Examination of Supply Chain Challenges in Large Scale Exterior Building Panels from the Perspective of an ETO Fabricator

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Abstract

Finding the appropriate balance for Engineer-to-Order (ETO) prefabrication firms between work in process (WIP), finished goods inventory, buffer hedging, transportation time and the field installation consumption rate is difficult to determine. The difficulty arises due to the high degree of variability in the product offerings to meet the architectural and performance requirements of different projects and locations where the products will be delivered and installed. Variability also exists in plant production rates, on-site equipment availability, and efficiency of on-site installation crew. This paper examines these challenges of ETO panel fabricators and evaluates potential applicable solutions. In addition to the analysis for a single firm, a survey of firms performing similar work spread across the continental US was conducted to gauge their respective solutions to similar problems. The majority of the respondents plan to commence fabrication in advance of field operations and half of the respondents have experienced situations where they had to slow or halt production of the panel products due to storage constraints.

Keywords
Prefabrication, Construction, ETO, Supply Chain, Exterior Panels

1. Introduction

Substantial research and publications have addressed the productivity trend in the construction industry and its failure for appreciable improvement for decades. Industry stakeholders continue to be frustrated with expanding construction schedules and increased project costs. Construction is a capital intensive and, payment terms vary throughout the tiers of contracting and supply chain. All stakeholders in a construction project want to minimize carry costs while completing projects, however, carry costs for some firms are more substantial.

Industrialized Construction (IC) and Modern Methods of Construction (MMC) are evolving applications of manufacturing methodology and lean practices to improve the productivity and final project outcomes in the construction industry. This is achieved through the decoupling of sub-assembly operations from the traditional construction site and fabricating these building components at facilities located off-site. An accepted overarching term utilized throughout the construction industry is *prefabrication*. To meet this demand the majority of prefabrication companies deliver their products in an Engineer-to-Order (ETO) model.

Precast concrete has been available to building owners for decades as an exterior cladding option for their facilities. Unitized glazing systems have offered building owners an exterior system that can be preassembled on or offsite and installed as large units on the façade, improving overall productivity. Other prefabricated exterior systems, such as the panel systems fabricated by the ETO companies examined by this research, are multi-layered high-energy performance cladding systems that aggregate multiple building materials to create the panels. Panel products generally are assembled with a structural frame made of cold-formed metal studs, glass mat sheathing, a liquid applied air barrier, some form of insulation and varying finishes such as metal panel, cement siding or EIFS.

Whether it be precast, unitized glazing or prefabricated exterior panels, these units are large and take up substantial space while being staged at either an offsite facility or onsite. Depending on the jobsite or the prefabrication facility location, staging areas are often limited. Some jobsites may constrain the subcontracting companies to follow a Just-In-Time (JIT) delivery approach because there are insufficient staging areas within the confines of the site.

Large scale prefabricated components require mechanical lifting assistance at multiple locations such as at the factory, intermediate staging yard (if necessary) and for final installation at the construction site. In aggregate, these multiple locations through the supply chain for a specific project increases handling costs because of the frequency of utilization for lifting equipment. Depending on the project, some projects employ ground based typical crawler or hydraulic cranes that can be substantially utilized throughout the workday for the installation of prefabricated exterior panels. Unquestionably this improves productivity of the onsite installation crew but increases demand on the factory because the consumption rate of the finished goods is increased. Due to various site conditions, cranes may be managed as a shared resource and the erection time in a given shift may be limited to as short as 2 hours a day or may be required on a second shift. This situation can constrain the productivity of the installation crew. The productivity of the installation crew has a direct impact on the demand of finished goods from the ETO and the demands for managing finished good inventory.

The complexity of the design solution resulting in the panel products also has an impact on the supply chain because it impacts the fabrication time of the panel products. Fabrication times for panel products can range from 5 factory days to 11 factory days. However, the complexity of the panel has little impact on the installation efficiency as an average panel installation crew can install a panel in a time range of 17-60 minutes. The imbalance in these production and installation times generally requires that the majority of a panel project is fabricated prior to the commencement of installation to buffer against onsite delays.

ETO companies must assess multiple strategies for addressing management of their finished goods inventories to align both installer and customer demands.

