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Labor-Driven Analysis of the Economic Impact of Robotics-Based Manufacturing on Industrialized Construction

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ABSTRACT: Industrialized construction (IC) seeks to leverage advanced manufacturing technologies in order to boost construction time and cost savings. However, these savings vary significantly according to the labor market, job conditions, and technology production factors. The uncertainty surrounding the integration of state-of-the-art technologies, specifically industrial robotics, impedes their widespread adoption in the offsite manufacturing of IC. Therefore, the present study seeks to develop a framework to evaluate the labor-driven economic impact of robotics-based manufacturing on IC projects. The proposed framework estimates cost savings of robotics-based manufacturing at the project, organization, and industry levels. The production-driven framework addresses the task-specific manufacturing savings at a project level and the market-driven framework estimates the average cost overrun savings at organization and industry levels. Through the utilization of these frameworks in a multi-family apartment case study, it was found that the impact of the high upfront cost of manufacturing robotics on labor-driven savings varies significantly based on transition time and construction labor market state. This labor-driven analysis will contribute to establishing economic guidelines that clarify the economic impact of the integration of robotics-based manufacturing in IC, thereby promoting their widespread implementation in construction firms.
Keywords: Robotics, Productivity Analysis, Market-Driven Analysis, Offsite Manufacturing, Industrialized Construction.

1. INTRODUCTION

Robotics and automation are established fields in the manufacturing industries that have just started to flourish in the construction industry. Similar to the industrial revolution, the rapid development and widespread implementation of robotics will likely change the commercial and industrial landscape in the near future. Modern robotics combined with modern information technology allows for a paradigm shift within the industrial sector, with new strategies and workflows fully supplanting older ones (Tehrani et al., 2024). This technological revolution has been long coming in the construction industry which is known for resisting innovation and lagging technical progress (Alwisy et al., 2018; Regona et al., 2022).

The cost-effectiveness of robots, compared to manual labor, is influenced by both direct savings from reduced operational costs and indirect savings from improved accuracy and efficiency. The yearly cost of operating and maintaining a robot is significantly lower than the average salary of the workers it can replace (Chea et al., 2020). Automated labor is more precise than manual labor, leading to fewer reworks, fewer materials overall usage, and lower costs (Pan et al., 2018). These time and cost savings are more evident when automating complex tasks, as the precision and repeatability of advanced technologies, such as robots, enable them to assemble complex structures in ways that are both faster and more efficient than human workers (García de Soto et al., 2018). Furthermore, robots can perform tasks that would be unpleasant or dangerous for human workers, increasing the safety and job satisfaction of workers while completing the tasks more cost-effectively and often faster than human workers (M. Tehrani & Alwisy, 2023). The combination of these factors can potentially lead to an increase in the long-term profitability of construction companies that implement advanced automation technologies, such as robotics.

Additionally, the transition from manual to automated or semi-automated tasks inherently includes the reorganization of roles and changes in the number of workers needed for a job (Hatoum & Nassereddine, 2020). This reorganizational change can be advantageous to the construction industry which still struggles with a variety of problems related to the manual, labor-intensive nature of construction tasks (Abdel-Hamid & Mohamed Abdelhaleem, 2020). The skilled labor shortage has been one of the leading issues of cost and time escalations in the construction industry for over a decade, with 80% of general contractors reporting difficulties hiring enough skilled workers (Kim et al., 2020). A lack of skilled labor on a job site has cascading impacts, including lower productivity, frequent safety incidents, schedule overrun, and lower quality of end-products (i.e., buildings) (Karimi et al., 2018). Modern construction robots can fill the roles of skilled workers in a wide array of tasks, making it easier for construction companies to fulfill their demand for skilled workers and increase their productivity.

To take advantage of these benefits, this research promotes the shift towards robotics-based manufacturing in IC by conducting a labor-driven analysis of their economic impacts.

