

A Case Study Application of a Sankey Diagram to Workforce Migration Patterns in Construction and Engineering

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Abstract

Question: Can Sankey diagrams be used to identify relevant migrations in the workforce, specifically in construction and engineering?

Purpose: This paper explores the utility of Sankey diagrams in three approaches: First, provides a use case of Sankey diagrams in multiple disciplines, Second, identify uses in construction research, and finally, a case study of implementing Sankey diagrams in construction workforce migration research is provided.

Research Method: An existing database maintained by the U.S Bureau of Labor Statistics was used as the basis for identifying inflow rates, which represent workers hired, and outflow rates, which denote separation. Python and Jupyter were used to create the Sankey diagram for visualizing worker migration.

Findings: Using a case study, the Sankey diagram is shown to be an effective tool to demonstrate workforce separations, additions, and total workforce over time, making the Sankey an effective way to evaluate and visually represent longitudinal data.

Limitations: Intervention times may not be evident in the Sankey diagram provided, and other data, like gender or age, could help understand which populations leave and when. A comparison of construction dollars, more specifically, the cyclical nature of economic downturns like recessions, was not performed.

Implications: The leaky pipeline has long been used as a metaphor for migration in STEM education, and the Sankey diagram has been used to illustrate actual leaky pipelines. However, this is the first use of the Sankey to describe the migration of the

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construction and engineering workforce.

Value for authors: This paper illustrates how the Sankey diagram can be used to describe the change and migration of the workforce.

Keywords: Sankey Diagram, Construction Workforce, Engineering Workforce, Leaky Pipeline

Paper type: Case Study

Introduction and Background

The construction industry plays a critical role in global economic development, yet it faces persistent workforce shortages that threaten project timelines, productivity, and overall industry growth (Ginige et al. 2007, Ayodele et al. 2020). It is frequently posited that the construction industry adapts to change slowly (Christensen et al. 2019, Reinbold et al. 2025) and key performance indicators like satisfaction are underutilized, while budget and time are highly valued by contractors (Elfving & Seppänen 2022). Construction workforce shortages have become more pronounced in recent years due to several factors, including an aging workforce, high turnover rates, and declining interest among younger generations in pursuing construction careers (Greenberg et al. 2024). According to the Associated General Contractors of America (AGC), 85% of construction firms report open job positions, and 88% of those firms also report difficulty in filling craft positions, indicating an urgent need for an improved skilled labor development pipeline (AGC, 2023). Beyond the skilled labor force, the construction management workforce pipeline also merits a deeper analysis as these roles face many of the same workforce development challenges as the skilled-labor workforce, but are projected to grow at a “much faster than average” pace over the forthcoming decade (BLS 2025). As construction workforce gaps delay project completion, increase labor costs, and reduces overall efficiency, the need to investigate inefficiencies or “leaks” in the construction workforce development pipeline has been identified.

The “pipeline” metaphor is used to illustrate the flow of inputs and outputs of a system, whether it be an actual pipeline, e.g., aqueduct, (Lehrman 2018) or students moving in and out of an academic major (Loder 2024). The “leaky pipeline” metaphor has been used to describe the loss of under-represented minorities (URM) in STEM academic majors for over three decades (Pell 1996), with research continuing to the present (Saraswathiamma et al. 2010, Appelhans et al. 2019). Specifically, the leaky pipeline is effective at demonstrating differences in the magnitude at which different student groups “leak” out of an academic major or workforce development pipeline over time. However, the leaky pipeline metaphor may be lost in graphs and tables (Witteveen and Attewell 2020) or perceived as extremely linear without acknowledging movement (Malla et al. 2024). To facilitate movement visualization, Sankey diagrams are an effective tool to demonstrate the “leaky pipeline” effect. Sankey diagram examples in higher education include student flows into and out of psychology (Loder 2024) and migration into and out of an engineering major (Ebrahim Nejad et al. 2020).

While student migration has been studied (Appelhans et al. 2019, Loder 2024, Saraswathiamma et al. 2010), a related concern is the perceived shortage of engineers (Williams 2021, Archer 2025, RUSO 2025). This shortage is worsened by a bottleneck between degree attainment and professional practice. Valle et al. (2024), perhaps describe it best, identifying the relationship between licensed workers who meet the legal and safety requirements for high level oversight and the escalating industry demand.

