A VALUE-BASED COST-BENEFIT ANALYSIS OF PREFABRICATION PROCESSES IN THE HEALTHCARE SECTOR: A CASE STUDY

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ABSTRACT

In the building construction industry, the healthcare sector is considered to have the highest opportunity to implement prefabrication. Some of the benefits attributed to its implementation are cost savings, schedule acceleration, improved quality and safer work environments, among others. The decision to use prefabrication tends to be based on anecdotal evidence rather than rigorous data, given that no formal methods are available to determine the impact of prefabrication on project performance outcomes. A value-based cost-benefit analysis was conducted on an on-going 831,000 square feet hospital consisting of 360 patient beds, with the input from the major parties involved in the prefabrication process. Four specific prefabricated components were studied: prefabricated bathroom pods, exterior wall panels, overhead MEP utility racks, and patient headwalls. To determine the impact of prefabrication on the project, prefabricated versus traditional site-built performance outcomes were compared in terms cost, schedule, safety, and quality. Each prefabricated component was analyzed individually, as well as the combined impact from all four components. A cost premium of 6% over the traditional site-built cost, as well as a schedule reduction of 10% and over 150,000 work-hours diverted from the jobsite were among the findings from this study. A value-based benefit-to-cost ratio of 1.14 was estimated to be accomplished in this project. This case study shows that direct costs savings is not considered to be the primary benefit of prefabrication, but rather the indirect benefits achieved, such as schedule savings and reduced on-site labor, which can be quite significant when quantified.

KEY WORDS

Prefabrication, Cost-Benefit Analysis, Healthcare Sector, Bathroom Pods, Wall Panels, Overhead Utility Racks, Headwalls

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INTRODUCTION

The healthcare sector has recently reported to be the building sector with the highest use of prefabrication among all types of building construction projects, as well as the sector with the highest opportunity in implementing such construction strategies. Currently, nearly half of all healthcare projects use prefabrication, and it is reported that schedule and costs are the biggest drivers to use prefabrication, followed by safety and quality (McGraw-Hill 2011). Cost savings, schedule acceleration, improved quality and safer work environments are among the most common benefits attributed to the use prefabrication (Haas and Fagerlund 2002). Cost is typically the driving factor when considering the benefits of using prefabrication as a construction strategy, therefore, when considering other value components of using prefabrication, these components are translated into actual dollars.

The decision to use prefabrication has been shown to be based on anecdotal evidence rather than rigorous data, and this has been mainly due to the fact that no formal measurement procedures or strategies are available (Blismas et al. 2006). A major issue in conducting comparative evaluations and analyses on traditional and prefabricated building components is that these methods do not typically account for all the factors that affect cost (indirectly) and other recognized benefits. As Blismas et al. (2006) describe this issue, typical evaluations are *cost-based* and not *value-based* analyses.

By using these existing methodologies, this study has taken an approach that holistically evaluates other value components that are indirect benefits attributed to prefabrication, as experienced by the Exempla Saint Joseph Heritage project. By using actual data as experienced by Mortenson Construction, the general contractor in this project, and its subcontractors involved directly with the prefabrication scope of work, the evaluation method implemented has taken a value-based approach. The hospital project is an on-going 831,000 square feet hospital consisting of 360 patient beds, in which cost, schedule, labor, safety and quality, being some the main performance drivers that were available to the researchers, were analyzed to determine actual project prefabrication performance outcomes.

The purpose of this study is to present the combined effect of four significant prefabricated components implemented in this hospital project and compare and contrast its main performance outcomes with traditional site-built processes. Furthermore, this study is presented an as extension of previous studies that have conducted comparative evaluations for prefabrication components, including prefabricated bathroom pods, in which certain value components were also analysed, and to further extend the methods of proper evaluation of such construction strategies.

