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A Framework for Improving Trade Contractors' Productivity Tracking Methods

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***Abstract*—**Despite being one of the most significant economic contributors of the country, Canada's construction industry is lagging behind other sectors when it comes to labor productivity improvements. The construction industry is very collaborative as a general contractor, will hire trade contractors to perform most of a project's work; meaning low productivity from one contractor can have a domino effect on the shared success of a project. To address this issue and encourage trade contractors to improve their productivity tracking methods, an investigative study was done on the productivity views and tracking methods of various trade contractors. Additionally, an in-depth review was done on four standard tracking methods used in the construction industry: cost codes, benchmarking, the job productivity measurement (JPM) standard, and WorkFace Planning (WFP). The four tracking methods were used as a baseline in comparing the trade contractors' responses, determining gaps within their current tracking methods, and for making improvement recommendations. 15 interviews were conducted with different trades to analyze how contractors value productivity. The results of these analyses indicated that there seem to be gaps within the construction industry when it comes to an understanding of the purpose and value in productivity tracking. The trade contractors also shared their current productivity tracking systems; which were then compared to the four standard tracking methods used in the construction industry. Gaps were identified in their various tracking methods and using a framework; recommendations were made based on the type of trade on how to improve how they track productivity.

***Keywords*—**Trade contractors' productivity, productivity tracking, cost codes, benchmarking, job productivity measurement, JPM, workface planning WFP.

I. Introduction

A. Background

CONSTRUCTION is vital throughout the world producing infrastructure, jobs and profit. The construction industry is an essential part of Canada's economy, accounting for approximately 12% of Canada's GDP [1]. However, in comparison to other sectors of the economy, the construction industry has had a decline in overall productivity since the 1980s in contrast to an overall increase in productivity for all other sectors [2]. The cost of labour generally equates for 33-50% of a construction project's total budget and is often the most volatile component to control [3]. Of this 33-50% labour cost, 70-90% of the work is performed by trade contractors; therefore, it is critical that contractors know how their labour is performing as improving productivity amongst contractors will bring shared project success [4].

B. Research Problem and Rational

One of the largest general contractors in North America that operates in building construction, civil infrastructure, and heavy industrial sectors has requested the analysis of trade contractors' productivity tracking methods. The organization is interested in not only finding out how trades track productivity but is also looking into increasing trade contractors' knowledge on the value tracking productivity can bring to a project.

Construction projects are collaborative as a general contractor will hire numerous trade contractors to complete most of the work on a project. This collaboration means that low productivity from one contractor can have a domino effect on the productivities of other contractors. Analyzing how trades track and view productivity will help to rectify this issue, as gaps can be identified, and recommendations made as to how contractors can improve their productivity tracking. While recommendations were made they have not been put into practice due to the project's time limitations.

II. Literature Review

A. Labour Productivity

Labour efficiency is volatile to many determinants, such as the skill of labour, quality of supervision, absenteeism/ turnover, weather conditions, safety restraints, lack of material/tools, and site congestion [5]. Many factors can negatively affect labour performance, which means it is crucial that contractors are tracking their productivity to identify any variances to their work so that proper action can be taken to mitigate change. A common phrase used in construction is that to improve something, it first needs to be measured [6].

Labour productivity refers to the ratio of output to input, where the output is measured production and the input is time, for example, m^2/hr [7]. Inversely, productivity can be expressed as the time required to produce a unit of output; for example, 16 hrs/100 linear feet [8]. The productivity ratio

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breaks down tasks performed on a project to measurable values; it is then straightforward to compare productivity rates whether they are hourly, daily, or weekly. While there are numerous ways to evaluate labour productivity, quantitative evaluations at the activity and task levels provide an in-depth look at labour performance which can be analyzed more accurately than at field or project levels [8]. Four commonly used and emerging productivity tracking methods within the construction industry are cost codes, benchmarking, the JPM standard, and WFP.

B. Cost Codes

Cost codes can be used alone or combined with other tracking techniques. Traditionally, cost codes involve tracking the quantity of work completed and the cost of each pay item, which is defined by a cost code [9]. Cost codes breakdown a project's specific labour tasks, by chronological order, physical location, and logistical types [10]. In many projects, cost codes are used under a work breakdown structure as projects are broken down to specific deliverables such as tasks [11].

There is flexibility in how often one chooses to track cost codes. Surprisingly, many contractors do not track labour expenditures hourly, but rather all charges are recorded under a generic cost code as 'field labour'. Using one code generally means no attempts are made to track hourly expenditures but rather concurred labour charges are all lumped together. Other contractors may record daily work completed and use time cards to track labour hours [12]. The Construction Specifications Institute (CSI) has developed common cost codes compatible with the MasterFormat; for example, code 03310 is used for structural cast-in-place concrete [13].

Cost codes are useful in visualizing the sequencing and breakdown of a task to manageable actives. However, the drawbacks to cost codes include the possibility of having a mass number of codes for large projects which leads to confusion and makes it difficult to track all costs. Another disadvantage is that cost codes mainly focus on the costs of labour as opposed to productivity measurements.

C. Benchmarking

Benchmarking is a continuous and systematic approach in identifying construction best practices to create labour performance goals and provide a yardstick for which productivity improvement efforts are measured [8]. In benchmarking, one first defines the labour activities to be benchmarked and sets the benchmark in terms of worker hours per unit installed [8]. Daily production data are then gathered and evaluated against the benchmark [8]. Some companies develop a Benchmarking and Metrics model that assists in the implementation of measures to continuously improve labour productivity [14]. The R.S. Means and Construction Industry Institute Benchmarking and Metrics Program publishes standard task level metrics that are based on installed quantity and actual work hours [15].

Baselines are often used in conjunction with benchmarking; compared to benchmarking that is a level of aspired performance, a baseline is a standard level of performance or a 'norm' [16]. Baseline productivity is most often calculated using Thomas and Zavrski's model "Theoretical Model for Internal Benchmarking Labor Productivity" [17]. The model uses a standard calculation for productivity, measuring total work hours over total quantities of work installed [18]. Reference [18] used Thomas and Zavrski's model to measure and compare the productivity for masonry activities on eleven construction projects and found the model to be a reliable indicator for productivity tracking [17].

Benchmarking does more than just productivity tracking; it also enables best practices to be incorporated into one's operations and provide productivity targets. The main disadvantage of benchmarking is that it can be time-consuming as research and data need to be collected to develop benchmarks and baselines (a metrics database may need to be built). Another disadvantage is specific project constraints and conditions, such as delays, crew experience, and interface with other trades can make it difficult to reach targets [8].