2. LITERATURE REVIEW

While some prior research has been conducted investigating the labor-driven impact of automation, this study will approach the issue of transition from a unique angle that quantitatively evaluates the economic impact of robotics-based automation on construction labor at different levels (project, organization, and industry levels) and proposes guidelines for the transition time that maximize the proposed cost savings.

A study by Chui investigated the ability of task automation to meet the labor shortage in construction. This study evaluated current labor impacts from automation and used them to extrapolate future impacts. However, that study approached the issue of automation's impact on labor from a general SWOT analysis angle that focused on the long-term impacts of full implementation of automation technologies in the future rather than the current transition process from manual to automated labor. Their study also focused more on industry impacts than impacts on a company level (Chui, 2020). Hossain et. Al. (2020) provided a detailed comparison between the traditional construction process and 3D printing in construction, along with a description of the automated methods followed during different construction tasks. However, their economic analysis of the impact of 3D printing on the labor market was limited to a high-level discussion of the potential benefits and organizational structure and workflow without quantifying the economic impact of construction automation (Hossain et al., 2020).

While the previously mentioned papers highlight the existing research focus on analyzing the transition to automated tasks in construction from various perspectives, they underscore the dearth of studies addressing the labor-driven economic implications of robotic integration in the construction industry at different levels. Additionally, none of those studies discussed the ideal time to start this transition in the context of profit and labor. Existing research only presented frameworks and guidelines to manage the transition from manual to automated tasks without providing any guidance on what conditions could cause a company to start this transition or how to identify those conditions. It is simply assumed that the transition to robotics is inevitable and that companies will handle the implications as they arise.

To address these shortcomings, this paper introduces a framework evaluating the labor-driven economic impact of the transition to robotics-based automation in construction, focusing on robotics-based manufacturing in IC. The project's two primary objectives are:

1- To develop a data-driven economic framework that estimates the production-driven and market-driven financial impacts of transition.
2- To provide guidelines for determining the optimal transition time for robotics-based manufacturing automation in IC considering project size and labor market status.

3. RESEARCH METHODOLOGY

Cost savings realized from the deployment of robots stem from the potential increase in productivity and reduction in dependency on labor. These robotics-based savings can vary according to the transition time that is influenced by the labor market state in terms of labor surplus/shortage. As such, this research paper introduces a data-driven economic framework to estimate cost savings realized from the integration of robotics-based manufacturing into IC projects at project, organization, and industry levels. Figure 1 shows the proposed methodology.