Therefore, bridging this gap is essential if the pipeline produces graduates who do not transition into long-term construction roles, making the industry's capacity to scale remain limited. Efforts to address these shortages must include an enhanced focus on construction education, apprenticeship programs, and industry-academic partnerships to attract, train, and retain skilled workforce. This study explores the impact of workforce migration in the construction industry and discusses potential interventions as case study of using the Sankey Diagram in construction research and to identify locations to plug leaks in the pipelines.

Case of Sankey Diagrams in Other Disciplines

Sankey diagrams have been used to illustrate inflows and outflows of a system extensively, a well-known example of Napoleon's troop movements at Waterloo being one of the first (Minard 1869). While a brief search of existing literature may receive many "hits" or "instances," not all of these papers actually illustrate the diagram to which they refer in their abstracts (Rohde & Godwin 2019, Skurla & O'Neal 2021, Richardson & Knight 2024). Sankey diagrams have been used in a variety of industries, including healthcare (Mica et al. 2020), production and processes (Kampf & Hlatka 2019), and energy processes (Karaağaç et al. 2019).

A search was performed using online library resources and the American Society of Civil Engineers (ASCE) publications, which produced a small number of Sankey diagrams, indicating that their use in Civil Engineering is quite limited (ASCE 2024). There are examples of Sankey diagrams being used to describe inputs and outputs in civil engineering, like water systems (Curmi et al. 2013, Lehrman 2018). An appropriate use of the Sankey diagram of a water system would clearly illustrate inflows and outflows, size, location, and/or time. Other uses in civil engineering include building information technology and sustainability (Andriyani et al. 2024), project planning and scheduling (Sheikhhoshkar et al. 2023), effects of working from home (Zubair et al. 2024), and information management (Malla et al. 2024).

While Sankey diagrams are not new as graphical descriptors for visualizing flow, they are not always used appropriately (Kampf & Hlatka 2019, Richardson & Knight 2024, Rohde & Godwin 2019, Skurla & O'Neal 2021). Sankey diagrams are best suited for multiple inputs and outputs, which is why they are so effective in describing the movement of students (Lykkegaard and Ulriksen 2019, Burgoon et al. 2025) or the workforce. While identifying the where, when, and why of students changing majors, the same understanding is needed for the engineering workforce. Where, when, and why are engineering graduates leaving the workforce? A determination of when engineers typically leave the workforce will provide a timeline for interventions.

Precarity and Transitive Nature of Construction Work

Perceived workforce shortage is frequently a byproduct of the industry's inherent precarity, a localized lack of workers often reflects a failure of the labor market to connect transient human capital with fluctuating demand rather than a fundamental deficit in the overall labor pool. This misalignment underscores the transitive nature of the sector, where labor leakage is often a result of geographic instability rather than a lack of interest in the trade (Ayodele et al. 2020). Also, Williams (2021) suggests that the workforce leaves over time due to both employer and employee rationales. Mader states that anticipated infrastructure construction means 138,000 Plumbing-Heating-Cooling technicians are needed (2017). Business NH Magazine (2018) also presents a workforce

shortage in the construction industry, especially with craft workers. Both articles focus on the perception of the construction industry as a “dirty job” (Mader, 2017 and Business NH Magazine, 2018). However, a workforce shortage may not be entirely due to the perception of construction as a dirty job. There is also precarity in the workforce, where precarity is defined as contract employment, day labor, or having a lack of security and benefits (Jankowski, 2024). The precarious nature of changing projects, locations, and economic climate may also play into the construction workforce shortage.

Voluntary employee turnover has previously been identified as a factor in the U.K. construction workforce and can be partially explained by the “Unfolding Model of Voluntary Turnover” (UMVT) (Jones et al. 2010). While voluntary workforce reduction is based on the employee, their choice to leave may be due to a sudden change or “shock,” incompatibility with the employer, or “image violation,” (Jones et al. 2010), or involuntary workforce reductions (lay-offs or strategic firings), which cause the former feelings of shock and image violation (Williams 2021).

A correlation has been found in construction workers between perceived organizational injustice and psychological strain, or a negative result (Chih et al. 2017). The author stated that organizational injustice has an inverse correlation to worker commitment to the organization. Further ageism occurs in construction, causing higher levels of stress, anxiety, and depression in addition to effects on physical health (Kereri & Nyang’au 2024). In an industry where there is ever increasing demands for workforce, this is a deterrent to long-term employment. One of the problems plaguing the construction workforce is the high turnover rate (Ayodele et al. 2020). This turnover and losses due to retirement are continuing concerns in the construction industry (Assaad & El-adaway 2021, Ayodele et al. 2020).