D. JPM

The American Society for Testing and Materials (ASTM) has developed the standard ASTM E2691-16 known as the JPM, for productivity measurement [19]. JPM calculates a ratio of output per unit of input by comparing labour usage to the Construction Put in Place (CPIP) or how much work was produced by how many labour hours. JPM measures productivity for installation processes and considers the difficulty of tasks while evaluating changes to productivity using trend monitoring [20]. Monitoring trends in productivity enable the JPM standard to act as an early warning system to identify what is causing changes to productivity so that they can be corrected [19].

JPM also utilizes cost codes and baselines. At a project's pre-construction phase, the baseline and budget are set, JPM then tracks the productivity for each task based on individual cost codes [21]. In using JPM, the project manager and superintendent work together to identify the scope of work, list the ASTM standards that coincide with each task, record the contents/steps for each task, and calculate the labour productivity reference point (LPRP). The LPRP is a ratio calculated at the beginning of a project for the number of hours required to complete one percent of the construction based on a baseline labour hour budget [20].

The benefit of JPM is that it was developed for and focuses specifically on productivity which makes it considerably easier to understand and track productivity rates. Most importantly, JPM measures ongoing productivity even when changes are occurring on site. The drawbacks are that it requires personnel who are very knowledgeable in field labour, and JPM is mainly suited for more extensive projects therefore may not be cost-effective for smaller projects [20].

E. WFP

The Construction Owners Association of Alberta (COAA) developed the concept of WFP and considers it an industry

best practice. WFP has become a common contractual requirement for Alberta's industrial projects as it is a publicly supported model [22]. Using WFP, a project is broken down into defined, manageable components that can be executed, budgeted, measured and controlled [23].

Unlike most productivity tracking methods, WFP is an execution strategy that starts in a project's design stage, where the contractor works with engineering to develop construction work packages (CWPs) [22]. CWPs define a specific scope of work and include a budget and schedule that is compared with the actual performance; CWPs also include estimated manpower [23]. After the CWPs are produced, they are then developed into installation work packages (IWPs); an IWP is approximately 500-1500 manhours or the equivalency of one shift for one crew (typically 10-14 days) [22].

The actual productivity tracking takes place during the construction stage, as a designated WFP coordinator updates the status of the IWPs and adds them to a backlog to produce a 3-week lookahead schedule. The superintendent reviews the coordinator's work ensuring that the IWPs are accurate and completed [22]. The COAA does not specify the level of tracking required for a project's IWPs but does provide a basic formula to measure labour productivity: productivity = value produced/value invested in terms of labour hours [23].

One significant benefit of WFP is that it is gaining popularity, is supported, and originated in Alberta; therefore, it may be easier to get contractors to accept the method. WFP considers more than just productivity; it also addresses the planning, execution, and end stages of a project [22]. WFP also engages the project owner, contractors, and designers which facilitates open and transparent communication. Large projects that implement WFP can improve labor efficiency by an estimated 25%, which can equate to a 10% savings on overall costs [23]. While WFP has many benefits, it may not be feasible for smaller projects as it has been designed for large industrial projects. As WFP is a new concept, there is limited research and literature available on its use in other projects; therefore, it is unknown if its success can be replicated in smaller, commercial projects. See Appendix A for a comparison table of the four methods.

III. Objectives

A. To Research Productivity Tracking Methods Used within the Construction Industry

A literature review will be used to research tracking methods using books and articles. Then, a table will be developed to compare the advantages and disadvantages of the standard tracking methods.

Conducting a literature review will provide reliable, peer-reviewed information on the types of tracking methods used in construction. Comparing the tracking methods outlined in the secondary sources will also act as the foundations for the recommendations.

B. To Examine Trade Contractors' Productivity Views and Tracking Methods

Trade contractors will be interviewed using standardized questions to identify their tracking methods and familiarity with productivity

Interviews will enable direct interface with various trades, providing detailed information on how they view and track productivity. The constraints of interviewing are that it can be very time-consuming setting up, having a limited sample size due to response rates, and various interviewers may transcribe information differently.

C. To Recommend a Framework for Trade Contractors to Improve Their Productivity Tracking Methods and to Convey the Value of Tracking Productivity

A framework will be used to recommend productivity tracking improvements applicable to trade contractors based on the type of trades and gaps found between their current methods and industry standards. The framework will then be shared with PCL to acquire expert feedback.

A framework will outline all the stages taken to the recommendations and show the linkage between the research steps. While frameworks are easy to comprehend, they are limited in the amount of information they can provide due to its schematic design.

IV. Data Collection and Analysis

Interviews were conducted with various trades using standardized questions to contrast and compare their responses. A total of 15 interviews were conducted with trade contractors (TCs) to discover not only the TC's tracking methods but also their familiarity with the value of tracking productivity. See Appendix B for the list of trades and Appendix C for the unsummarized interview responses.

A. Q1: How Would You Define Productivity?

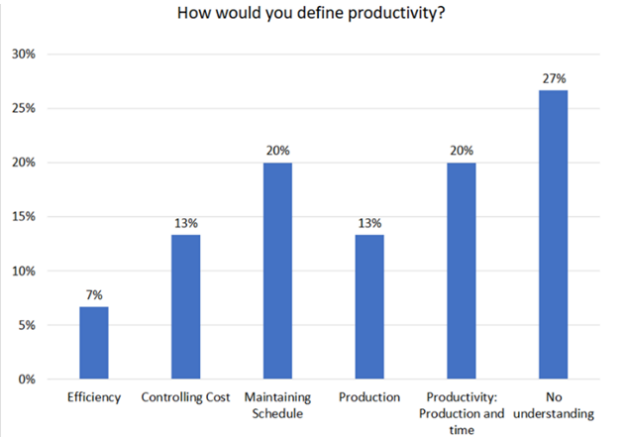

Fig. 1 Productivity

This question was used to gauge the TC's overall understanding of productivity. As a baseline to compare the TCs' responses and to determine gaps in their views of productivity, the following definition will be used:

productivity is a ratio where the output is measured production and the input is time [7].

1) Data Interpretation

As shown in Fig. 1 *7%* of the contractors defined productivity as on-site efficiency. *13%* defined productivity as comparing cost performance with the schedule. *20%* of the contractors defined productivity as the total amount of manhours. *13%* defined productivity in terms of production. *20%* defined productivity as measured production over the total number of manhours. *27%* of the contractors were unable to define productivity.