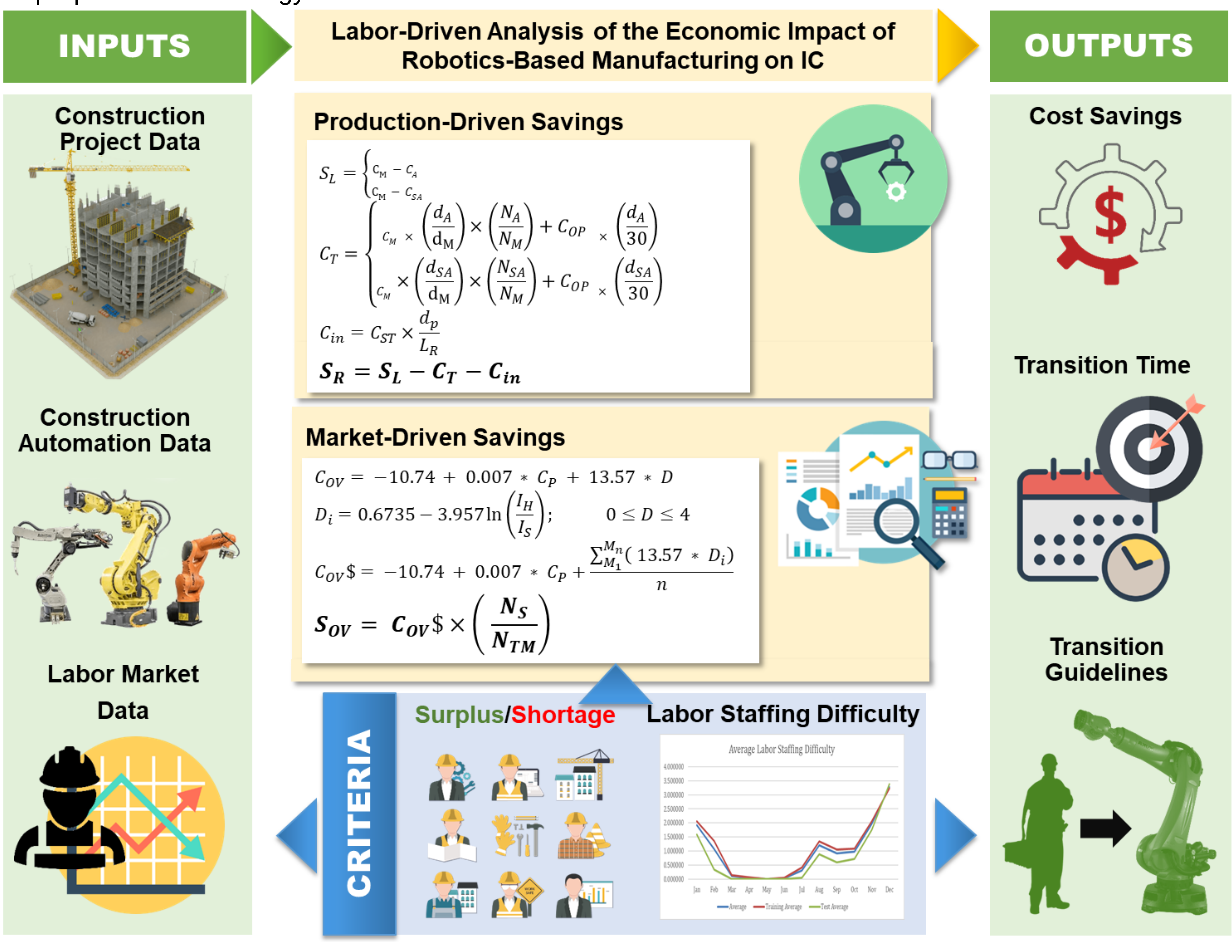

Figure 1: Research Methodology

The *production-driven cost savings* at a project level include labor-driven cost and time savings realized from the integration of robotics at different levels, corresponding to the number of manual, offsite manufacturing tasks transited into automated ones. To accurately estimate the economic impact of the different levels of automation transition, the proposed task-specific cost comparison utilizes construction project data for manual tasks and construction automation data for robotics-based automated manufacturing tasks. The *market-driven cost overrun savings* are then estimated at organization and industry levels using labor market data that reflects the company and construction market state in terms of labor surplus and shortage. These savings express the role of robotics in lessening the economic impact of labor staffing difficulties by helping the construction industry transition a number of labor-intensive, manual manufacturing tasks into automated ones. Furthermore, the value of cost savings will advise construction professionals on the right time to make the transition. For instance, a negative cost-saving value can result from a surplus labor market status, and, or a high upfront cost of robots that outweighs the cost savings of specific automated tasks. Therefore, the proposed framework would be used to recommend a different transition time with different labor market states or a larger scope of automated manufacturing tasks.

3.1 Production-Driven Savings of Construction Robotics

The manufacturing tasks in IC are often manual and employ the same procedures and tools as traditional construction, effectively representing "traditional construction under a roof." Therefore, the proposed production-driven model that focuses on task-specific cost savings utilizes a commercially available database, RSMeans ®, to estimate the baseline information of manual offsite manufacturing tasks of IC due to its (Tehrani et al., 2022). Labor cost data, crew sizes, and productivity rate values necessary to calculate the cost and duration of manual construction tasks can be obtained from the RSMeans database. However, due to the lack of data sources for construction robotics, the cost and duration of automated tasks will be estimated using suitable simulation environments, such as ABB RobotStudio ® Suite.