PREFABRICATION – DRIVERS, BENEFITS & BARRIERS

Lean construction aims at minimizing waste while maximizing value as one of its core objectives. The utilization of prefabrication fits with the lean building model in its ability to increase productivity significantly (Olsen and Ralston 2013). Pasquire and Connolly (2002) show how lean construction has a direct application through prefabrication of building components and the benefits that result from it. However, they also indicate that such strategies as prefabrication will fail to be incorporated properly if the advantages offered through these strategies are not or cannot be properly evaluated. Prefabrication is defined as “a manufacturing process, generally taking place at a specialized facility, in which various materials are joined to form a component part of a final installation" (Tatum 1987). The term prefabrication in this study is used collectively to refer to the assembly of prefabricated assemblies, modules, or components taken from the field to offsite production (OSP) for subsequent installation in the project site.

Among those benefits that fail to be properly evaluated, significant value-adding components that can be attributed to the use of prefabrication are listed in Table 1. This list provides a well-rounded list in which many of the value components evaluated in this paper are also indicated as being evaluated quantitatively as part of the Benefit/Cost ratio (B/C) or qualitatively (QUAL).

Table 1: Value Components, Expectations (adapted from Table 1-1 in Cook 2013)

Value Component	Prefab Expectation	Evaluated in Study (B/C or QUAL)
Cost (Material and Labor)	Neutral or Lower	**B/C**
Time (Schedule)	Compressed	**B/C**
Design Flexibility	Difficult to make changes	No
CM/GC Coordination Time	Reduced	No
Quality	Equal or Better	**QUAL**
Site Deliveries and Supplies	Reduced	No
Sub-Trade Activity on Site	Reduced	**B/C**
Safety and Worker Health	Increased	**B/C**
Ergonomics	Better	**QUAL**
Weather Conditions	Controlled	No
Environmental Impact	Reduced	No
LEED Certification	Mixed pros and cons	No
Waste and Disposal	Reduced	No
Public Relations	Favorable	No
Marketing	Favorable	No
Maintenance (Lifecycle)	Improved	No

A recent detailed study comparing site-built vs. prefabricated hospital bathroom pods (Cook 2013) found that the bathroom pods reduced the construction schedule from 45 to 19 days, a 58% decrease in time, which is a significant overall construction schedule improvement. In another study, Blismas (2007) evaluated 7 case studies in Australian construction implementing OSP methods ranging from buildings, to transport, to stadium projects in which many different prefabrication components were ultimately evaluated to determine the main drivers and benefits of OSP in general. Typical barriers were also identified, such as lengthened lead times, need to fix designs at an earlier stage of the project process, need to specifically design products and building components, very low IT integration in the construction industry, and high fragmentation in the industry among many others. Finally, as indicated, a big part of prefabrication in achieving lean construction goals is through the improvement of productivity, for which Eastman and Sacks (2008) have shown that OSP in the construction industry has had a consistently higher productivity growth than on-site construction productivity.

THE CASE STUDY

Mortenson Construction was charged with building the 831,000 sf, 360 patient bed Exempla Saint Joseph Heritage Project in 29.5 months. As reported by the Denver Business Journal (Proctor 2012), the fact that the hospital has to open by January, 2015 drove Mortenson to figure out how to accelerate construction and yet maintain the highest quality standards while doing so. The traditional, on-site linear approach would have resulted in a 36-month schedule which was not acceptable. An overall 15% schedule compression was required, to achieve a 29.5 month schedule.

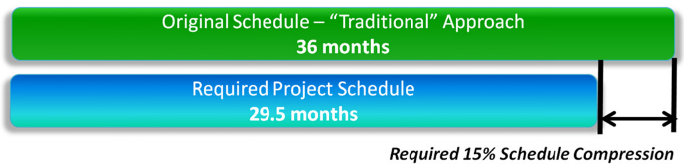

Figure 1: Required Schedule Compression

Prefabrication quickly became the solution and was a major contributor to this acceleration which allowed for some building elements to be built off-site simultaneous with the construction of the hospital. This also allowed for a significant number of trades to be pulled forward that otherwise could not begin on site until later in the schedule under a traditional approach. The project team searched for all possible components in the facility which would be conducive to the repetitive prefabrication process. The four major prefabrication efforts that were chosen included patient and administrative bathrooms, exterior wall panels, multi-trade utility racks and patient room headwalls. The amount of prefabrication for each component is summarized below in Table 2. Although the holistic analysis performed on a per level basis cannot be appreciated given the space limitations of this paper, it is worth noting the per level workforce density that can be expected to be reduced, as shown in this table.