2) Data Analysis

Efficiency: [24] describes efficiency as a ratio of actual performance over theoretical maximum performance. While efficiency is a ratio like productivity, efficiency focuses more on comparing labour performances as opposed to analyzing production completed within a period.

Controlling Cost and Maintaining Schedule: The contractors focused on cost and schedule should also consider production in describing productivity as improving productivity will result in better cost and schedule performances [25].

Production: Those who discussed only production also need to consider the time it takes to complete the work. Productivity extends beyond just the amount of work completed, as it is the rate of production.

Productivity: 20% of the trades demonstrated a thorough understanding of productivity in terms of productivity as a ratio.

B. Q2: Is Productivity Tracking Needed to Maintain Your Project Schedule?

This question was used to identify whether the TCs utilize their productivity tracking information regarding schedule.

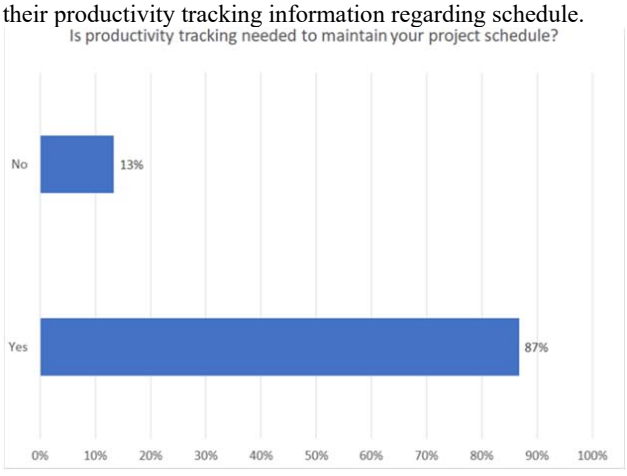

Fig. 2 Project schedule

1) Data Interpretation

As shown in Fig. 2, *13%* of the contractors disagree that productivity tracking is needed to maintain schedule. *87%* agreed that productivity tracking is needed to maintain schedule.

2) Data Analysis

Productivity tracking is not needed: After questioning the 13% of contractors who disagreed, it was discovered that the contractors do not track productivity at all which is likely why they do not believe productivity tracking is needed to maintain schedule.

Productivity tracking is needed: This feedback was positive, demonstrating that a majority of TCs recognize the value in tracking productivity.

C. Q3: How Do You Identify Whether Your Company Has a Productive Week?

This question was used to analyze whether trades identify tracked productivity as their primary source in determining if they had a productive week, see Fig. 3.

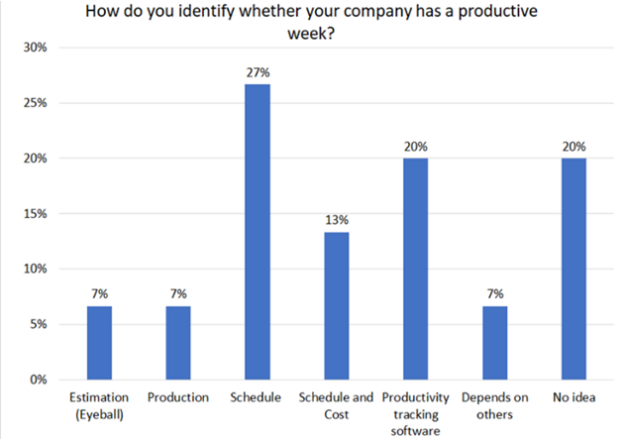

Fig. 3 Productive week

1) Data Interpretation

7% stated that their superintendent estimates productivity by visualization (eyeballing). *7%* defined a productive week as meeting production. *27%* described a productive week as meeting schedule. *13%* of the contractors associate a productive week with meeting schedule and making a profit. *20%* of contractors use productivity tracking software to generate weekly labour cost reports. *7%* of the contractors depend on the productivity of the other contractors in determining if they will have a productive week. *20%* have no means in determining a productive week.

2) Data Analysis

Estimation: Estimating or 'eyeballing' is not a systematic approach in evaluating if a week has been productive as no work is being measured. If a contractor does not measure their work, they cannot properly manage it [26].

Production: Looking at production can be a reliable method as weekly production can be compared to the total hours worked in the week, which can be used to calculate the productivity ratio.

Schedule and/or Cost: Only looking at schedule and/or costs for a week will not provide enough information to determine if a week has been productive. For instance,

schedule and costs may be satisfactory for a week; however, labour productivity may be underperforming. Without tracking production in addition to the schedule, contractors are missing opportunities to improve their productivity.

Productivity Tracking Software: A tracking software can be reliable if used correctly, meaning all the required information still needs to be tracked and recorded. Many productivity software generates weekly labour cost reports providing a detailed summary of productivity numbers.

Depends on Others: For trades solely dependent on the work of others, it is critical that the general contractor is facilitating proactive coordination between the TCs to solve coordination issues and ensure the timely completion of work [27].

D. Q4: How Do You Control Costs on Site?

As costs are often at the forefronts of project concerns, this question focuses on whether TCs utilize cost control in addition to productivity tracking.

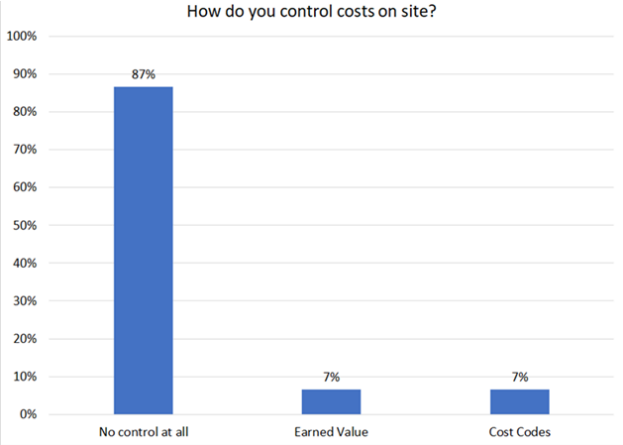

Fig. 4 Cost control

1) Data Interpretation

As indicated in Fig. 4, *7%* use cost codes to control costs. *7%* conduct an earned value analysis to control costs. Most of the contractors, *87%,* responded that they have no form of on-site cost control.