3.1.1 Labor-related savings

The labor-related savings, measured in U.S. Dollars (USD), due to using a robotic station in offsite manufacturing instead of human laborers (S_L) can be defined as the difference between the operational costs of a robotic station and human workers performing the same task, as shown in Equation 1.

$$[1]\ S_L = \begin{cases} C_M - C_A & Automated\ Task \\ C_M - C_{SA} & Semi-Automated\ Task \end{cases}$$

Where S_L is the estimated saving of automated or semi-automated tasks (Dollars), C_M is the cost of an offsite manufacturing task when conducted manually by human workers (Dollars), and C_A, C_{SA} are the cost of the same construction task when automated or semi-automated by a robotic station (Dollars).

These labor-driven savings will utilize labor cost data over three distinct time units (hourly, monthly, and annually). The hourly rates will provide the level of detail necessary for the production-driven model to estimate direct cost savings realized from the shift toward robotics-based automation in specific tasks. The monthly and annual labor cost data, on the other hand, will support the proposed economic model for market-driven savings by representing the economic impact of the monthly and annual fluctuations in labor staffing difficulties. As such, the monthly time range—duration—of a construction project can be accounted for, leading to a projected labor cost that accounts for the seasonality in the construction industry (Hoła et al., 2022).

3.1.2 Temporal costs

The proposed temporal cost accounts for the time-related saving adjustments to the labor-related savings resulting from the integration of robotics-based manufacturing at different automation levels, namely semi-automated tasks. The duration of fully automated tasks is mainly governed by the speed of robot teams (i.e., industrial robotic arms in a manufacturing station). Human workers' roles in these automated tasks are limited to the preparation work that includes material supply, action initiations, project setups, maintenance, and troubleshooting. Thus, the temporal costs of automated tasks account for the supportive human tasks necessary for task-specific setup and retaining. Semi-automated tasks, on the other hand, involve human teams working alongside robot teams, and their costs and durations usually increase compared to automated tasks accounting for the speed and cost of both teams. The proposed temporal cost of automated and semi-automated tasks (C_T) will account for the costs of the supportive human teams. Equation 2 is used to estimate the temporal costs of automated or semi-automated tasks can be formulated as follows:

$$[2]\ C_T = \begin{cases} C_M \times \left(\frac{d_A}{d_M}\right) \times \left(\frac{N_A}{N_M}\right) + C_{OP} \times \left(\frac{d_A}{30}\right) & Automated\ Tasks \\ C_M \times \left(\frac{d_{SA}}{d_M}\right) \times \left(\frac{N_{SA}}{N_M}\right) + C_{OP} \times \left(\frac{d_{SA}}{30}\right) & Semi-Automated\ Tasks \end{cases}$$

Where $d_A, d_{SA}\ d_M$ are the durations of the same task when fully automated, semi-automated, or manual (Days); N_M, N_A, N_{SA} are the crew size of human workers conducting manual, automated, and semi-automated tasks; C_{OP} is the operational cost for the robotic station including power and maintenance costs ($/Month).

It should be noted that this equation uses the average manual crew salary for temporal cost calculations, without accounting for salary variations between workers performing automated or semi-automated tasks with robotic manufacturing stations. Future research will address the impact of skill level and resulting salary differences on temporal cost. The equation also assumes no added cost for generating manufacturing strategies beyond existing design costs, due to readily available automated design-to-manufacturing software (including the author's patent-pending tool) bundled with such equipment.

3.1.3 Investment cost

The investment cost (C_{in}) accounts for the average lifespan of a robotic station, project duration, and initial setup cost including all hard and soft components required for the proper functioning of a robotic station. As such, the proposed project-based investment cost for automated and semi-automated can be calculated as per equation 3.