Table 2: Summary of Total Prefabricated Units per Component and Floor Level

Floor Level	Bathroom Pods		Wall Panels		MTR's		Headwalls	
LL	10	2%	0	0%	0	0%	0	0%
1	34	8%	0	0%	0	0%	15	4%
2	28	6%	0	0%	0	0%	0	0%
3	12	3%	0	0%	0	0%	1	0%
4	63	14%	82	24%	54	33%	76	20%
5	15	26%	74	21%	48	29%	108	29%
6	16	26%	72	21%	41	25%	108	29%
7	62	14%	18	34%	23	14%	68	18%
Total:	440	100%	346	100%	166	100%	376	100%

Figure 2: Typical Prefabricated Bathroom Pod & Wall Panel

The prefabricated bathrooms pods installed in the project were manufactured by a leading third party manufacturer of prefabricated bathroom pods for hospitals, hotels, dormitories, and multi-unit residential projects. Prefabricated bathroom pods are completely finished inside and are designed and accessorized per the architectural and MEP plans. Everything is pre-installed, including towel bars, mirrors and paper holders.

The prefabricated wall panels were built at an off-site fabrication facility established by the framing subcontractor for the purpose of the project from which the framing, sheathing, weather barrier, spray foam air barrier, brick ties and rigid insulation were assembled prior to delivery to the construction site for installation.

Figure 3: Typical Prefabricated Multi-Trade Rack & Patient Headwall

The multi-trade utility racks (MTRs) were prefabricated off-site at a warehouse that was set up for the purpose of prefabricating the MTRs and patient headwalls within 10 miles from the actual construction site. The warehouse was approximately 60,000 SF, which had sufficient storage space for all the material needed and up to two 2 floors worth of fabrication ahead of schedule. This, being one of the benefits of prefabrication, allowed the team to maintain a strong buffer to account for unforeseen events on-site. The MTRs fabrication off-site consisted of the rack structure, cable tray and electrical components, HVAC ductwork, piping, insulation, and to some extend framing and drywall for special installation scenarios. The patient headwalls, similarly were prefabricated with the main framing of the headwall, installation of mechanical outlets and piping such as oxygen and carbon dioxide, electrical, data and light components, and finally the casework.

In general the process comparison that was evaluated for this research, in retrospect to what can be considered the life cycle of the prefabricated components, was focused on mainly considering the beginning of the off-site production for each of the four components, through delivery and final installation of each component. This boundary for the purpose of the study was necessary given that the project is still currently in progress and the conclusions past detailing are hard to quantify at this moment.

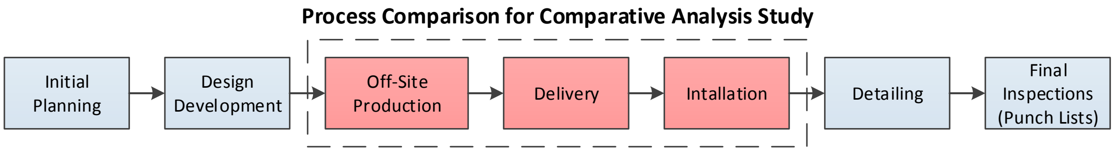

Figure 4: The Study's Focus during the General Prefabrication Process

METHODOLOGY: A VALUE-BASED COST-BENEFIT ANALYSIS

Proponents of prefabrication typically agree that cost comparisons based on the deductive credit that accounts direct material and labor costs, ignores other indirect value-adding benefits. Such comparisons that only take direct cost into consideration, often give the site-built cost and equal or lower cost than the prefabricated cost as shown in Table 1. In order to conduct a comparative cost-benefit analysis on the performance outcomes achieved by the use of prefabrication in this project, the researchers established the performance outcomes of the prefabricated components as the base case, and compared it to the site-built hypothetical scenario.