2) Data Analysis

Cost Codes: Cost coding can be useful in controlling costs as it provides up-to-date activity statuses, enabling project personnel to identify activities experiencing cost difficulties and implement corrective actions [9].

Earned Value (EV): EV is another effective cost control method, EV combines cost and time-related data into one metric; this metric provides information on a project's overall cost performance and is also useful for managing day-to-day activities [28].

E. Q5: What Measures Are Taken to Increase Labour Productivity?

It is imperative that contractors understand how to increase their productivity if their tracked numbers are not meeting expectations. This question probes contractors on what measures they take to improve their productivity, see Fig. 5.

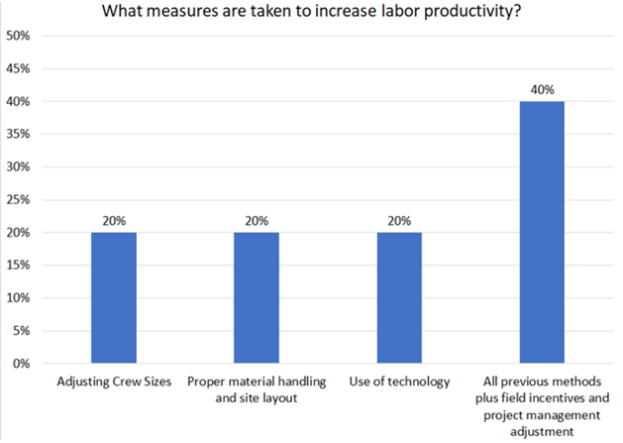

Fig. 5 Increasing productivity

1) Data Interpretation

20% of the contractors discussed adjusting crew sizes/ makeup, and task allocation. *20%* described coordinating material handling and having proper site layouts increases productivity. *20%* discussed proper training in using advanced technology. *40%* discussed a combination of the methods above. In addition to the measures highlighted by the contractors, field incentives and adjusting project management practices can also be used.

2) Data Analysis

Crew Size/Makeup: Adjusting crew sizes, crew members, and rotating crews are viable means in increasing productivity. For instance, projects that require crews to perform repetitive work may continuously rotate crews to improve productivity while minimizing idle and non-productive times [29].

Material Handling/Site Layout: Material and storage handling is an indirect way to increase productivity. The faster one moves the materials, the higher the productivity level will be [30]. Disorganized materials storage and confusing size layouts increase travel time, thus, decreasing productivity.

Technology: Investing in technologies, such as the use of BIM which enables better visualization of a building for workers, can increase productivity. However, investing in advanced technologies can have a significant impact on small companies due to the upfront costs and training [31].

V. General Contractor and TCs' Productivity Views Comparison

Three of the General Contractor's project managers were interviewed on their views on productivity. In comparison to the TCs' responses, the General Contractor views productivity in the standard terms of production and time. While there were numerous trade responses in determining whether a week has been productive; the General Contractor considers a productive week to be meeting or exceeding schedule, meeting production goals, and based on the results of their labour cost

reports.

VI. TCs' Tracking Methods

Objective 4: Determine and Compare the Gaps between TCs' Productivity Tracking Methods to the Tracking Methods Commonly Used within the Construction Industry

There were numerous different productivity tracking methods used by the trades interviewed. Therefore, the productivity tracking methods depicted in Fig. 7 are out of the total 15 responses since some TCs use more than one method.

Fig. 6 TC's tracking methods

1) Data Interpretation

As shown in Fig. 6, the millwork, stucco, controls, tile, and one of the drywall contractors currently are not tracking their productivity. *Production over time*: The electrical, masonry, building envelope, steel, and two mechanical contractors track production over daily and/or weekly manhours. *Cost codes:* The electrical, hardware, and building envelope contractors use cost codes for measuring labour quantity and costs. *Stages:* The electrical, building envelope, hardware, mechanical, and drywall contractors separate projects into different phases/stages and instead of tracking production per hour it is done per stage. *Benchmarking*: The electrical, mechanical, masonry, millwork, and steel contractors use benchmarking to assess productivity based on historical data, baselines, and data from respective TC associations.

2) Data Analysis

No tracking: Stucco, controls, tile, and drywall contractors mainly install materials by a unit placed or area covered. These trades would enhance their operations through tracking productivity since they perform repetitive installation tasks. Tracking will enable them to see how they are performing on a consistent basis. For instance, benchmarking can improve labour productivity through setting productivity goals and ensuring labour is reaching a minimum baseline. Millwork installation is rather complicated compared to the trades mentioned above because millwork designs are constantly changing. The same manual installation technique by manpower can vary project to project based on design. As a result, millwork contractors could use JPM as it tracks productivity regardless of complexity/changes and measures what is completed versus the manhours used.

Production over time: Compared to most trades, mechanical, electrical, and building envelope contractors have very complex scopes of work in a project. Mechanical systems and installation methods differ by project. Electrical systems are also complex, as a contractor is responsible for many different tasks such as running wire and conduit, installing lighting fixtures, etc. Building envelope is a complex trade as well as it deals with the entire exterior shell of a building which includes glazing, roofing, and exterior walls. These trades should be tracking productivity based on what is installed on-site versus manhours used to improve the algorithm of performing the work while increasing productivity to reduce labour inefficiency. The productivity data collected on-site can be used alongside cost codes to control costs simultaneously.

Cost codes: The electrical, hardware and building envelope contractors use cost codes to manage productivity, cost, and schedule. The electrical contractor uses three generic cost codes for projects to lump similar tasks together. While the hardware and building envelope contractors use cost codes for most tasks; however, using this method on large, complex projects could make productivity tracking confusing due to a mass amount of cost codes. Cost codes are mostly suited for cost control which can be useful on a project if combined with another tracking method.

Stage over time: The mechanical, electrical, building envelope, hardware, and drywall contractors, where if the design is typical (i.e. repetitive floors/rooms), track productivity in stages since the installation method and tasks are repetitive. Rather than tracking production over time, these trades will track by zone, floors, or areas. For example, a hotel project has typical floors and rooms, that makes it easy for a trade to track production per floor/room. This method of tracking is like the WFP's IWPs, except instead of measuring tasks over one shift, it is measured over a specific area, floor, etc.

Benchmarking: Electrical and mechanical work is sufficiently complex that benchmarking using metrics from a historical or organizational database can ensure that labours are reaching performance targets. The masonry and millwork contractors both have in-house databases with historical metrics they use to set benchmarks and baselines. The steel contractor uses benchmarking in not only their on-site installation tasks but also in their prefabrication operations. Using benchmark productivity to compare with actual productivity will identify whether a contractor is reaching their performance goals or if changes need to be made in managing their labour.

