01 Jan 2024

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## Recommended Citation

T. Elbashbishy and I. H. El-Adaway, "System Dynamics Modeling For Investigating The Retention Of Skilled Labor In The Construction Market," *Computing in Civil Engineering 2023: Resilience, Safety, and Sustainability - Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2023*, pp. 564 - 572, American Society of Civil Engineers, Jan 2024.
The definitive version is available at https://doi.org/10.1061/9780784485248.068

# System Dynamics Modeling for Investigating the Retention of Skilled Labor in the Construction Market

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## ABSTRACT

Limited skilled labor has been one of the greatest challenges facing the construction industry, especially after COVID. In 2019, around 80% of contractors in the US reported problems in hiring enough skilled workers. Labor retention has been one of the major contributors to skilled labor shortages in construction. The goal of this paper is to study the impact of key construction industry characteristics and economic conditions on skilled labor shortages. This goal is achieved by simulating the flow of skilled workers throughout the construction industry. To this end, a system dynamics (SD) model was developed to represent skilled labor and analyze factors that impact their retention in the industry. After various validity and behavioral tests, the results of the SD simulation were shown to be consistent with the actual collected dataset. This proves the model's ability to portray the current status of the construction labor market, and thus test various scenarios including economic policies and labor retention regulations on the construction labor market level. This assists industry practitioners and government agencies gain insights into the reasons behind the current shortage of skilled labor in the construction industry and the economic conditions that impact the labor market dynamics in the industry.

## INTRODUCTION

Limited skilled labor has been one of the greatest challenges facing the construction industry. The industry began experiencing this shortage in the 1980s and has continued with a repetitive cyclic trend over the last four decades (Karimi et al. 2018). However, with the increase in the average age of the construction workers currently in the market and decrease in the rate of young skilled construction labor joining the industry, the construction sector is currently experiencing a skilled labor shortage that is at its highest levels this decade. In 2018, the Associated General Contractors of America (AGC) reported that 80% of general contractors have problems hiring enough skilled craft workers to match the level of demand (AGC 2022). One of the major contributors to skilled labor shortages in construction is the issue of labor retention. The construction industry is known for its deficiency in retaining skilled labor due to two major contributors. The first contributor is related to the arduous characteristics of the construction industry that might repel workers from joining or continue working in the industry. Such characteristics include low wages (Olsen et al. 2012), lack of training (Kashiwagi and Massner 2002), poor industry image (Castañeda et al. 2005), and nature of the work (Welfare et al. 2021).

The second contributor is related to factors external to the industry. One major external factor is the underlying economic conditions within which the industry is operating (Karimi et al. 2018). Previous literature that addressed skilled labor issues were mainly focused on the project level (Aiyetan and Das 2018; Abbaspour and Dabirian 2019). However, there still remains a need to conduct a comprehensive examination of the construction labor market as a whole in order to gain more generalizable insights. To that end, a holistic examination of skilled labor shortages should take into account factors that are innate within the industry on one hand, and external factors that affect the industry positively or negatively on the other.

Owing to the dynamic nature of the construction industry, the construction labor market is also dynamic, and thus its state changes over time. Moreover, it is viewed that the factors influencing the number of skilled labor entering, participating in, and exiting the construction industry are highly interdependent, where a change in one factor can impact others. Therefore, the modeling approach that is able to capture the relationships between these factors as well as their impact on the construction labor market over time is more suitable for examining the issue of skilled labor shortage. When adopted, System Dynamic (SD) modeling is able to capture the dynamic relationship between key characteristics of the construction labor market and the shortage of skilled labor in the construction industry. Further, SD allows for the integration of other factors that are external to the industry such as macroeconomic indicators that impact the labor market.

## GOAL AND OBJECTIVES

The goal of this paper is to study the impact of key construction industry characteristics and economic indicators on the shortages of skilled labor in the construction industry. This goal is achieved by modeling the construction labor market focusing on the flow of skilled workers throughout their career within the construction industry in order to understand the factors that influence their retention in the industry.