1.1 Objectives

The objectives of this paper are:

- Evaluate methods utilized by exterior panel prefabrication companies for addressing storage and staging constraints for finished goods inventory to examine three hypotheses:
    - ETO panel fabricators must commence fabrication well in advance of field installation operations to provide adequate finished goods to the project.
    - ETO panel fabricators routinely have storage capacity challenges relative to finished goods inventories.
    - Due to storage capacity challenges ETO panel fabricators have experienced negative impacts relative to their production efficiency.
- Evaluate past projects and trucking needs for a panel manufacturer to determine a potential location of an off-site staging facility to alleviate capacity challenges.
- Analyze trailer cost implications for lease/rental of units versus ownership for storage of finished goods.

2. Literature Review

Historical construction procurement and supply chain configurations in construction have looked to increase the number of vendors but that has proven to increase the costs of construction projects through a study of a precast facility, one of the original offsite claddings. (Arashpour, et al., 2017) Like precast and panel products, modular solutions need to integrate into the construction supply chain. (Doran and Giannakis, 2011) The construction supply chain is often fragmented and the often-unpredictable variability in demand creates barriers to change (Fernie and Thorp, 2007). The modern-day constructor is looking to efficient methods to improve project performance, therefore, IC and MMC are of particular focus.

Precast concrete companies have experienced, for years, the challenges currently being experienced by prefabricated panel manufactures. Ko (2011) determined that variability in demand on construction sites for precast products was a barrier to success because of the demand for on-time delivery to keep projects on schedule. Through this research a formulaic representation of the fabrication lead time (FLT) was developed. (Equation 1)

$$FLT = WDT + SDT + PT + AT + DT \text{ (Ko 2011)} \qquad (1)$$

where WDT is waiting for design information time, SDT is the show drawing production and review time, PT is the procurement time, FT is the fabrication time, AT is the preassembly time and DT is the delivery time. The ability to project a lead time allows the precast fabricator to project when they must commence with project activities to insure adherence to the project schedule and delivery demands. JIT for precast concrete products have contributed to 7-10% productivity improvements in precast projects (Low 2001). Even with the forecasting of lead times, often there are delays on the construction site due to weather, other subcontractor delays. This impacts the precaster through delayed requirements for delivery and therefore the need to store finished goods.

Communication between the project site and ETO companies can be challenging relative to demand needs and creates a disruption in the production process. Panova and Hilletofth (2018) utilized dynamic modeling to attempt to manage construction supply chain risks caused by delays. Their research recommends that suppliers implement safety stocks as a method of minimizing disruptions. Zhai, et al. (2018) determined that utilizing buffer space for safety stock also minimized disruption of the production sequence and onsite activities, ultimately reducing the bullwhip effect. While the managerial approach of creating safety stock to address the fluctuating demand prevents the potential site disruption caused by delayed deliveries may appear to address the problem, it creates a secondary problem of storage for large construction components and assemblies. Feng et al (2018) utilized Stackleberg Game simulations to forecast equilibrium for the decision makers in order to optimize the construction supply chain. Yi, et al. (2018) developed a formulaic approach to minimize inventory holding costs and the number of trucks for transporting prefabricated units. However, their approach looked at the weight and the volume and did not consider the actual dimensions that are critical to handling and trucking restrictions. Matt, et al (2014) developed a relational equation to align the manufacturing processes of ETO companies to synchronize with the demand called for on the construction site similar to a pull system in manufacturing (Equation 2).

$$\textit{ProductionPlan} = \textit{Installation Need (Product ID + 1)} + \textit{Target Stock} - \textit{Minimum}\ \text{Stock} \quad (2)$$

Alternatively, Dubois, et al. (2018) examined multiple approaches to logistic configurations for the construction supply chain. Of their configurations a coordinated configuration with a single logistical staging operation for a construction project would minimize the onsite storage constraints that many fabricators experience. Figure 1 depicts this configuration.