See Appendix D, Table IV, for a comparison of the trades' tracking methods to the four methods outlined in the literature review.

VII. General Contractor and TCs' Tracking Method Comparison

Based on the interviews conducted with the General Contractor's management, it was discovered that 90-95% of their work is performed by trades, while the remaining 10-15% is self-performed. The General Contractor self-performs their concrete work and tracks it by measuring the area of formwork and amount of manhours used. The tracked productivity data are compiled into a weekly labour forecasting report which enables them to see if they are on schedule, production, and budget.

The General Contractor's tracking method is similar to the trades that track productivity in terms of measuring production and time. Tracking using the ratio of production and time is an ideal method in measuring productivity as it directly describes labour productivity. Whether TCs are utilizing numerous methods in tracking productivity, it is critical that production and the amount of time it takes to complete the work are measured.

VIII. Recommendations

Objective 5: Recommend a Framework for TCs to Improve Their Productivity Tracking Methods and to Convey the Value of Tracking Productivity

One of the most prominent findings from interviewing the various TCs is the lack of awareness and gap in education when it comes to understanding the importance of labour productivity. 27% of the interviewed trades had no understanding of labour productivity, which means many contractors need to be made aware of how vital labour productivity is in determining the amount of success on projects.

To improve labour productivity on a project, it is quintessential that productivity is being adequately tracked first. By improving one's productivity tracking, this will enable contractors to see how their labour is performing on a consistent basis and if changes need to be made to improve their productivity. As TCs specialize in many different areas of work on a project, a decision tree has been developed based on the different types of trades and the recommended tracking method(s) most suited to their type of work. See Fig. 7 for recommended framework.

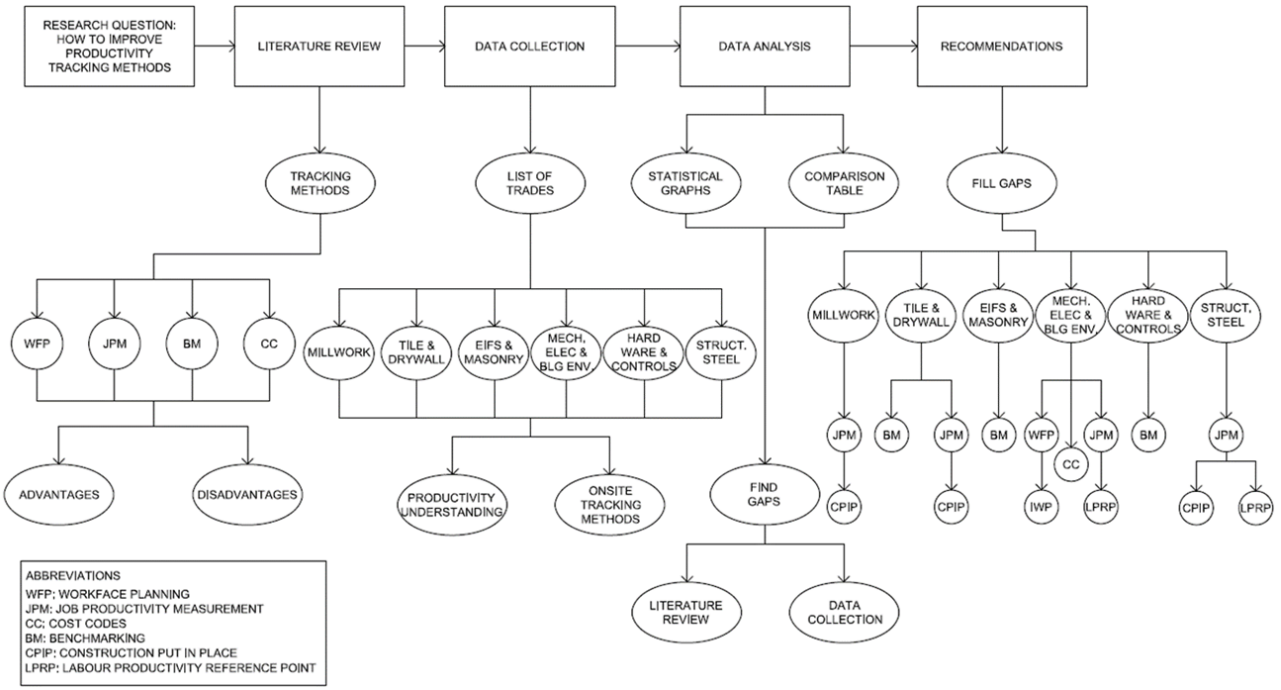

Fig. 7 Framework for improving TC's productivity tracking

1) Millwork

Job Productivity Measurement [JPM]: The construction-put-in-place (CPIP) component of the JPM would be utilized to track the progress of millwork components put in place by allocating specific resources to individual tasks and labour items. As millwork scopes are continually changing based on design requirements, each millwork activity needs to be customized for every project. CPIP will enable millwork activities to be separated by resources as each activity may have unique requirements.

2) Tile & Drywall

Job Productivity Measurement [JPM]: The construction-put-in-place (CPIP) component of the JPM is recommended for tile and drywall trades because it identifies the work done on site over a specific period. In tiling and drywalling, the

work done on each area may differ based on design, but the actual installation tasks are repetitive and will remain typical despite the scope of work.

Benchmarking: As tiling and drywalling tasks are repetitive, benchmarking can also be used to identify a preliminary baseline. Baselines would be especially useful for these trades as they can ensure that they are meeting a minimum performance on their installations.

3) Stucco (EIFs) & Masonry

Benchmarking: Benchmarking best suits these trades due to the repetitive nature and uniformity of their scope of work and installation tasks. Establishing benchmarks or productivity goals for projects will enable contractors to strive for improved labour performance. Additionally, establishing a baseline will ensure that a minimum performance is being reached on projects. This method is ideal for these trades because it is simplistic when it comes to tracking and interpreting data while still providing valuable productivity information.

4) Mechanical, Electrical, & Building Envelope:

WFP [IWP]: The IWP component of the WFP tracking method would work best with these three trades' scope of work as it allows contractors to breakdown large scopes of work into manageable parts. IWPs would be applied to separate crews for the different scopes of work. IWPs will also make it easier to track and differentiate between various crews on a project.