[3] $C_{in} = \frac{C_{ST}}{\mathrm{L_R} \times n_p}$

Where C_{ST} is the setup cost of a robotic station (in Dollars), L_R is the lifespan of a robotic station (in years), and n_p represents the annual number of projects that utilize the robotic station.

3.1.4 Production-driven saving calculations

Based on Equations 1, 2, and 3, the total production-driven savings (S_R) can be expressed as Equation 4 shows.

[4] $S_R = S_L - C_T - C_{in}$

3.2 Market-Driven Savings of Construction Robotics

The proposed market-driven model leverages labor market data to estimate average cost overrun savings at both organizational and industry levels. By considering automation levels and their impact on construction workers, we employ Karimi et al.'s (2018) empirical equation to estimate cost overruns based on staffing difficulty (Karimi et al., 2018). This approach accounts for the influence of labor market conditions, such as surpluses or shortages, on project costs as illustrated in Equation 5.

[5] $C_{OV} = -10.74 + 0.007 * C_P + 13.57 * D$

Where C_{OV} is the average cost overrun, C_P is the actual construction project cost, and *D* is the labor staffing difficulty of a construction project.

3.2.1 Labor staffing difficulties formula

The labor staffing difficulty values for new construction projects can be assessed using the construction labor data from the U.S. Bureau of Labor Statistics. The Bureau of Labor Statistics has data available for monthly separations and monthly hires in the construction industry in the United States. By creating a ratio of monthly hires to monthly separations, the status of the construction labor market can be quantitively estimated, with a labor market index of ***greater than one*** indicating a labor surplus and a value ***less than one*** indicating a labor shortage (Kroft et al., 2020).

By using the same timeframe for labor market indices as the original dataset used by Karimi et al., the estimated staffing difficulty values, converted from the labor market index values derived from the Bureau of Labor Statistics, can be used to calculate cost overruns. Equation 6 presents an empirical equation for staffing difficulty values. This equation was derived from a logarithmic regression analysis of labor market index values for completed construction projects between 2001 and 2014.

[6] $D_i = 0.6735 - 3.957 \ln\left(\frac{I_H}{I_S}\right); \qquad 0 \leq D \leq 4$

Where D_i the monthly labor staffing difficulty for i month, I_H is the total hires in the construction industry for study months (000's of workers), and I_S is the total separations in the construction industry for the study month (000's of workers). The generated D_i values were bound within the range of [0,4] and can be used to predict project cost overrun by using them in Equation 5.

3.2.2 Market analysis of labor staffing difficulties

The labor supply can be in a surplus, equilibrium, or shortage. In a surplus state, workers are plentiful, and wages tend to be lower. In a shortage state, there are not as many workers or people seeking work, and wages tend to be higher. At equilibrium, there is a balance between workers and wages. Due to the nature of labor markets, the supply of labor rarely remains at equilibrium, and the labor market can always be assumed to be at a certain level of surplus or shortage.

Given that the original study's staffing difficulty values were based on real projects from 2001 to 2014, it's reasonable to assume that the highest staffing difficulty occurred during periods of significant labor shortages, while no difficulty was encountered during labor surpluses. This aligns with Kroft et al.'s (2020) findings, which suggest that labor market surpluses should not impose staffing difficulties (Kroft et al., 2020). Consequently, equation 5 was then applied to every labor market index value to create a staffing difficulty value using the historic monthly data. The Shapiro-Wilk test of the generated staffing difficulty values showed a significant departure from normality, with W(168) = .854, p < .001.