## SYSTEM DYNAMICS MODEL DEVELOPMENT

To achieve the goal of this paper, the authors developed a system dynamics (SD) model that simulates the interdependencies of the factors that lead to shortages of skilled labor in the construction labor market. This approach explores the complex cause and effect relationships associated with skilled labor shortage in the construction industry. The model focuses on the factors that impact the rate of retention of skilled labor within the industry. However, it also includes other parameters that emulate how construction workers enter, retire, get laid off, and get rehired in the market. These factors were identified based on a comprehensive literature review. Two types of relationships were used to link the factors to one another: hard relationships using mathematical equations and soft relationships using linear regression. Components in the SD model can be categorized as stocks, flows, dynamic variables, and constant parameters. Stocks include the inventory of the population. Flows are the rates of increase or decrease of the stocks. Dynamic variables are functions of stocks, other variables, and/or constants. Lastly, constant parameters are variables that witness changes during the simulation so minimal that they are considered constant. Fig. 1 illustrates the stock and flow diagram for the developed model. The SD model developed in this paper consists of a combination of three main systems: (1) construction labor market, (2) industry characteristics, and (3) key economic conditions. The details for each system are provided in the following sub-sections.

**Construction Labor Market System.** This system describes how the construction workforce flows throughout the labor market. It simulates the behavior of skilled workers from the point they finish their skill training and enter the market to the point where they retire working in the industry. As can be seen in Fig. 1, the system consists of three stocks: (1) Initial workforce size, (2) workforce size, and (3) experienced workers. Each stock represents the cumulative size of the construction workforce at a certain stage of the workers' careers. To connect these stocks, six flows were created to indicate the rate of increase/decrease in the stocks: entering market, labor retention rate, leaving rate, rehiring rate, and two retiring flows.