Cost Codes will complement the use of IWPs as each item in the work packages will have a corresponding cost code which will be used to track and record the costs and resources associated with each installation task. Cost codes also simplify productivity tracking as it groups similar tasks by their codes. For instance, all glazing work for the building envelope will be grouped together with similar codes.

Job Productivity Measurement [JPM]: The labour productivity reference point (LPRP) component of the JPM, best suits trades that have repetitive scopes of work and tasks. For example, an electrical contractor repeating the same scope of work per floor on a hotel project would benefit from a tracking method that is suited to repetitive labour tasks. The LPRP method will create reference points from the first installation to the last installation which enables productivity differentials to be identified [20]. Trades can implement LPRP in projects where they will be performing repetitive tasks.

5) Hardware and Mechanical Controls

Benchmarking: Using benchmarking to track productivity will enable the identification of weaknesses in these trades' work to improve their performance and productivity. Through setting benchmarks for these trades' installation tasks, they will have goals to strive for in completing their work, thus improving their productivity. Hardware and control trades often rely on other trades to complete their work prior to the commencement of their own work; therefore, benchmarking would be beneficial for these trades to track multiple projects at a macro level.

6) Structural Steel

JPM [CPIP & LPRP]: Steel work varies based on project designs; however, their installation tasks remain similar. Using CPIP which will observe the percentage of work completed will act as a facilitator in determining labour productivity and progress. The data collected through the CPIP can then be utilized for LPRP to establish a reference point. This reference point will serve a marker to determine the actual time required to complete the task at hand and in identifying productivity differentials.

IX. Limitations

One limitation of this study is that the productivity tracking was only focused on the work performed on-site. However, prefabricated work is also an essential component of construction projects that differs from on-site work as the work is manufactured offsite. It would be interesting to explore if prefabricated work differs in terms of productivity tracking, and how prefabrication affects productivity on-site.

Another limitation is the study's sample size. There was a low response rate from trades within the industry who agreed to participate in this study. Furthermore, there was a limitation in the type of trades interviewed; for instance, there were three mechanical contractors, but only one electrical contractor interviewed. Further research would require less variance between the numbers of different trades; for instance, three mechanical and three electrical contractors would be interviewed to have proportional representation of each type of trade.

There was a limitation with TCs disclosing their tracking methods due to company privacy policies. While the trades were willing to discuss how they track productivity, many were unable to share the actual documentation and software programs associated with their tracking. Another limitation is that while recommendations were made as to how trades can track productivity using the framework, the tools that would be used in tracking have not been considered. Further research may investigate different tools, such as software and technology that can be used with the various tracking methods.

Lastly, there was a limitation regarding validating the framework due to time constraints. Future areas of research could include validating the proposed framework, by conducting a study on various trades who have implemented the recommended tracking methods to their organization. Testing the proposed tracking methods will bring verification that the tracking methods indeed improve productivity measuring.

X. Conclusion

Labour productivity is a frequently discussed topic within the construction industry, as labour is the largest cost on many projects meaning it significantly impacts profitability [7]. Additionally, labour performance needs to be closely managed on projects as several factors can negatively impact productivity. It is especially crucial that TCs are tracking their

own productivity as trades perform a majority of work on most projects. Trades that are adequately tracking their productivity will be able to identify if their labour performance is acceptable or if there are labour inefficiencies that need to be addressed.

Based on an in-depth literature review of productivity tracking within the construction industry, it was discovered that cost codes, benchmarking, the JPM standard, and WFP are commonly used tracking methods. Using these tracking methods as a baseline, 15 TCs were interviewed on how they track and view productivity. The results of the trades' responses suggest that there is a variance between contractors when it comes to their knowledge and understanding of productivity.

In addition to the mixed views on productivity, the TCs also differ in terms of tracking methods, with many contractors using a variety of methods while some contractors do not track productivity at all. To improve the different trades' productivity tracking and to suggest a tracking method to those without one, a decision tree was developed that outlines which of the four common tracking methods in the construction industry are best suited for each type of trade. Through using the decision tree framework, trades will be able to apply improved tracking methods to their operations, enabling them to better identify how their labour is performing. With improved tracking methods, contractors will more easily be able to identify if they have labour inefficiencies so that corrective action can be taken.

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XI. APPENDIXES

A. Appendix A

TABLE I
TRACKING METHODS' ADVANTAGES AND DISADVANTAGES

	WFP	**JPM Standard**	**Benchmarking, Baselines, & Metrics**	**Cost Codes**
Advantages	-Supported by COAA and considered a best practice [23] -Engages owner, engineering, contractor, CM, etc., therefore there is more open and transparent communication - WFP is estimated to increase labour productivity by 25-30% which would more than cover increased overhead costs in tracking [23] -Tackles much more issues than just the issue of labour productivity tracking (i.e. planning, lean construction techniques)	-Can give early warning signal to overall outcome of the project [20] -Identifies whether task productivity is under or below standard [20] -Measures ongoing productivity even when changes occur on-site [20] -JPM can more accurately calculate productivity because the work is deemed 100% completed only when the performance is fulfilled and accepted by client [19]. In other words, the productivity is only tracked where quality is acceptable, which means there is no rework.	-Best practices can be incorporated into a company's operations [8] -Provides targets that have been achieved internally or by others [8]	- Helps visualize the sequencing and breakdown of tasks - Helps identify what is causing wastage of resources vs what is profitable [32] - Can help increase efficiency and profit by identifying and eliminating excessive resources [32]
Disadvantages	-Is a project execution strategy, which means convincing multiple parties to support and participate in WFP (the owner, contractor, engineering, etc.) -WFP contributes to higher performance on large industrial projects, but it is unknown if the same results be repeated on smaller commercial projects	-Requires personnel extremely knowledgeable in field labour -JPM is mainly suited for big projects, but the additional work and expertise that JPM requires may not be cost-effective for smaller projects	-Time consuming, research and data must be collected to find baselines. -Sometimes baselines cannot be achieved or are not accurate based on change orders, project conditions and constraints	- Having too many cost classes and cost codes on a project can lead to mass confusion - Cost codes are sometimes not adequate to analyze exactly where resources and money was spent but instead only that it was costed to a specific code

B. Appendix B

TABLE II
LIST OF TRADES

	TC Type	Interviewee Title		TC Type	Interviewee Title
1	Building Envelope*	Construction Manager	9	Mechanical*	Superintendent
2	Electrical*	Project Manager	10	Mechanical	Foreman
3	Drywall*	Owner	11	Controls*	Foreman
4	Drywall	Superintendent	12	Millwork	Operations Manager
5	Drywall	Project Management	13	Steel	Project Manager
6	Hardware (Doors & Windows)	Construction Manager	14	Stucco (EIFs)	Estimator
7	Masonry*	Estimator	15	Tile*	Owner
8	Mechanical*	General Manager			

Note: The General Contractor's specific trades have been identified with '*'.