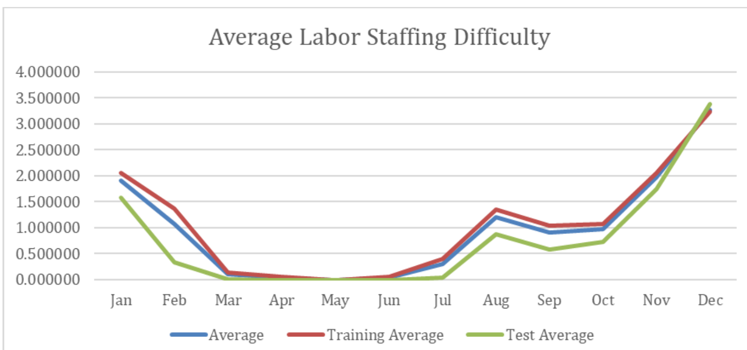

Figure 2: Average Labor Staffing Difficulty Over the Course of a Year

3.2.3 Market-driven saving calculations

Using the average monthly labor staffing difficulty values over the timeline of a construction project and the actual construction cost, the average cost overrun can be estimated according to current labor market conditions (i.e., manual tasks with no automation) on *an industry level*, as per equation 7.

[7] $C_{OV}\$ = -10.74 + 0.007 * C_P + \frac{\sum_{M_1}^{M_n}(13.57 * D_i)}{n}$

Where $C_{OV}\$$ is the average cost overrun of a construction project (in Dollars); C_P is the actual construction project cost (in Dollars); D_i is the labor staffing difficulty in Month I; M_1 is the first month of the automated task; M_n is the last month of the automated task; *n* is the total number of months of the automated task.

Using this equation along with industry-wide labor market information, the cost overrun savings from the implementation of robotics-based automation can be estimated based on the number of human workers substituted by the robotic station. As such, the ratio between the original total number of human workers in all the manual tasks and the total number of human workers substituted in the automated or semi-automated tasks will be used to reduce the original average cost overrun. This reduction in average cost overruns represents the cost savings realized by lessening the impact of labor staffing difficulties, as illustrated in equation 8.

[8] $S_{OV} = C_{OV}\$ \times \left(\frac{N_S}{N_{TM}}\right)$

Where S_{OV} is the estimated cost overrun savings (in Dollars); N_{TM} is the total number of workers in all the manual tasks of a project; N_S is the number of workers substituted by automated and semi-automated tasks. This new cost savings value is then subtracted from the original cost value, resulting in the predicted level of savings that implementing automated tasks would create. It should be noted that in situations where the market index value is equal to or greater than one and the corresponding calculated labor staffing difficulty value is equal to zero, there will be no cost overrun savings (i.e., $S_{OV} = 0$). This is because when there is no labor shortage and no labor market-driven cost overrun.

4. CASE STUDY

This case study showcases the potential cost savings realized by the transition towards robotics using the Comfort Residence Complex project, a 15-unit apartment building. The construction cost and time for the baseline, manual construction tasks are calculated using RSMeans®, and the labor market data for the market-driven analysis begins in June 2016, at the start of the framing phase. Finally, the robotics-based automation data is collected for prefabricated wood framing tasks, using simulated robotic productivity data in ABB RobotStudio ® Suite composed of two ABB IRB 6620 robots capable of conducting the framing and sheathing tasks for panelized construction.

The manual tasks transited into automated ones in this case study are two wall framing tasks, (1) a fully automated task for wall framing using wood studs with one human worker responsible for the task-specific setup and retaining of the framing robotic station, and (2) a semi-automated task for wall sheathing using oriented strand board (OSB) panels, with two human workers, one responsible for the task-specific setup and retaining of the sheathing robotic station, and the other conducting a collaborative subtask, namely the cutting of opening the openings. The framing materials include 2” x 4” x 8’ studs 24” on center (O.C.) for non-load bearing wall, 2” x 6” x 8’ studs 16” O.C. load bearing walls, and 5/8” 4’x8’ OSB sheathing panel using pneumatic nails. The building has ***1,146’ - 6”*** linear feet of load-bearing walls and ***2850’- 4”*** of non-load-bearing walls for the entire project.