Applying the Theory of Constraints (Goldratt & Cox 2004, Bloom 2024) to personnel, workforce is considered one of the greatest concerns in the construction industry (AGC 2025). However, it does not appear that the construction industry has evaluated their problem in retaining long-term employees. The idea of applying Lean principles to the hiring process is not new, as it has been applied in other industries (Johnson et al. 2018). To describe this loss of a valuable resource more appropriate to the language of Lean, it should be defined as waste, or creating no value (Mossman 2009, Sarhan et al. 2017). In the case of workforce loss, the specific wastes can be identified as effort, time, and money. Donarumo & Zandy (2019) identified the 8 wastes in construction as “DOWNTIME” D:Defects, O:Overproduction, W:Waiting, N:Non-Utilized Talent, T: Transportation, I: Inventory, M: Motion, and E:Excess.

The construction sector is wasting valuable resources due to precarity, the hiring and separation of employees. It is generally accepted that the cost to replace an employee is 1.5 - 2 times the annual salary of the employee (McFeely & Wigert 2019). While construction has been in long-term growth (Mosier et al. 2021). Figure 1 illustrates the overall construction workforce salary has been increasing during the period of interest (2013-2023) (USBLS 2025a). Using a standard work year in hours of 2,080 hours and the salary at the end of 2023 of \$46.50 per hour, the average annual salary is \$96,720. Therefore, the loss of one employee is approximately \$200,000.

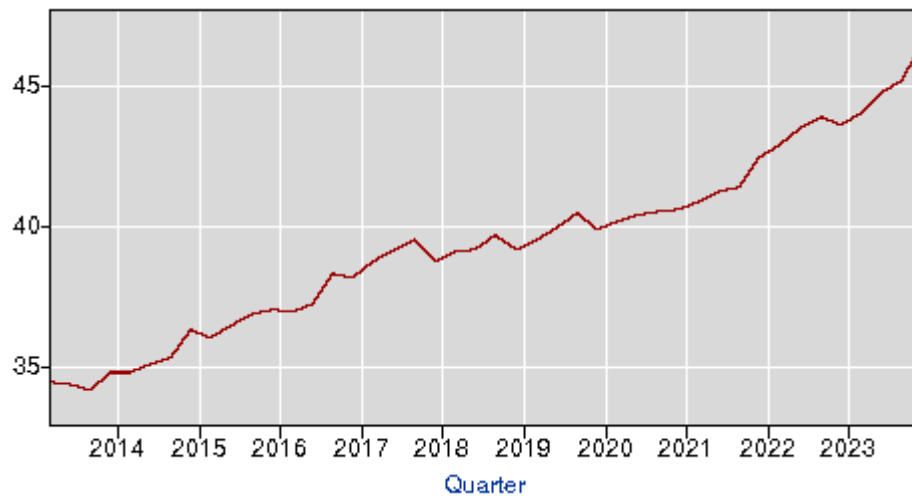


Figure 1. Construction Sector Salary in Dollars per Hour for Years 2013-2023 (USBLS 2025a)

Due to the high cost of employee turnover, this case study provides a method which can be applied for visual identification of magnitude of losses in the existing construction and engineering workforce through use of a Sankey diagram.

Methodology

To illustrate the inflows and outflows of employees in the construction sector, the official U.S Bureau of Labor Statistics (USBLS) database was used. The segment of the datasets used provided monthly, quarterly, and annual data on the current construction workforce size (employment), hiring, and separations from 2013 to 2023 (USBLS 2025b). The Sankey diagram can likewise be used to illustrate times when a greater number of the workforce enter or leave. It should be expected that in May-June, high school, career tech, and college graduates create an influx into the industry. There is a common business practice to fire during December, before the end of the year. Identifying the “when” of employee migration will allow the industry to identify when interventions should be made.

The USBLS provides data from a variety of surveys where information about employment, lay-offs, and hiring data are collected. Due to the USBLS (2025b) survey data series being collected from multiple sources (i.e. Current Employment Statistics, Current Population Survey, Job Openings, and Labor Turnover Survey), the data presented on the website can be inconsistent. The USBLS (2025b) database was filtered for “Construction,” then “Job Openings and Labor Turnover Survey,” “Rates of gross job gains and gross job losses,” and “Employment, Hours, and Earnings from the Current Employment Statistics Survey (National).”