C. Appendix C

TABLE III
TRADE INTERVIEW RESPONSES

Interview Question	TCs' Responses
How would you define productivity?	**One contractor** defined productivity as the on-site efficiency. Stucco Contractor *"Efficiency on site"* **Two contractors** defined productivity as the cost performance comparing with the schedule. Building Envelope Contractor* *"Cost versus schedule versus men on site"* Steel Contractor *"Schedule on track and cost within budget"* **Two contractors** defined productivity in terms of production Electrical Contractor* "*Length is used for wire and conduit, and we count other items such as light fixtures"* Controls Contractor* *"Productivity in controls may be very different from other companies. The productivity in controls is defined by installation of controls over the equipment or system."* **Three contractors** defined productivity as the total amount of crew hours over the duration of tasks. Hardware Contractor *"Scheduling of tasks – maintaining schedule*" Mechanical Contractor* *"Productivity is the total amount of crew hours divided by the duration of the tasks"* Mechanical Contractor* *"Productivity is the amount of time crews need to finish a task"* **Three contractors** defined productivity as measured production over the total amount of time used to complete the work. Tile Contractor* *"Productivity is the amount of work completed in a given amount of time, such as square feet installed in a day."* Masonry Contractor* *"Productivity is the total units completed per man day. The units could be either number of bricks (modules) or area (sq. ft) for cultured stone."* Drywall Contractor *"Productivity is the total time used to complete each task and the amount of square feet drywall installed."* **Four contractors** have no understanding of what productivity is.
Is productivity tracking needed to maintain your project schedule?	**Two contractors** disagreed that productivity tracking is needed to maintain schedule. Controls Contractor* *"No because we only install controls after the equipment and system is installed. Controls are finished installing, but the next equipment has not been installed yet."* Stucco (EIFs) Contractor simply responded with *"no."* **Thirteen contractors** agreed that productivity tacking is needed to maintain schedule. Some of the responses were as follows: Tile Contractor* *"Yes, without a way to measure what has been done compared what remains to be done it is difficult to determine if you are on schedule or on budget."* Building Envelope Contractor* *"Yes, it is essential to maintain schedule, it tells us where we are at any point in the project."* Hardware Contractor *"Yes, without any tracking we would have no real job data."* Steel Contractor *"Yes, it is essential to the schedule and job to understand what has been spent vs what has been completed as opposed to what was allowed for in the estimate."* Mechanical Contractor* *"Yes, the management team will assist in developing the crew productivity based on the data provided by the site superintendent."*
How do you identify whether your company has a productive week?	**One contractor** argued that superintendents can estimate productivity by visualization (eyeballing). Stucco (EIFs) Contractor *"Supervisor eyeballs it"* **One contractor** discussed the total production made during the week in identifying whether they have been productive. Drywall Contractor* *"A productive week is determined by the amount of work completed"* **One contractor** stated that they depend on the productivity of other contractors to assess whether they have a productive week. Controls Contractor* *"It really depends on the mechanical and electrical equipment speed. Our productivity depends on them."* **Two contractors** consider a productive week as meeting schedule and making a profit (cost). Tile Contractor* *"I consider a week where we have met the schedule set by the contractor, hit milestones that affect other trades and made a profit, to be a productive week."* Building Envelope Contractor* *"We initially create a forecast of each job prior to starting. From that forecast, we compare the actual cost, schedule and onsite man hours to what was estimated in the forecast. From there we can have a better gauge of the week's productivity status."* **Three contractors** use custom productivity tracking software to generate weekly labor cost reports. Masonry Contractor* *"Our week's productivity is determined by our weekly labor cost reports"* *Hardware Contractor "We use a software called Gantic - Task Completion & resource allocation."* *Electrical Contractor** To determine whether they have had a productive week, their custom, in-house program will generate reports based on their hourly & weekly productivity tracking **Four contractors** described a productive week as meeting schedule and determining the total manhours used. Mechanical Contractor* *"Most important is that the schedule is on track and that there are minor deficiencies in piping layout, insulation, and firestop systems."* Mechanical Contractor* *"It all depends on the schedule, as long as the schedule is met, the week is considered productive. No major safety issues happened during the week. Quality assurance and quality control is met. No liquidated damages."* Drywall Contractor *"Only the schedule defines if the week is productive."* Steel Contractor *"We break down man hours used against estimated man hours."* **Three contractors** have no meaning of know a productive week.
How do you control on-site costs?	**One contractor** uses cost codes to ensure that all costs are accounted for on-site. Building Envelope Contractor* *"The PM & CM control the costs on site. Cost codes are used for specific job and line items to ensure that all costs are all accounted for."* **One contractor** has their project manager conduct earned value analysis to control on-site cost. Steel Contractor *"The costs are controlled through the PM ensuring that the project is on track as per schedule and budget."* **Thirteen contractors** responded that they have no form of on-site cost control methodology.
What measures are taken to increase labor productivity?	**Three contractors** argued that proper training on using advanced technology increases overall productivity. Steel Contractor "*Give the crew proper training and tools required to fulfill their tasks in a timely manner."* Mechanical Contractor* The company provides special training on BIM 3D models, paper models, rough areas, prefabrication, and QA/QC Mechanical Contractor* *"There are a lot of hidden pipes and supports in drawings and laborers do not notice that. However, using a 3D or 4D BIM model, laborers can better picture blind spots. The lack of knowledge of picturing a 2D drawing in a 3D*