A cost-benefit analysis is used to evaluate investments when the investor, which for this case-study is seen from the perspective of the general contractor, is trying to determine if the resulting benefits from the investment exceed the cost of the investment. To measure such an investment in prefabrication, this measure can be expressed as the benefit-to-cost ratio (B/C) of the investment:

B/C = total benefit from prefabrication / total prefabrication cost (1)

If the B/C ratio is greater than or equal to one, then the investment in prefabrication would be considered economically acceptable, and when the ratio is less than one then it is not. This is an approach that was developed from a similar study in which the analysis of the investment on construction craft training in the United States was evaluated in a similar manner (Wang et al. 2010). Having established this analysis, the research team then determined what value components would be realistic to obtain from many of the subcontractors performing these scopes of work, and how reliable and objective such data could be. As discussed in Blismas et al. (2006), the traditional cost-based approach often lacks the "soft" aspects of benefit evaluation models, which considers other value components such as labor, safety, and quality that are not typically accounted for, thus providing a more balanced evaluation. To determine the B/C ratio shown above, the hypothetical cost and performance of the same scope of work for the base case was determined for site-built processes. The overall B/C ratio was defined as:

$$B/C = \frac{[SiteBuilt\ Costs + Schedule\ Savings + Incident\ Costs\ Avoided]}{Prefabricated\ Costs} \qquad \textbf{(2)}$$

In this case, the *Site-Built Costs* are the direct material and labor costs for the same scope of work performed for the prefabricated processes in this project, the *Schedule Savings* is the amount of potential general conditions (GC's) avoided due to prefabrication, and the *Incident Costs Avoided* is the cost of potential injuries avoided due to the use prefabrication as reflected per the general safety performance statistics on the project. In order to determine these three values, the site-built hypothetical scenario was compared to the prefabricated performance in terms of costs, schedule, safety, and labor, discussed next.

CASE STUDY RESULTS

In the following section, the results for each of the main performance outcomes measured in this case study are presented. For each prefabricated component, each outcome was analyzed individually (shown as pods, panels, MTRs, and headwalls) and then the four prefabricated components were analyzed collectively (total prefab) to determine the overall impact on the project. Due to the site limitations of this paper and confidentiality of the data provided by the suppliers and the general contractor involved, detailed itemized costs, material, labor-hours and safety statistics are not shown, except for the conclusive results.

COST

In this section, the *direct* costs due to labor and material for each of the four prefabricated components were analysed. For each of the prefabricated components analysed, a detailed cost breakdown sheet was developed in which all of the subs involved in the scope of work related to the specific prefabricated components were asked to provide detailed data for the analysis. Using the parties involved directly in the project provided a more realistic input for the expected direct costs under the hospital-specific conditions, which were then validated with documentation from the general contractor. For each prefabricated assembly, either a *typical type 1 bathroom pod*, a *15'W x 30'L wall panel*, a *typical 25'L x 8'H x 3'H MTR*, or a *typical patient room headwall* were considered to be the units of analysis. These are discussed in detail above in the case study description. From this analysis, the productivity rates, labor cost, work-hours, and material cost allowed for the analysis to make an overall comparison of prefabrication vs. site-built costs.

Table 3: Direct Cost Comparison Results

	Bathroom Pods	Wall Panels	MTRs	Headwalls	Total Prefab
Unit of Analysis:	**Type 1 Bathroom Pod**	**15'H x 30'W Wall Panel**	**25'Lx8'Wx3'H MTR**	**Patient Room Headwall**	**All Prefab**
Total Units:	440	346	166	376	**1,328**
Area (SF) / Unit:	51	284	200	72	**N/A**
Length (LF) / Unit:	N/A	19	25	N/A	**N/A**
Total Area (SF):	22,440	98,325	33,200	26,997	**N/A**
Total Length (LF):	N/A	6,458	4,150	N/A	**N/A**
Prefabrication Direct Cost	**$ 9,498,000**	**$ 3,405,000**	**$ 3,006,000**	**$ 6,655,000**	**$ 22,560,000**
Site-Built Direct Cost	**$ 9,082,000**	**$ 3,535,000**	**$ 2,471,000**	**$ 6,187,000**	**$ 21,280,000**
Total Direct Cost Delta	**$ 416,000**	**$ (130,000)**	**$ 535,000**	**$ 468,000**	**$ 1,280,000**
% Direct Cost Delta	**4.6%**	**-3.7%**	**21.7%**	**7.6%**	**6.0%**

By using the results from the detailed cost breakdown for each prefabricated component, the overall direct cost impact due to using these prefabricated components can be calculated. Note that given the complexity between the many different amounts of prefabricated units developed, such as different types of bathroom pods and wall panels, a generalization for the total cost for each of the prefabricated components was carried out to develop a cost comparison based on the amount of prefabrication found in the project (number of units).