The Sankey diagram creates a visualization of movement, to easily identify trends in employment migration. The data were transposed to create chronological columns of data. The data were then imported into Python and Jupyter to create the Sankey diagram. The visualization was created through the creation of a source or parent node and a target node. For transitions, an arc flows from the parent node to the target node. The sizes of the node and arc (e.g., width, height, thickness) represent the number of members within the node/arc, which then illustrates the magnitude of flow in any direction (Glover et al. 2022, Otto et al. 2022).

Overall, the data show the workforce has increased over time. However, the industry is still concerned over the lack of workforce (Mader 2017, Business NH Magazine 2018). When comparing the new hires to losses, the USBLS data show more new hires than losses (Table 1). However, based on identified need, it is evident that the new hires do not provide a replacement for the workforce leaving the construction sector.

Table 1: Transposed USBLS (2025b) Datasets

Year	Hires	Employment*	Separations / Losses
2013	3933	5,932,000	3703
2014	3716	6,293,000	3410
2015	3982	6,630,000	3645
2016	4059	6,818,000	3922
2017	4597	7,091,000	4276
2018	4530	7,396,000	4217
2019	4986	7,527,000	4873
2020	4970	7,357,000	4988
2021	4361	7,601,000	4162
2022	4422	7,892,000	4133
2023	4459	8,099,000	4207

*Employment data was initially presented in 1,000s, therefore rounding errors are inherent.

Sankey Diagram

The Sankey Diagram in Figure 2 shows the construction workers hired, employed, and separated each year between 2013 and 2023. It should be noted apart from 2019-20, there were no identified US recessions or economic downturns during this time span. The numeric Values shown represent thousands of people. For example, in 2023, there were 8,099,000 workers employed in the construction industry and 4,207,000 workers separated from their companies the same year, representing 52% of the workforce. This Sankey Diagram easily showcases the significant number of construction workers switching jobs each year. As the USBLS data has been aggregated, it is not possible to determine if these workers who separated each year re-entered the workforce in construction. However, if data were available, that information could be easily added to the Sankey Diagram to better understand the construction force employment flow.

It can be observed that each year shown in the Sankey Diagram, there has been an increase in the workers hired, workers employed, and workers separated. In this case, the Sankey diagram (Figure 2) illustrates the employment data in numbers of thousands, or for year 2013, the value is shown as 5,932 where the value is actually 5,932,000. Further, the totals are not accumulated in this diagram.

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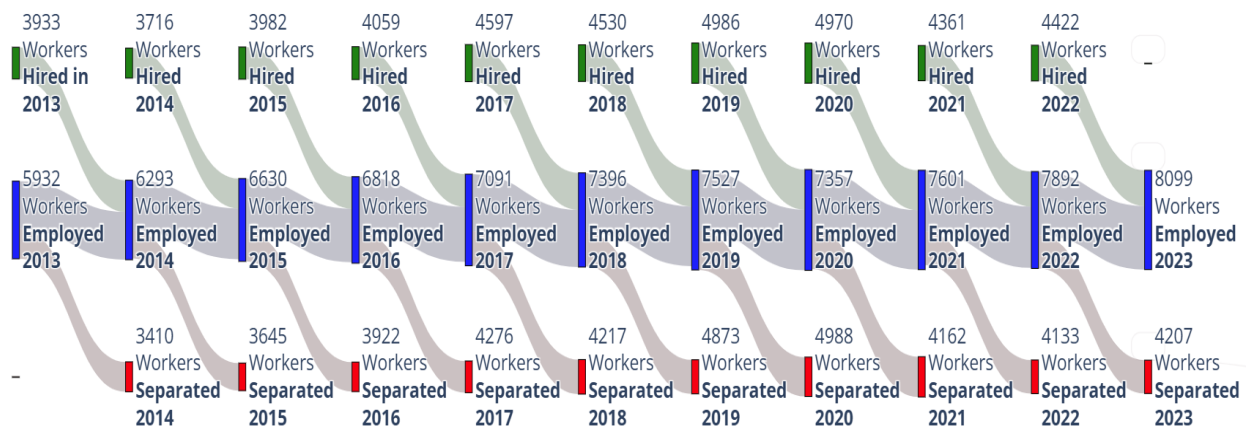


Figure 2. Sankey Diagram Construction Worker Migration 2013-2023

Alternatively, the Sankey diagram can express the data in thousands, as it was presented in Table 1. In this case (Figure 3), the data was accumulated, showing the change in workforce over time. What is most succinctly expressed is the change in the workforce over time. Although the total workforce has annual increases, the cumulative overall turnover indicates separations can be visualized at a substantial rate. The Sankey diagram illustrates the need to limit these separations. While the Sankey diagram illustrates the need to reduce separation, it is also worth noting that the construction industry experiences high voluntary turnover due to the nature of contract work with limited durations (Jankowski 2024). Even so, interventions are likely worth exploring.