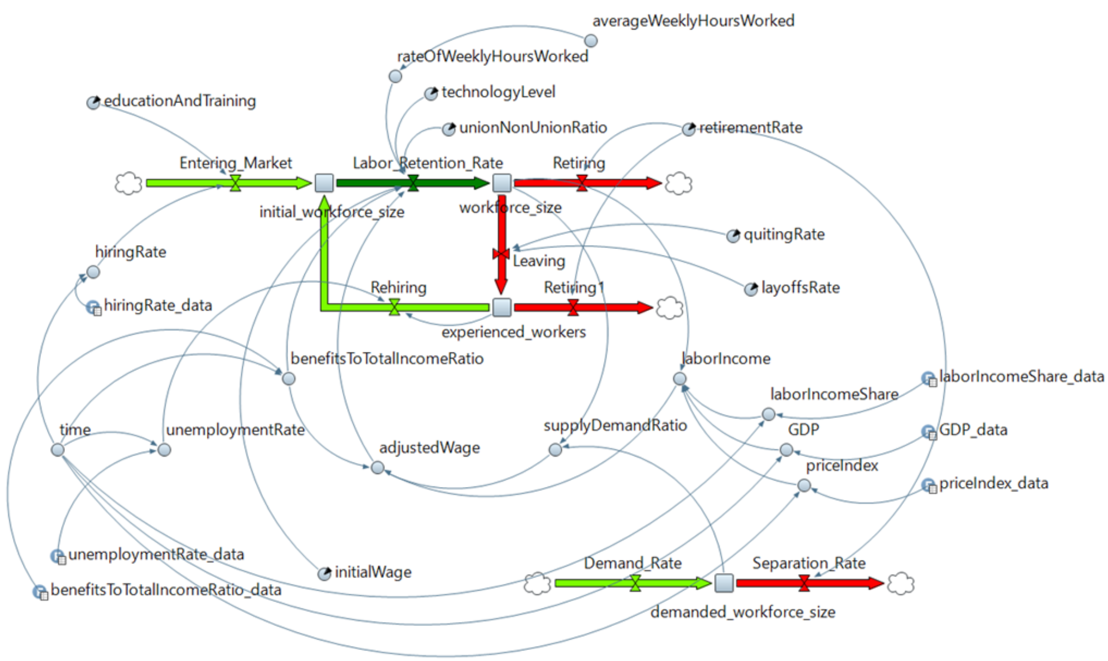


**Fig 1: Stock and flow diagram of system dynamics model for the construction labor market**

In the construction labor market system, the inflow of skilled labor is determined by newly trained workers. These workers enter the workforce (represented by the "initial workforce size" stock) when hired in accordance with the industry's hiring rate. Following, the "labor retention rate" describes the percentage of such workforce who decide to continue working in the industry. This rate is influenced by a number of industry and economic factors that are to be discussed in later subsections. A high labor retention rate reflects a healthy industry that aims to preserve skilled labor within the labor market. The higher the labor retention rate the higher the rate of increase in the workforce size. The "workforce size" stock corresponds to the number of skilled laborers who remain involved in the industry. Following, skilled workers in the "workforce size" stock population either retire or leave their jobs. Retiring workers exit the system of the model in accordance with the industry's retirement rate (Please refer to the Industry Characteristics System for further explanation). Workers who leave their jobs may also choose to retire later on. Otherwise, they can look for jobs and get rehired again. The "experienced workers" stock represents the population of workers "leaving" their jobs because they chose to quit or got laid off. The amount of experienced workers who are rehired is dependent on the construction industry's employment rate, and their quantity is accounted for in the "initial workforce size". Details regarding the SD elements created in this system are presented in Table 1.

**Industry Characteristics System.** The Construction labor market system described above needs inputs in order to be adjusted for different circumstances and scenarios. The industry characteristics system is a group of inputs related to the features of the construction industry that affect the conditions of skilled labor. The system focuses mainly on factors that impact the rate of retention of skilled labor within the industry. However, it also includes other parameters that determine the rate at which skilled construction workers enter, retire, get laid off, and get rehired in the market. Inputs in this system are listed and detailed in Table 2. The hiring rate is used in the SD model to represent the entry rate of newly trained workers into the construction workforce. As for the initial wage, benefits to total income ratio, technology level, union-nonunion ratio, and average weekly hours worked, they are used to formulate the "labor retention rate" using linear regression. The retirement rate of construction labor was used to define the rate of exiting the labor market in the SD model. The rate of leaving a job is the summation of the quitting rate and the layoffs rate. Lastly, the rate of rehiring experienced workers is represented by the industry's employment rate (1 – unemployment rate).

In addition to the inputs discussed above, the supply-demand ratio was used to represent the law of demand when applied to the construction labor market. According to the law of demand, when the demand for skilled workers surges above the supply, labor wages will increase. Similarly, when the supply of labor is higher than the demand, the wages will decrease (Ling et al. 2022). To capture the dynamic relationship between labor demand and wages, the authors modeled the construction industry demand for skilled labor using a second group of stock and flows. As can be seen at the bottom right corner of Fig. 1, the "demanded workforce size" stock increases by a yearly demand rate that was retrieved from the literature and decreases by a separation rate that is assumed to be equal to the retirement rate. Using the "workforce size" to represent labor supply and the "demanded workforce size" stock to represent labor demand, the "supply-demand ratio" variable was created in accordance with the equation provided in Table 2.

**Table 1. System elements, types, and equations of the construction labor market system**

| Element Name | Element Type | Inputs / Description |
|---|---|---|
| Entering Market | Flow | Entering Market ($\frac{unit}{year}$) = Education and Training ($\frac{unit}{year}$) X Hiring Rate ($\frac{unit}{year}$) |
| Initial Workforce Size | Stock | Initial Workforce Size *(unit)* = ∫ Rehiring ($\frac{unit}{year}$) + Entering Market ($\frac{unit}{year}$) - Labor Retention Rate ($\frac{unit}{year}$) . dt *(year)* |
| Labor Retention Rate | Flow | **Linear Regression.** input variables of the regression are: Technology Level, Initial Wage, Adjusted Wage, Benefits To Total Income Ratio, Rate of Weekly Hours Worked, Union Non Union Ratio. |
| Workforce Size | Stock | Workforce Size *(unit)* = ∫ Labor Retention Rate ($\frac{unit}{year}$) – Leaving ($\frac{unit}{year}$) – Retiring ($\frac{unit}{year}$) . dt *(year)* |
| Retiring | Flow | Retiring ($\frac{unit}{year}$) = Retirement Rate ($\frac{unit}{year}$) |
| Leaving | Flow | Leaving ($\frac{unit}{year}$) = Layoffs Rate ($\frac{unit}{year}$) + Quitting Rate ($\frac{unit}{year}$) |
| Experienced Workers | Stock | Experienced Workers *(unit)* = ∫ Leaving ($\frac{unit}{year}$) – Retiring 1 ($\frac{unit}{year}$) – Rehiring ($\frac{unit}{year}$) . dt *(year)* |
| Rehiring | Flow | Rehiring ($\frac{unit}{year}$) = IF (Experienced Workers > 1), (1 – Unemployment Rate), 0) |