SCHEDULE

In order to determine the impact that using the prefabricated components had on the project, each particular prefab component was individually analyzed to determine how the schedule was affected. The impact that all prefab components together had on the project schedule was then determined, that is the total impact. A baseline schedule was first established in which all of the prefabricated components were included in the schedule logic and durations. This *baseline schedule* was the project schedule, updated through at the time of analysis. The start of construction of the main hospital building was December 15, 2011. The baseline completion date, considered to be the Certificate of Occupancy date in this study, was July 1, 2014. The overall construction duration for the hospital is therefore *929 calendar days*, which is equivalent to *649 workdays* for the project including all standard federal holidays that fall in between these dates. This was the baseline schedule length used for the analysis of the schedule.

For each of the prefabricated components, it was first determined how best to adjust the baseline schedule to reflect how using the traditional approaches can be realistically reflected within this baseline schedule. To do this, for each of the components, the primavera schedule of the project was adjusted by inserting schedule fragnets that reflected the traditional site-built processes developed, where the prefabricated activities were scheduled. The fragnet included all on-site activities and logic necessary to build the components traditionally, on-site, with the trade flow on each floor. Once each schedule was adjusted reflecting the alternative site-built option, the impact on the project schedule due to each adjustment (additional days added to the overall construction duration) was then used to determine the potential impact on the project. The indirect impact that each component has on the project was quantified by calculating the potential general conditions (GC's) that were avoided by the general contractor and subcontractors, having finished the project earlier due to prefabrication.

Table 4: Schedule Impact Comparison Results

	Bathroom Pods	Wall Panels	MTRs	Headwalls	Total Prefab
Total Baseline Duration (Work Days)	649	649	649	649	**649**
Additional Work Days due to Site-built	52	41	20	0	**72**
Total Duration for Site-Built (Work Days)	701	690	669	649	**721**
% Schedule Delay Avoided	**7.4%**	**5.9%**	**3.0%**	**0.0%**	**10.0%**
Avoided GC's Cost (rates not shown)	**$ 3,124,000**	**$ 2,384,000**	**$ 1,192,000**	**$ -**	**$ 4,275,000**

From the results shown above, it can be observed that of the four prefabricated components, the prefabricated bathroom pods have the most significant impact on the schedule by avoiding a potential schedule delay of up to 2.5 months (52 workdays for this project). This is equivalent to a 7.4% schedule delay of the baseline schedule discussed above. All of the prefabricated components (bathroom pods, wall panels, MTR's, and headwalls) grouped together avoid 72 workdays from the project once the schedule is adjusted with all four components, which is approximately a 10% schedule delay of the baseline schedule. The fact that the prefabricated bathroom pods have such a significant impact on the overall schedule demonstrates the importance of this scope of work in the schedule's critical path.

LABOR & SAFETY

As discussed before, one of the major indirect benefits that prefabrication brings is the amount of labor reduced and moved from on-site to off-site work. This, in turn, results on improved safety performance for the project as a whole given the amount of reduced exposure to typical dangerous on-site working conditions. This may not only affect the workers directly being involved in the prefabricated components but also the workers working near or within the same scope of work. A summary of the estimated impact on labor for the project due to prefabrication is shown below for each prefabricated component, and then cumulative for all components together. Similarly, due to space restrictions and confidentiality, only the total comparative results are shown below for reference.