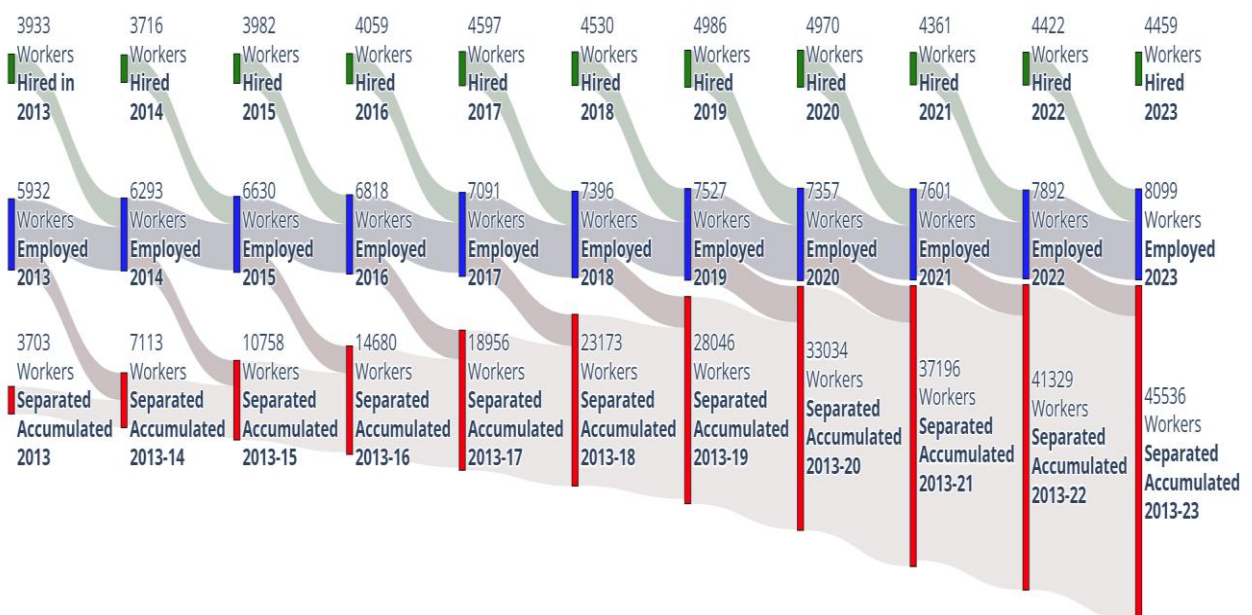


Figure 3. Sankey Diagram Construction Worker with Accumulation 2013-2023

Results

This study demonstrated a single instance where the utilization of Sankey Diagrams could be a useful visualization tool for assessing workforce migration patterns. However,

the potential benefits of Sankey Diagrams in workforce migration patterns are numerous, and additional applications will be discussed in this section.

While this case study utilized macro (national level) data to demonstrate the utility of Sankey Diagrams in reporting workforce trends, the same tool could be utilized at an organizational or regional level to explore longitudinal workforce trends and to identify factors that may be correlated with high employment turnover. For example, at an organizational level, Sankey diagrams could be a valuable tool for visualizing various human resource-related factors, such as when employees leave the organization or if turnover rates vary by region, job role (superintendent, project manager, or foreman), or demographic factors (gender, age, parental status). By exploring and comparing employment retention trends across these factors, organizations can quickly identify disparate turnover outcomes in specific positions or groups. The Sankey diagram (Figure 3) clearly illustrates the revolving door of turnover in construction, a trend often associated with low job satisfaction, which is frequently correlated with money (Jones et al. 2010). In fields where employees are in great demand, a job offer is not needed for an employee to choose to leave their current employer (Jones et al. 2010). Using the accumulated value of employee losses of 45,536,000 (Figure 3), the total cost to the construction industry can be approximated at \$9 trillion over the ten-year period.