**Table 2. System elements, types, and equations of the industry characteristics system**

| Element Name | Element Type | Inputs / Description |
|---|---|---|
| Unemployment Rate | Parameter | The number of unemployed workers as a percentage of the total construction labor force (BLS 2022). |
| Hiring Rate | Parameter | The number of newly hired workers as a percentage of the total construction labor force (BLS 2022). |
| Initial Wage | Parameter | The average total earnings of construction workers in a year, excluding benefits and other services (BLS 2022). |
| Benefits to Total Income Ratio | Parameter | The construction workers' total benefits as a percentage of the average total compensation (BLS 2022). |
| Retirement Rate | Parameter | The number of retired workers as a percentage of the total construction labor force in a given year (BLS 2022). |
| Quitting Rate | Parameter | The number of workers quitting their jobs as a percentage of the total construction labor force in a given year (BLS 2022). |
| Layoffs Rate | Parameter | The number of workers who got laid off as a percentage of the total construction labor force in a given year (BLS 2022). |
| Union- nonunion Ratio | Parameter | The number of workers belonging to unions as a percentage of the total construction labor force in a given year (BLS 2022). |
| Average Weekly Hours Worked | Parameter | The number of hours per week the average construction worker works in a given year (BLS 2022). |
| Rate of Weekly Hours Worked | Variable | Rate of Weekly Hours Worked *(%)* = 40 ($\frac{hours}{week}$) / Average Weekly Hours Worked ($\frac{hours}{week}$) |
| Demanded Workforce Size | Stock | Demanded Workforce Size *(unit)* = ∫ Demand Rate ($\frac{unit}{year}$) – Separation Rate ($\frac{unit}{year}$) . dt *(year)* |
| Demand Rate | Flow | Demand Rate ($\frac{unit}{year}$) = 0.027 ($\frac{unit}{year}$) |
| Separation Rate | Flow | Separation Rate ($\frac{unit}{year}$) = Retirement Rate ($\frac{unit}{year}$) |
| Supply Demand Ratio | Variable | Supply Demand Ratio = Workforce Size / Demanded Workforce Size |

**Table 3. System elements, types, and equations of the economic conditions system**

| Element Name | Element Type | Inputs / Description |
|---|---|---|
| GDP Construction | Parameter | The contribution of the construction industry to overall GDP of the U.S in a given year (BLS 2022). |
| Labor Income Share | Parameter | The part of the national output of the construction industry allocated to workers' wages as a percentage of the total construction industry output (GDP construction) (BLS 2022). |
| Labor Income | Variable | Labor Income *(USD)* = (GDP (*USD*) X Labor Income Share *(%)* X $\frac{1}{\text{Price Index}}$) / workforce_size *(unit)* |
| Consumer Price Index | Parameter | The relative price changes of a basket of goods and services over two consecutive years (BLS 2022). |
| Adjusted Wage | Variable | Adjusted Wage *(USD)* = (Labor Income *(USD)* - (Benefits to Total Income Ratio *(%)* X Labor Income *(USD)*)) X supply Demand Ratio *(%)* |

**Economic Conditions System. T**he economic conditions system depicts the influence of the state of the economy on the construction labor market operating within this economy. This is achieved through a set of inputs that represent key macroeconomic indicators related to labor wages. These indicators affect the construction industry and its ability to attract and retain workers through sustainable labor wages. Accordingly, the economic conditions system includes the variables listed and detailed in Table 3. GDP construction is a measure of the output of the construction industry in a given year. Labor income share is the percentage of GDP construction allocated to pay labor compensation. Labor income is the proportion of GDP that is given to labor as wages and social benefits transfers (Wei et al. 2012). It is the multiplication of GDP construction and labor income share. CPI measures the relative price changes of a basket of goods and services over two consecutive years (BLS 2022). It is one of the most widely used measures of inflation (Ashuri et al 2012). In this paper, CPI is used to enable the model to simulate the effect of inflation rates and price changes on labor wages. Lastly, adjusted wage is the average yearly wage received by a construction worker excluding benefits and services such as health insurance. It is worth noting that the adjusted wage is different from the initial wage parameter mentioned in the previous subsection. While both parameters have the same definition, the initial wage, in the industry characteristics system, is retrieved directly from data reported by the US Bureau of Labor Statistics. However, the adjusted wage is calculated based on labor income and supply-demand ratio, which is the variable that reflects the impact of labor supply and demand on workers' wages (as discussed in the previous subsection).