Table 5: Labor Comparison Results

	Bathroom Pods	Wall Panels	MTRs	Headwalls	Total Prefab
Total Prefab Work-hours:					
Off-Site Prefab w-h	50,600	27,770	28,280	14,350	**121,000**
+ On-Site Prefab w-h	3,520	6,290	7,500	3,010	**20,320**
= Prefab w-h	54,120	34,060	35,780	17,360	**141,320**
Total Site-built Work-hours:					
Site-built w-h	81,820	39,210	31,070	18,700	**170,800**
Total Diverted Work-hours:					
Reduced On-Site Labor Hours	78,300	32,900	23,600	15,700	**150,500**
Diverted w-h	27,700	5,150	-4,710	1,340	**29,480**

Reducing labor on-site has a direct impact on productivity improvements on-site given the reduction of congestion within working areas throughout a building, and it also creates the space and morale of a more efficient and safe working environment.**Error! Reference source not found.** As shown, using prefabrication in this hospital project, it is estimated that the number of work-hours on-site throughout the life of the project will be reduced by 150,500 hours. Using a standard measurement of 2080 work-hours per year per worker, which is 40 hours a week for 52 weeks, an estimated amount of workers per prefabricated components can also be calculated:

$$\textbf{\# workers = (total work-hours)/(2,080 w-h/year) x (Duration/365) yrs.} \quad (3)$$

The duration is the amount of workdays that were concluded in the schedule analysis. The estimated direct cost avoided by reducing this amount of workers is taken into account per the direct cost discussed earlier, however, the indirect burden for each additional employee depending on each subcontractor, such as hiring costs, supervision and training costs could be quite significant.

In order to determine how the use of prefabrication in this project impacted safety performance, project-specific safety performance outcomes were analyzed. Based on previous academic work on safety risk quantification, a methodology based on probability, frequency and severity was used to quantify safety risk (Hallowell 2010). The type of incidents reported for this project are first-aid injuries, medical-only (MO), restricted-duty (RD) and lost-time (LT) incidents, which are also considered to increase in severity in that same order. Only MO, RD, and LT are considered to be recordable injuries, which are the incidents that determine the recordable injury rate (RIR) for the project. Incident history for the project at the time of data collection was used to produce the following results. Note that the frequency and severity rates have been hidden for confidentiality porposes.

Table 6: Safety Impact Comparison Results

		Bathroom Pods	Wall Panels	MTRs	Headwalls	Total Prefab
Total On-site Diverted w-h		**78,300.0**	**32,900.0**	**23,600.0**	**15,700.0**	**150,500.0**
Avoided On-site Incidents	**Frequency (w-h/incident)**					
First Aid		2.33	0.98	0.70	0.47	4.48
Medical Only		0.94	0.40	0.28	0.19	1.81
Restricted Duty		0.20	0.08	0.06	0.04	0.38
Lost Time		0.10	0.04	0.03	0.02	0.19
Total Avoided On-Site Incidents		**3.57**	**1.50**	**1.08**	**0.72**	**6.86**
Avoided Incident Direct Risk Cost	**Severity ($/incident)**					
Avoided On-site First Aid		$ 1,385	$ 582	$ 417	$ 278	$ 2,662
+ Avoided On-site Medical Only		$ 1,545	$ 649	$ 466	$ 310	$ 2,970
+ Avoided On-site Restricted Duty		$ 2,685	$ 1,128	$ 809	$ 538	$ 5,161
+ Avoided On-site Lost Time		$ 2,784	$ 1,170	$ 839	$ 558	$ 5,351
= Incident Direct Risk Cost Avoided		$ 8,399	$ 3,529	$ 2,532	$ 1,684	$ 16,144
+ Incident Indirect Risk Cost Avoided (5xDirect)		$ 41,995	$ 17,646	$ 12,658	$ 8,421	$ 80,719
= Total Incident Risk Cost Avoided		**$ 50,395**	**$ 21,175**	**$ 15,189**	**$ 10,105**	**$ 96,863**

BENEFIT-TO-COST RATIO

These benefits that prefabrication brings that can be quantified to some extent, such as direct labor and material costs, schedule cost savings, and indirect injury avoidance costs, can all add up to the benefits experienced by the general contractor by implementing prefabrication in this project. These benefits, having been explored in depth by analyzing project-specific data available, have been quantified to discuss the overall benefit-to-cost ratio of prefabrication per individual prefabrication component and grouped together, as experienced in the project.