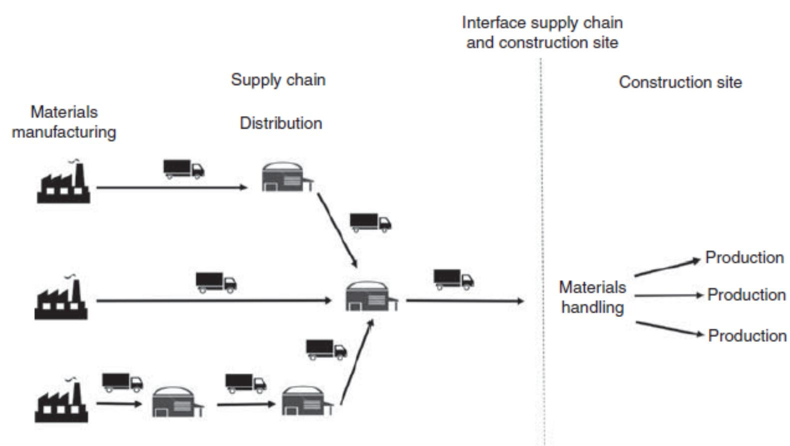

Figure 1. The supply network coordinated configuration (Dubois et al., 2018)

The importance of thorough planning in construction supply chain is a critical step increasing the likelihood of a successful project (Thunberg and Fredriksson, 2018) and it becomes even more critical when utilizing ETO prefabricated components (Rauch et al, 2018). Lyu et al. (2020) examined the positive impact on the project costs and nonvalue add process of Zero Inventory compared to the benefits to the project utilizing a Smart Manufacturing Zero-Warehousing approach that relies on communication and feedback between the ETO companies and construction site. An example of this configuration is presented in Figure 2. The importance of communication between the onsite installation and the ETO company is critical to the successful outcome of the project. Inter-organizational coordination, cooperation and learning to form an overall project team focused on executing a successful project versus multiple independent teams can be achieved (Love et al, 2004). Digital tools such as RFIDs (Naranje and Swarnalatha, 2019) and mobile based platforms (Shi et al. 2016) have been utilized as a means to provide the feedback to the factory relative to demand.

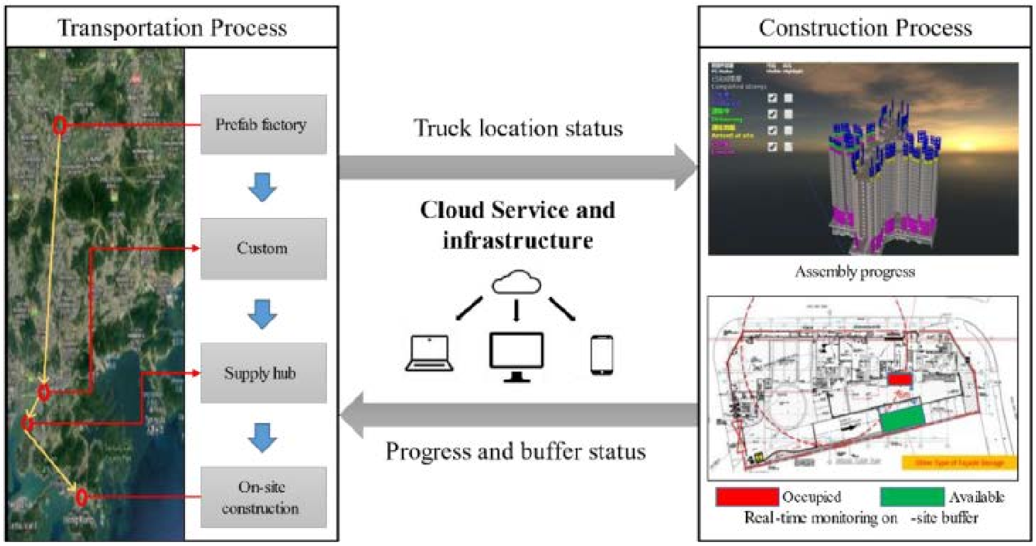

Figure 2. Zero-Warehousing Smart Manufacturing Configuration (Lyu et al., 2020)

The supply chain in traditional construction has not driven value to the point of enabling enhanced productivity but, has adapted to respond to needs of specific actors. However, with the industry's migration to IC and MMC, an efficient supply chain is necessary to provide the full benefits of decoupling the work from the jobsite. Although there are benefits and synergies gained for the project through the engagement of ETO firms, unique risks exist if not thoughtfully and effectively managed. Modern research applications of supply chain principals to construction projects utilizing ETO components will enhance outcomes.