## MODEL INITIALIZATION AND SIMULATION

After considering all influential factors, the model was implemented in AnyLogic (edition 8.7.9), as demonstrated in Fig. 1. Following, data collection efforts commenced to set the initial values for the model's parameters and stocks. Three types of data were needed: data for the stocks in the construction labor market system, data for the parameters of the industry characteristics system, and data for the variables in the economic conditions system. In this paper, various sources were used for data collection, including the U.S. Bureau of Labor Statistics, and the U.S. Bureau of Economic Analysis. The model in this paper was trained using data on the country level.

## RESULTS AND ANALYSIS

Fig. 2 presents the results of the simulation of the SD model for skilled labor market. Due to data constraints, the simulation is limited to the period from 2004 to 2021. Fig. 2(a) shows the cumulative number of newly hired skilled labor, the number of skilled labor currently involved in the workforce, and the demanded labor at each year of the simulation. Fig. 2(b) demonstrates the number of experienced skilled workers who quit their jobs or got laid off by their employers. Lastly, Fig. 2(c) illustrates the rate of retention of skilled labor in the construction market.

The simulation results in Fig. 2 show that the size of the skilled labor workforce in construction witnessed a steady minute increase over the simulation period from 2004 to 2021. However, such increase is negligible compared to the slightly higher rate of increase in the size of the skilled workers newly entering the market. Labor demand can be seen to be almost constant over the simulation period, indicating that the construction industry required around 67 thousand skilled workers each year. The count of experienced skilled workers who get laid off or decide to leave their jobs decreases by less than 1% each year. Such a finding confirms the stability of the construction market in terms of the reduced probability of a worker quitting or being fired (Kim and Philips 2012). Labor retention rate was constant throughout the period from 2004 to 2009. Then, it started witnessing a fall following year five for approximately three years. This fall coincides with the global financial crisis of 2008, the consequences of which heavily impacted the construction industry and accordingly the construction labor market (Castelblanco et al. 2008).

Fig. 3(a) shows the results of the model for the workforce size, compared to the actual data of the workforce size from BLS. As shown, the workforce size calculated from the model is very close to the actual data. However, the population calculated can be seen to be more linear. This is because some of the parameters in the model such as retirement rate, quitting rate, layoffs rate, union- nonunion ratio, and average weekly hours worked are assumed to be constants, while in reality they are time-dependent. Fig. 3(b) shows the labor retention rate calculated by the model vs. the actual rate retrieved from BLS. Overall, the output of the model has a seasonality trend similar to that of the actual data, which indicates that the model is able to capture the general pattern of the data.