Table 7: Benefit-to-Cost Ratio Analysis

B/C Analysis	Bathroom Pods	Wall Panels	MTRs	Headwalls	Total Prefab
Benefit					
Total Site-Built Cost Investment	$ 9,082,000	$ 3,535,000	$ 2,471,000	$ 6,187,000	**$ 21,280,000**
+ Total Schedule Cost Savings	$ 3,124,000	$ 2,384,000	$ 1,192,000	$ -	**$ 4,275,000**
+ Total Incident Cost Avoided	$ 50,395	$ 21,175	$ 15,189	$ 10,105	**$ 96,863**
= Total Benefit	$ 12,256,395	$ 5,940,175	$ 3,678,189	$ 6,197,105	**$ 25,651,863**
Cost					
Total Direct Prefab Cost	$ 9,498,000	$ 3,405,000	$ 3,006,000	$ 6,655,000	**$ 22,560,000**
Benefit/Cost Ratio	**1.29**	**1.74**	**1.22**	**0.93**	**1.14**

Based on the presented value-based cost-benefit analyses performed on the most significant performance drivers for prefabrication (schedule, cost, and safety), the B/C ratios shown above show the efficiency of the prefabricated components for the project. The value-based benefits that all of the prefabricated components studied in this project add can be quantified to provide an overall B/C ratio of 1.14. The benefits can be interpreted as having the ability to provide the actual building components being prefabricated (at a regular site-built cost), the indirect schedule cost savings and the incident costs avoided due to prefabrication. The cost for each of the prefabricated components is interpreted as the direct cost of using prefabrication. For every dollar spent on prefabrication for this project, approximately 14% of the invested amount is expected to be returned on benefits to the project.

QUALITY & QUALITATIVE ASPECTS

Initial findings regarding the impact of prefabrication on quality outcomes are were inconclusive at the time this study was conducted. As the project is currently in progress, it is not possible to quantify the resultant quality comparison as a "punchlist" has not been generated yet. Preliminary anecdotal responses from team members indicate an improvement in quality-related discrepancies for each component thus far. Ultimately, a comparison should be made between the quantities of punchlist items generated in each prefabricated component compared to the quantity of punchlist items generated in a site-built scenario within the project. This data can convey the difference in labor-hours required for punchlist, the labor cost savings or premium and the schedule impact.

CONCLUSIONS & FUTURE STUDIES

This value-based cost-benefit analysis performed on four prefabricated components for the Exempla Saint Joseph Heritage Project has shown how some of those benefits that fail to be properly evaluated, significant value-adding components that can be attributed to the use of prefabrication, have impacted this project significantly. As shown in Table 1, many more feasible value components that could be quantified can make this increase of decrease respectively. This has only considered some of the performance outcomes and benefits that add the most value, therefore this is B/C ratio is the minimum expected return in investment.

The individual return on investment for prefabricated wall panels could potentially be up to 1.74 given the significant impact on schedule that has been shown. A large part of the return on investment from prefabrication on this project could be attributed to the schedule cost savings accomplished by the use of prefabricated wall panels in particular. The impact on safety performance is significantly lower per the estimated quantities for incident avoidance based on historical project-specific data. The representative workforce involved on in this project, however, is approximately only 4.6% of all of the workforce, therefore, such a big improvement in safety cannot be expected to come from such a small percentage of the work for the size and complexity of this project.

Future studies to expand on this findings could further determine measurable metrics to implement for the comparison of quality performance for prefabrication vs. site-built processes by quantifying these outcomes. Environmental and sustainability impacts are also other measurement that could be included to provide a more holistic evaluation. Furthermore, to expand the results from this study, considering the shown B/C ratios, a post-analysis of the same project could shed light into the actual use of such value-based analyses and if the expected benefits drive with the suggested B/C ratios. Should one consider the average B/C ratio of several components or only use components with a B/C ratio greater than 1.0? Such considerations must look beyond the direct costs savings as the primary benefit of prefabrication, and take into account the indirect benefits achieved, such as schedule savings and reduced on-site labor, which can be quite significant when quantified.

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