3. Methods

3.1 Survey Methods

In order to evaluate solutions to supply chain challenges affecting the industrialized construction ETO fabricators of exterior panels, a survey is conducted of ETO fabricators to solicit what methods they traditionally utilize to manage their finished good inventory prior to shipment to the jobsite for installation. A survey was created using the online platform Survey Monkey. The survey included collecting information relative to the ETO's years of experience fabricating exterior panels, geographic region, finished goods storage techniques, impacts of field production on production. A Likert Scale (Barua, 2013) was utilized for multiple questions in the survey to determine the respondent's reaction or level of agreement to an affirmative statement. Similar survey approaches were utilized by other researchers. Low (2001) utilized a survey relative to precast concrete prefabrication and Thunberg and Fredriksson (2018) utilized a survey to examine the problems in the construction supply chain.

3.2 Centroid Method

The paper is based on a case study review of a ETO fabricator located in Michigan. An examination of the prior 24-months of completed projects are examined to determine, using the Centroid Method, a city for the ETO fabricator to evaluate a staging yard for finished goods inventory. The result of this calculation will then be compared to future projections relative to project location and truck quantity to determine if the calculated solution provides a long-term solution.

According to Jacobs and Chase (2014), the Centroid Method is "a technique for locating single facilities that considers the existing facilities, the distances between them, and the volumes of goods shipped." The approach is utilized to find a future location of a warehouse or other facility relative to an existing starting point which is often a factory or production facility. In order to calculate a solution utilizing the centroid method one needs to have determined the relative X and Y coordinates for current delivery locations relative to the factory, the volume of goods shipped to each of those locations and the total volume of all the goods shipped.

3.3 Trailer Cost – Lease/Rent versus Purchase

Finished panel products are transported over the road utilizing flatbed air-ride trailers. Depending on the size of the project, the need for staging, the availability of hoisting equipment and concern for damage to the project if handled excessive times, ETO fabricators require the utilization of several trailers. An analysis of rental/lease of the necessary trailers compared to purchasing a fixed quantity of trailers will be evaluated as a complimentary or stand-alone solution to the staging yard.

The purchase price of a trailer with calculated utilizing monthly installment payments will be compared to the current one-year lease payments. In this scenario, the necessary maintenance of the trailer, including certifications, is the responsibility of the lessor and costs of same are included within the lease payment.

Yearly leases of trailers mitigate maintenance related costs as most of the units include necessary maintenance being provided by the lessor. Menichini and Romano (2018) evaluated lease versus purchase scenarios for construction equipment. They determined that maintenance related costs are a cost variable that is difficult to manage through typical lease agreements and often is a cost overlooked through a direct purchase agreement. Supriatna, et al. (2017) investigated the required down time and the amount of maintenance required on construction equipment to keep them operating efficiently. Here again the comparative cost of lease versus purchase needs to be evaluated to take into account the holistic view of ownership versus a defined commitment. Future projected revenue along with backlog can provide insight into the quantity of trailers required throughout a fiscal year of the ETO.

4. Results and Discussion

4.1 Numerical Results

4.1.1 Survey

Based on information and belief of the author, there are less than 24 companies in the United States and Canada with dedicated facilities producing similar panel products as the ETO being examined. A survey was created to solicit feedback from 12 companies that do not have a competitive conflict with the ETO. Of those 12 companies, 8 responses were received netting a 66% response rate. The survey was structured with two basic forms of questions. There were structured as statements in the affirmative with choices utilizing a Likert scale. There were also questions that provided predetermined ranges for the respondent to select a choice they felt best represented the experience of their firm. The questions solicited responses to support or disprove the hypothesizes. Table 1 presents the relevant questions and attendant available answers per question.