By visualizing trends in turnover patterns, organizations can utilize this information to pinpoint potential underlying causes and explore interventions intended to reduce employee turnover, such as increased training, targeted compensation, or career progression opportunities. Furthermore, in addition to identifying the magnitude and timeframe in which employment turnover occurs, Sankey Diagrams can also be utilized to identify the effectiveness of targeted employment interventions after implementation. For example, if individuals leave an organization at a much higher than normal rate in the years typically associated with childbirth, interventions focused on parental leave or reducing stigma related to “long-hour culture” could be implemented and evaluated as a means of supporting employee retention. Or, for example, if foremen begin to leave an organization at a disproportionately higher rate after the five-year mark, training programs designed to support career progression to new roles (e.g., superintendent) or expanded opportunities within their existing role could be explored and evaluated. As such, Sankey Diagrams can be a valuable visualization tool for understanding the effectiveness of pre and post-employment intervention.

In addition to the employed workforce, Sankey Diagrams could be beneficial in exploring the professional construction management pipeline beginning in higher education and continuing into industry. For example, if women who enroll in construction education programs leave their CM program at a disproportional rate as compared to men during their first two years of enrollment, targeted interventions such as mentorship programs could be evaluated through Sankey Diagrams. By utilizing an intuitive visualization tool such as a Sankey Diagram to represent the professional construction pipeline, stakeholders from various backgrounds (HR, C-Suite, Educators, etc.) can jointly identify trends and patterns and where interventions may be merited (or effective) in supporting the construction workforce pipeline.

Conclusions

The Sankey diagram is not a novel approach to illustrating the movements of people. However, it has not previously been used to illustrate the movement of the workforce,



making this a novel use. The ability to visualize the movement of employees into and out of the workforce using the Sankey diagram is a novel solution to an existing problem. Over the last 10 years, the construction workforce has increased; however, the construction industry continues to have concerns over the lack of workforce (Mader, 2017, Business NH Magazine 2018). The increase in workforce is related to population growth and construction dollars during the same time. If the workforce has increased over time, then is there a real workforce shortage? The workforce shortage may be more about how we treat our employees and workforce satisfaction as compared to the available workforce (Chih et al. 2017, Jones et al. 2010). While identifying intervention times may not be evident in this diagram, more specific data may elucidate optimal time periods for interventions. From a Lean perspective, the construction industry should be re-oriented to consider employee losses as waste.

This Sankey diagram is an effective tool to demonstrate workforce separations, additions, and total workforce over time, making the Sankey an effective way to evaluate and visually represent longitudinal data. While the USBLS (2025b) was used as a basis for the Sankey diagram, the diagram cannot provide a direct correlation due to the USBLS collection methodologies. Further, the Sankey diagram highlights data that otherwise would be masked. The purpose of this case study was to provide a demonstration of how the Sankey diagram could be used to describe the leaky pipeline and as a visualization method which allows identification of the accumulated turnover rate. By identifying areas of concern, interventions can be tailored to specific problems. While the focus has frequently been on attracting more employees to construction, it is also important to determine if voluntary employee separations remain in the industry or whether there is a long-term loss of workforce participants to other industries. It should be noted that the industry was in growth for the entire period of interest, which would correlate with a need for workforce.

This methodology should be applied in Workforce Development and Human Resource concerns, such as employee turnover and migration, which are otherwise not easily identifiable in a table or traditional reporting formats. The Sankey diagram also allows the reader to easily identify the trends described. Further, the waste due to loss of workforce should be identified in effort, time, and money, which is costing the industry on average \$200,000 per replacement.

Practical Applications

The leaky pipeline has long been used as a metaphor for migration in STEM education. The Sankey diagram is also used to illustrate actual leaky pipelines like the California water system (Curmi et al. 2013, Lehrman 2018). However, the Sankey diagram has not yet been used to describe the migration of the workforce. This is one more application which is appropriate to civil engineering, the construction workforce, and any workforce facing precarity. The tool presented and the diagrams highlight employee turnover rates as a potential cause of the workforce problems in construction. Further, real costs to the construction industry are identified.

Next Steps

While identifying intervention times may not be evident in the Sankey diagram provided, additional and more specific data is required to predict interventions. Additional data, like gender, age, and minority classification to compare with the overall data would help understand which populations leave and when. Additionally, a comparison of

construction dollars, more specifically the cyclical nature of economic downturns like recessions would be appropriate. It is important to determine where the construction workforce goes in times of economic downturn and if they return.

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