4.1 Production-Driven Savings

The production-driven savings, calculated using equations 2, 3, and 4 (see Table 1), totaled -$1,393 for the specified project scope and tasks. This negative figure indicates that the implementation of robotics in this specific case study would result in a net cost increase. The primary factors contributing to this outcome include the substantial upfront investment in robotic systems and the conservative assumption of using the robotic workstation solely for this particular project in the first year of robotic implementation.

Table 1: Case study values for equations 2, 3, and 4

Equation		**Description**	**Unit**	**Load bearing**	**Non-Load bearing**	**Sheathing**
Eq. 2	C_M	Manual Task Cost	Dollar	$23,888	$42,760	$28,316
	d_A	Automated Task Duration	Day	2.39	5.94	-
	d_{SA}	Semi-Automated Duration	Day	-	-	7.39
	d_M	Manual Task Duration	Day	12.74	22.80	15.10
	N_A	No. Supportive Workers	Worker	1	1	
	N_{SA}	No. Collaborative Workers	Worker			2
	N_M	No. Manual Task Workers	Worker	4	4	4
	C_{OP}	Robotic Station Operational Cost	Dollar	$1,000	$1,000	$1,000
	$\mathbf{C_T}$	**Temporal Costs**	Dollar	$1,199	$2,982	$7,175
Eq. 3	C_{ST}	Robotic Station Setup Cost	Dollar	$250,000	$250,000	$350,000
	L_R	Robotic Station Life Span	Year	10	10	10
	n_p	Annual Number of Project	Prj/Yr	1	1	1
	$\mathbf{C_{in}}$	**Robotic Station Investment Cost**	Dollar	$25,000	$25,000	$35,000
Eq.4	$\mathbf{S_R}$	**Production-Driven Labor Saving**	Dollar	$(2,312)	$14,778	$(13,859)
						$(1,393)

4.2 Market-Driven Savings

The framing tasks for the case study project were conducted in June 2016, so labor data and wages will be taken from 2016 using data from the Bureau of Labor Statistics. These values will be used in equation 6 to calculate the market-driven savings (See Table 2).

Table 2: Case Study Values for Equations 6, 7, and 8. (Labor Staffing Difficulty Level = 0)

Equation		Description	Unit	Value
Eq. 6	I_H	Total Hires in the Construction Industry for Study Months	000's of Workers	340
	I_S	Total Separations in the Construction Industry for the Study Month	000's of Workers	256
	D	Labor Staffing Difficulty (in June); Calculated	[0,4]	(0.45)
	D	Labor Staffing Difficulty (In June); Used	[0,4]	0

In this specific case study, the market-driven savings are 0. This is because the market state in the study month of June was reflecting a labor surplus, which means that the labor staffing difficulty level was 0. When there is no staffing difficulty due to the labor market, the addition of automated labor cannot lessen the impact of staffing difficulty because there is already no difficulty. If the framing tasks of this job were to take place in a different month or different year, it is possible that the implementation of automated labor would have a greater impact on the market-driven robotic savings for the project.

5. TRANSITION TIME RECOMMENDATIONS

The total cost savings from the integration of robotics in the previously described case study show a negative value of **$*4,171***. This suggests that deploying construction robots during a period of labor surplus and a slow market might not be financially viable due to the substantial setup costs. Nevertheless, the construction labor market changes on a yearly cycle. As such, it can be expected that the actual predicted total cost savings will change following the labor market status (labor surplus, labor shortage), allowing contractors to implement automated labor when it will result in the greatest savings.

5.1 Tasks-Specific Analysis of Transition Time

In optimal market conditions for the transition toward robotics-based automation, the market-driven savings are larger due to the higher initial labor staffing difficulty. In 2016, the labor staffing difficulty was the highest in ***December***, with a value of D_i = 3.29. Using this value to represent purchasing the construction robots in December instead of July, the estimated level of savings can be calculated using equations 7 and 8 (See Table 3).