Table 1. Survey Questions and Available Answers

Question	Answer Choices
How much of the panel project (as a %) do you target to have complete prior to installation starting?	25%; 26-50%; 51-75%; 76-90%, 90%+
How many projects do you typically have some portion of in storage as finished goods inventory?	1; 2-3; 4-5; 5+
Where do you store your completed panels?	In the Factory; On trailers staged on your facility property; On trailers staged at a temporary location (3rd party owned); At grade at your facility; on the jobsite until installation
There have been instances where your production line needed to slow down or stop because you had exceeded your storage capacity for finished panels.	Strongly agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree; Other
As part of your planning and fabrication, you establish a minimum or safety stock of completed panels to minimize the potential that the panel installation process will be halted due to lack of available finish panels.	Strongly agree; Agree; Neither Agree nor Disagree; Disagree; Strongly Disagree
How do you procure the trailers utilized for the transportation of the finished panels?	Own; Lease/Rent; Rely on trucking company to provide

Hypothesis 1: *ETO panel fabricators must commence fabrication well in advance of field installation operations to provide adequate finished goods to the project.*

The survey included a question asking the ETOs to select what percentage of a panel project do you plan to have complete prior to the commencement of installation operations. Five predetermined responses were provided ranging from a minimum of 25% to a maximum of 100%. Figure 3 presents the responses received.

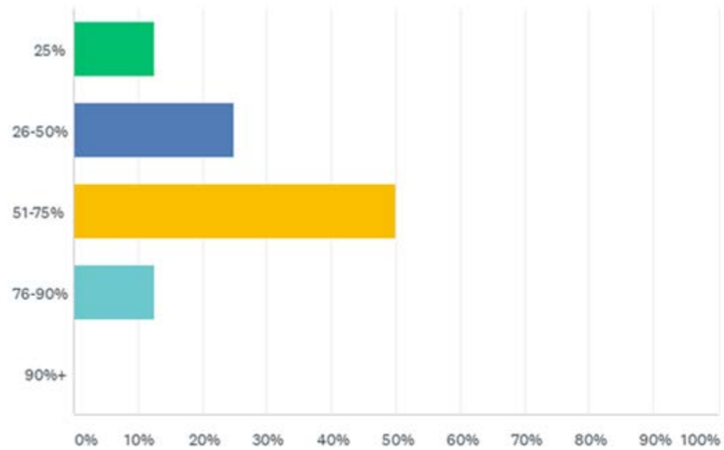

Figure 3. Target Percentage of Panel Project Completed Prior to Starting Installation

Based on the responses, the majority of the respondents target more than 50% of the project complete prior to the commencement of installation operations.

To further evaluate the ETOs strategy relative to the quantity of finished goods necessary prior to installation commencing, the survey requested the degree to which the ETO agreed that their firm, as a standard practice, established a minimum safety stock for finished good for each project. The results are presented in Figure 4. A review of the responses shows 25% of the respondents do not plan for safety stock as a method to minimize disruption of field operations. Half of the respondents agree that establishment of a safety stock is part of their standard practice.

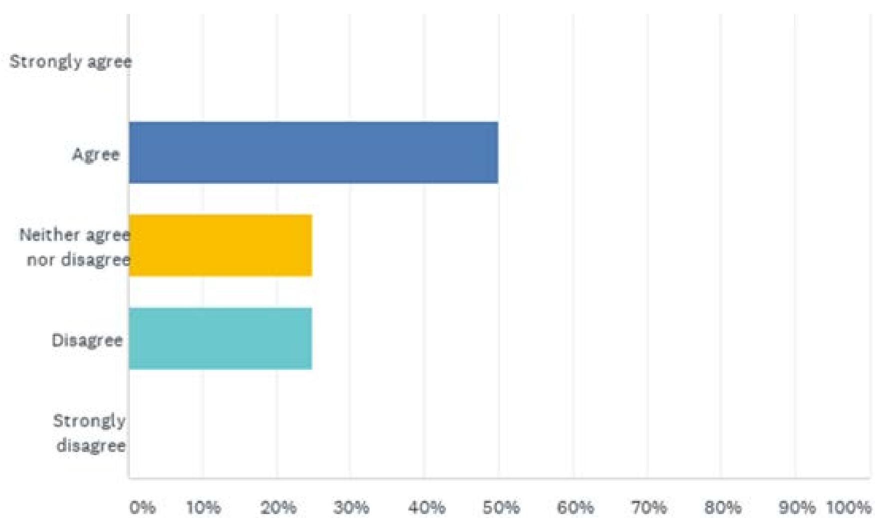

Figure 4. Establishment of a Safety Stock

<u>Hypothesis 2</u>*: ETO panel fabricators routinely have storage capacity challenges relative to finished goods inventories.*

The respondents were asked to choose from a predetermined set of five answers regarding the number of panel projects that, all or a portion of, are typically in storage as finished goods. Figure 5 presents the results of received from the respondents. 50% of the ETOs surveyed responded that they have more than 1 projects stored at any given time.