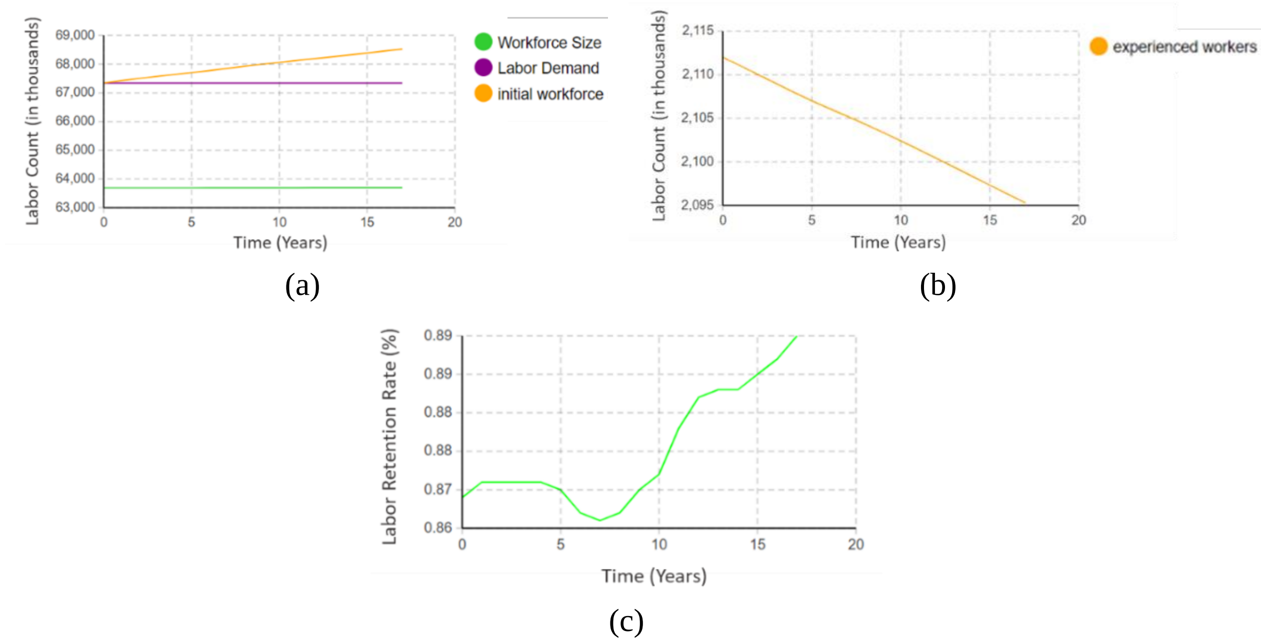


**Fig 2: Simulation results of the system dynamics model: (a) workforce size, labor demand, and initial workforce size over time, (b) experienced workers over time, and (c) labor retention rate over time.**

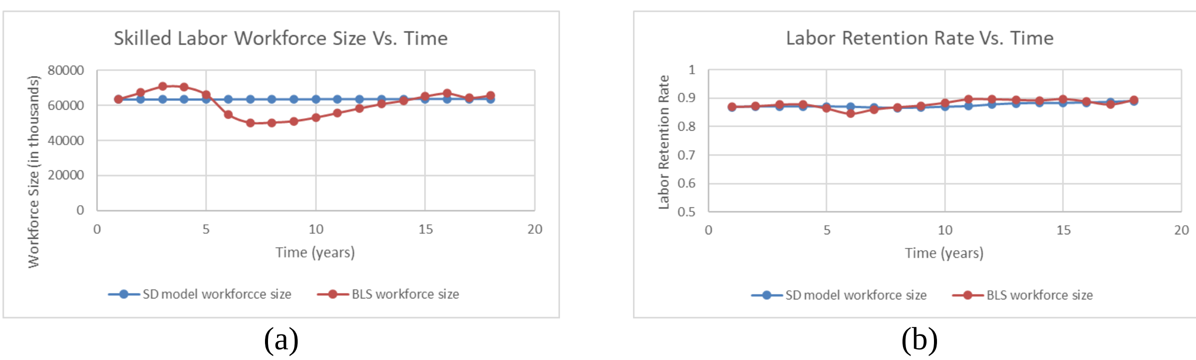


**Fig 3: (a) skilled labor workforce size: model output and actual data from BLS (BLS 2022); (b) Labor retention rate: model output and actual data from BLS (BLS 2022).**

To assess the behavioral validity of the SD model, a pattern verification test was conducted. This test compares the trends of the actual datasets with those provided by the results of running the model simulation. Figures 3 shows that the patterns of the actual data are consistent with those generated by the model for skilled labor workforce size and the labor retention rate.

## CONCLUSION, LIMITATIONS, AND FUTURE WORK

This research investigates the relationship between the characteristics of the construction labor market and skilled labor shortage in the construction industry. The value of the SD model developed in this paper relies on its integration of both macroeconomic indicators and construction-specific market factors that impact the retention of skilled labor within the industry. A pattern verification test showed that the results of the model are acceptably close to the actual results of the US construction labor market. This model can be used as a base model to test various scenarios including high-level economic policies and labor retention regulations that affect the construction skilled labor market. For instance, high-level economic policies such as infrastructure investments or subsidies could be simulated within the model to assess their potential influence on the availability of skilled labor in the construction industry. Similarly, labor retention regulations, such as training programs or enhanced worker benefits, can be tested within the model to evaluate their impact on skilled labor availability and retention rates. One limitation of the SD model developed in this paper is that the variables included in are mainly beyond the control of construction workers. However, the decision whether to join leave, or retire from the construction labor market can also be based on personal conditions as well as external factors. As such, future research work can further enhance the proposed model by considering variables that are related to the personal choices of construction workers such as: career goals, and location. Another current limitation that would be a valuable addition to the model is to consider factors related to competitive industries that may persuade construction workers to leave the construction workforce and switch to another sector.

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