Table 3: Case Study Values for Equations 7 and 8. (Labor Staffing Difficulty Level = 3.29)

Equation		Description	Unit	Value
	D	Labor Staffing Difficulty (in December)	[0,4]	3.29
Eq. 7	C_P	Total Construction Cost (Framing and Sheathing Tasks)	Dollar	$284,891
	$C_{OV}$$	Cost Overrun of a Construction Project	Dollar	$19,976
Eq. 8	N_{TM}	No. Workers in Manual Tasks (Framing and Sheathing)	Worker	12
	N_S	No. Workers Substituted by Automated and Semi-Automated Tasks	Worker	8
	S_{OV}	Cost Overrun Savings	Dollar	$13,318

This results in an additional ***$13,318*** in savings due to the status of the labor market. Combined with the production-driven savings, this results in net savings of ***$11,925*** which is a significant improvement from the savings—net cost increase—when there was no labor staffing difficulty. As such, the impact of transition time is evident in this assumed labor-market scenario for the case study. The implementation of automated labor can create additional savings when there is a shortage in the labor market, rather than a surplus. These cost savings can have an even greater impact on larger projects where robotics-based automated tasks have a larger scope.

One important takeaway from these results is that the transition time has a significant impact on the projected savings. This is because the use of automated labor during a time of labor shortage can significantly lessen the impacts of staffing difficulties, leading to lower rates of cost overrun in a construction project. Based on the seasonal cycle of the construction labor market, it is most cost-effective to implement automated labor between the months of ***August*** and ***February***. The presented labor staffing difficulties data will contribute to a clearer understanding of the relationship between labor markets and automated labor and how to best navigate that relationship.

It is crucial to acknowledge that the case study presented, while illustrative, employs simplified models of real-world construction scenarios with limited detailed clarifications of all assumptions and simplifications. Notably, the robotic productivity data is simulated, and the economic analysis assumes a single-project utilization of the robotic system within the first year. These simplifications, while allowing for a clear demonstration of the proposed methodology, inevitably introduce limitations to the direct applicability of the quantitative results to complex, real-world construction projects. Future research will aim to address these limitations by incorporating more extensive empirical data and expanding the scope of the analysis to include a wider range of project variables.

6. CONCLUSION

The increased use of automated tasks plays a vital role in the industrial revolution. This transition must be researched and understood to avoid potential negative outcomes of high, upfront investment and reap all potential benefits of productivity, precision, and safety improvements. Given current research trends, it is likely that the use of robotics in construction is just beginning, so staying on top of this wave of new technologies and techniques will enable construction firms to utilize these technologies effectively as they become commercially available. As construction automation technology continues to advance and more construction firms begin to implement robotics-based automation, it will become increasingly important to understand the economic impact of robotics on construction projects.

This research delivers actionable strategies for wider IC adoption by identifying optimal automation levels and transition timelines. It quantifies the benefits of robotics integration, addressing the persistent barrier of manual practices and unlocking IC's full time and cost efficiency potential. Notably, utilizing production-driven and market-driven frameworks, the study reveals that cost savings from automation are highly sensitive to transition timing relative to labor market conditions. The case study demonstrates that the cost savings associated with robotics implementation are highly sensitive to the timing of the transition relative to the construction labor market. Specifically, during periods of labor surplus, as observed in June 2016, the initial investment in robotic systems may not yield immediate cost reductions, resulting in a net cost increase of $4,171 in our example. Conversely, during periods of labor shortage, such as in December 2016, the same robotics deployment can generate significant cost savings, yielding $11,925 in net savings due to reduced labor staffing difficulties. Therefore, construction professionals are recommended to strategically time the implementation of robotic automation between August and February, when labor shortages are typically most pronounced, to maximize cost savings and mitigate potential cost overruns. This strategic timing, informed by labor market data, allows for optimal utilization of robotic technologies and enhances the financial viability of industrialized construction projects

Further Research investigating the economic impact of robotics on construction projects and the labor market will become increasingly important as automation technologies continue to propagate in the construction industry, and this study represents a preliminary step in this journey.

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