crossan, M. M. (1995). "Believing Is Seeing: Joint Ventures and Organization Learning" *Journal of Management Studies*, 32(5), 595-618.

[4] Grugulis, I., and Stoyanova, D. (2011). "Skill and Performance" *British Journal of Industrial Relations*, 49(3), 515-536.

[5] Goodwin, R. (1993). "Skills Required of Effective Project Managers" *Journal of Management in Engineering*, ASCE, 9(3), 217–226.

[6] Odusami, K. T. (2002). "Perceptions of Construction Professionals Concerning Important Skills of Effective Project Leaders" *Journal of Management in Engineering*, ASCE, 18(2), 61-67.

[7] Stasz, C. (2001). "Assessing Skills for Work: Two Perspectives" *Oxford Economic Papers*, 53(3), 385-405.

[8] Castañeda, J., Tucker, R., and Haas, C. (2005). "Workers' Skills and Receptiveness to Operate Under the Tier II Construction Management Strategy" *Journal of Construction Engineering and Management*, ASCE, 131(7), 799–807

[9] Hijazi, A. M., AbouRizk, S. M., and Halpin, D. W. (1992). "Modeling and Simulating Learning Development in Construction" *Journal of Construction Engineering and Managemen*t, ASCE, 118(4), 685-700.

[10] Everett, J. G., and Farghal, S. (1994). "Learning Curve Predictors for Construction Field Operations" *Journal of Construction Engineering and Management*, ASCE, 120(3), 603-616.

[11] Lutz, J. D., Halpin, D. W., and Wilson, J. R. (1994). "Simulation of Learning Development in Repetitive Construction" *Journal of Construction Engineering and Management*, 120(4), 753-773.

[12] Le, M. A. T., and Law, K. H. (2009). "System Dynamics Approach for Simulation of Experience Transfer in the AEC Industry" *Journal of Management in Engineering*, ASCE, 25(4), 195-203.

[13] Huselid, M. A. (1995). "The Impact of Human Resource Management Practices on Turnover, Productivity, and Corporate Financial Performance" *Academy of Management Journal*, 38(3), 635-672.

[14] Tomek, S. (2011). "Developing a Multicultural, Cross-Generational, and Multidisciplinary Team: An Introduction for Civil Engineers" *Leadership Management Engineering*, 11(2), 191-196.

[15] Brown, P. (2001). "Skill formation in the twenty-first century". In P. Brown, A. Green and H. Lauder (eds.), High Skills: Globalization, Competitiveness and Skill Formation.*Oxford: Oxford University Press*, 1–55.

[16] Katz, R. L. (1974). ''Skills of an effective administrator'' *Harvard Business Review*, 52(5), 90–102.

[17] Kim, D. H. (1993). "The link between individual and organizational learning" *Sloan Management Review*, 35(9), 37–50.

[18] Marquardt, M. J. (1996). *Building the learning organization*, McGraw- Hill, New York, NY.

[19] Vroom, V. H. (1964). *Work and Motivation*, John Wiley and Sons, New York, NY.

[20] Alvanchi, A., Lee, S., and AbouRizk, S. M. (2012). "Dynamic Workforce Skill Evolution in Construction Projects" *Canadian Journal of Civil Engineering*, Accepted.

[21] Harrison, J. R., Lin, Z., Carroll, G. R., and Carley, K. M. (2007). "Simulation Modeling in Organizational and Management Research" *Academy of Management Review*, 32(4), 1229-1245.

[22] Sterman, J. (2000). *Business Dynamics: System Thinking and Modeling for a Complex World*, Boston: Irwin Mcgraw-Hill, New York, NY.

[23] Williams, T. 2002. *Modelling Complex Projects*, Wiley, New York, NY.

[24] Han, S., Lee, S., and Peña-Mora, F. (2011). "Identification and Quantification of Non-value Adding Effort Due to Errors and Changes in Design and Construction Projects" *Journal of Construction Engineering and Management*, ASCE, 138(1), 98-109.

[25] Alvanchi, A., Lee, S., and AbouRizk, S. M. (2012). "Dynamics of Working Hours in Construction" *Journal of Construction Engineering and Management*, ASCE, 138(1), 66-77.

[26] Lee, S., Han, S., and Peña-Mora, F. (2009). "Integrating Construction Operation and Context in Large-Scale Construction Using Hybrid Computer Simulation" *Journal of Computing in Civil Engineering*, ASCE, 23(2), 75-83.

[27] Peña-Mora, F., Han, S. Lee, S., and Park, M. (2008). "Strategic-Operational Construction Management: Hybrid System Dynamics and Discrete Event Approach" *Journal of Construction Engineering and Management*, ASCE, 134(9), 701-710.

[28] Law, A., and Kelton, W. D. (2006). *Simulation Modeling and Analysis*, 3th, McGraw-Hill, New York, NY.