	world is the obstacle for most laborers." **Three contractors** stated that coordinating material handling and planning a proper site layout will increase labor productivity. Electrical Contractor* *"Centralized lunchrooms in working towers and in-depth material site layouts for all contractors."* Tile Contractor* *"Generally, having a clean, organized job site will reduce wasted time. Excessive material handling due to site conditions can also waste a lot of time."* Drywall Contractor *"Make sure when installing drywall, no other companies are working in that area because moving drywall and cutting drywall requires a lot of working space, and if people are there, it would obstruct traffic."* **Three contractors** discussed that adjusting crew sizes/ makeup, and proper tasks allocation increases labor productivity. Building Envelope Contractor* *"A crew change to individuals more familiar with certain tasks will prove better productivity."* Masonry Contractor* *"Adjusting and juggling crew sizes, swapping workers within various crews."* Mechanical Contractor* *"Changing every crew member tasks every week to identify which task certain crew member is faster in one tasks type than the other."* **Six contractors** discussed a combination of the previously mentioned methods. In addition to the measures highlighted by the contractors, field incentives and adjusting project management practices are also used.
Do General Contractors (GCs) generally have strict rules over TCs?	**Two contractors** stated that GCs do not have strict rules. Stucco (EIFs) Contractor *"No GCs don't have strict rules, they provide all the required information."* Controls Contractor* *"Unless it is a manufacturer project where control is a critical point, GCs of commercial projects do not have strict rules."* **Three contractors** stated that the GCs have strict safety rules on-site that can reduce productivity. Tile Contractor* *"Safety is generally strict (which can improve productivity with less lost time or reduce productivity if it is too onerous). As for preventing information sharing, non-disclosure agreements prevent the sharing of certain information and photos with the public or media."* Masonry Contractor* *"There are high safety expectations that can slow down productivity."* *Steel Contractor "Yes they do, generally in terms of safety. Most GCs are pretty good with providing the required information."* **Three contractors** explained that GCs are often very schedule driven and usually do not allow extra time over the schedule. Mechanical Contractor* *"Most GCs are schedule driven, and when schedule is not met some will issue chargebacks."* Mechanical Contractor* *"GCs that are very schedule driven may board drywall even if plumbing rough-ins are not finished. Then they may issue chargebacks."* Drywall Contractor *"GCs often do not allow extra time from schedule deadlines."* **Seven contractors** chose not to respond to this question.
What it is the best way productivity information can be communicated between General Contractors and Subcontractors? What does the communication need to look like?	**Three contractors** suggested the use of technology, such as BIM models to facilitate productivity and progress tracking. Mechanical Contractor* *"Using a 4D BIM model where components are highlighted in the BIM model allows everyone to look at the project progress."* Steel Contractor "*Daily and weekly meeting do help quite a bit but the use of software such as BIM really help speed up the tracking process."* **Twelve contractors** stated that having daily and/or weekly meetings with the GC and other trades where all participants are transparent in sharing information would be the best method in sharing productivity information.

Note: The General Contractor's specific trades have been identified with '*'.

D.Appendix D

TABLE IV
TC TRACKING METHOD ANALYSIS

Trade	WFP	JPM	Benchmarking	Cost Codes	Other Remarks:
Building Envelope*	Use components of WFP's work packages in their multi scope building envelope projects	The glazing scope of the trade uses tracking similar to JPM's CPIP method where productivity is measured through the onsite progress of work completed.	N/A	Cost codes are used with Excel spreadsheets to separate material and labor costs by line item.	Foreman reports daily productivity to Construction Manager (CM) CM has weekly meetings to review labor performance
Controls*	N/A	N/A	N/A	N/A	Company does not track productivity.
Drywall	Like IWPs, the company will divide a project into different areas & track how many man hours a crew used per area.	N/A	N/A	N/A	For high-rises, they track square feet installed and how long it takes to complete each room and/or floor. For smaller projects they focus on tracking time not production.
Drywall	N/A	N/A	Company has their own baseline metrics for how long it should take to complete tasks	N/A	Use Buildertrend, a construction project management app to monitor project costs, time sheets, and worker hours. Company also utilizes Excel and Microsoft Project
Drywall*	N/A	N/A	N/A	N/A	Has no formal productivity tracking methods
Electrical*	Similar to IWPS, the company breaks down their project by phases.	The company does track productivity on an ongoing basis (hourly) and periodically (weekly) basis as well as the average productivity over the project's life time. This is an important aspect of JPM that the company seems to also follow.	Using their custom productivity tracking software, the company uses benchmarking metrics from past projects as well as the 'NECA (National Electrical Contractors	Company uses 3 generic cost codes for each project, but mainly focus on project phases	Company's custom in-house software is cloud based and enables very in-depth tracking of production, schedule, productivity, efficiency, and costs

Trade	WFP	JPM	Benchmarking	Cost Codes	Other Remarks:
			Association) line' as their baseline for projects		
Hardware	Similar to WFP, each job is broken down by types of components and hardware to be installed.	N/A	N/A	Use cost codes to measure what resources and costs been used for each project.	Use a software called Gantic for productivity tracking and have an in-house estimation software that is used for baselines
Masonry*	N/A	Company uses similar calculations to the JPM ratio of output per unit of input (CPIP).	Use an in-house database w/ historical data and metrics	N/A	Have been using a custom app for the past 3 years, collects daily input from foremen and generates weekly reports
Mechanical *	Similar to IWPs, they breakdown a project into what they referred to as 'zones' and each zone will require 'x' amount of manhours.	N/A	Company will use the estimated budget and man hours as a baseline in which they measure and track their schedule against using Primavera V6	N/A	Company uses a variety of in-house softwares and techniques so it is unknown what actual calculations are used in tracking their productivity
Mechanical *	N/A	They highlight the mechanical components on the drawing and compare it with the total amount time spent on the task. By highlighting, one will know productivity by the total length of pipe installed divided by the total amount of hours spent. This method is very similar to JPM's CPIP	N/A	N/A	Highlight pipelines, risers, & ducts installed on their drawings every week & compare it w/ the total amount of manhours used to finish the installed (highlighted) work
Mechanical	N/A	Follow same highlighting method as the above mechanical trade	N/A	N/A	N/A
Millwork	N/A	N/A	N/A	N/A	Company uses Report Hawk, a camera monitoring software to track productivity. Company also mentioned using Quickbooks to track productivity, this would focus more on budget but also has the capability to track employee hours.
Steel	N/A	Company uses components similar to JPM They measure the amount of steel erected onsite vs what was allowed for in the estimate.	Company does use benchmarking along for installation tasks	N/A	Use of Revit for BIM model and an internal software for resource tracking
Stucco	N/A	N/A	N/A	N/A	Company has no tracking method, their site supervisor 'eyeballs' if the company has been productive during the week
Tile*	N/A	N/A	N/A	N/A	Do not have any formal system of tracking productivity, typically company will work to complete areas/tasks as required by a schedule set by others

Note: The General Contractor's specific trades have been identified with '*'

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