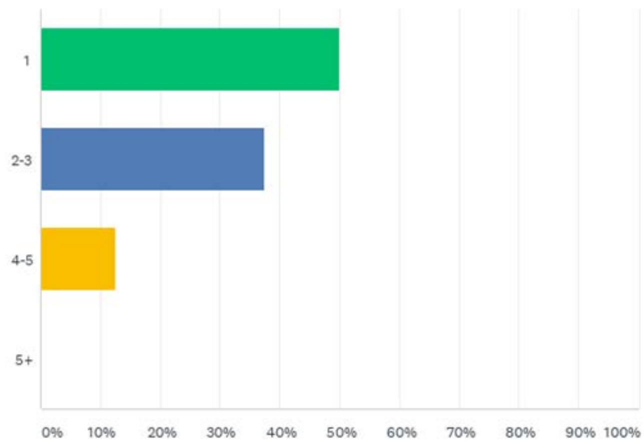

Figure 5. Typical Quantity of Panel Projects in Inventory

As a basis for the hypothesis there is a belief that storage capacity can be a limiting issue for ETO panel fabricators the respondents were asked to choose from a predetermined set of potential answers as to where and how they typically store their finished panels prior to shipment or installation. Figure 6 presents the findings from this question. All respondents provided answers that they utilize trailers for staging of finished panels. The majority (75%) of respondents store their finished goods at their facility.

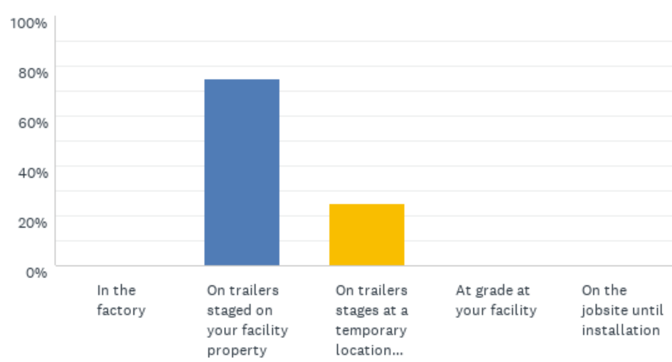

Figure 6. Location ETO Respondents Store Panels

<u>Hypothesis 3</u>*: Due to storage capacity challenges, ETO panel fabricators have experienced negative impacts relative to their production efficiency.*

Utilizing a Likert Scale question response format, the respondents were asked to rate their experience relative to their companies having past instances where the respondent's production line needed to be slowed down or halted because of exceeded storage capacity of finished panels. Figure 7 presents the responses showing 50% of the surveyed ETO's have had to slow or stop their line due to storage related issues.

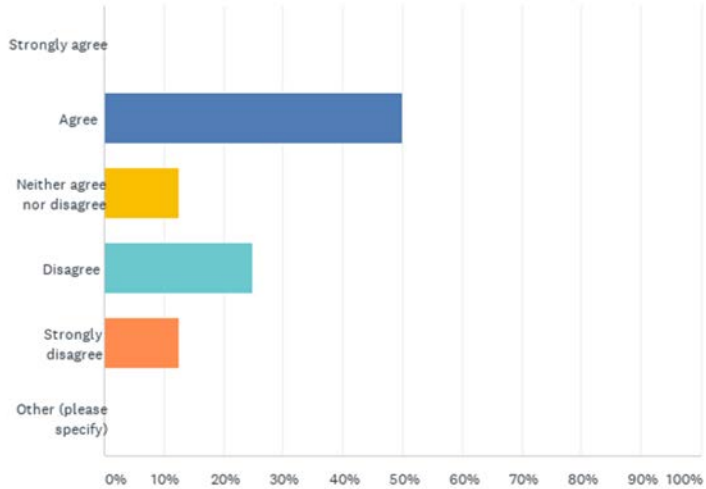

Figure 7. Instances of Slowing or Halting Production Due to Storage Capacity Challenges

With every respondent keeping at least a portion of one project and as many as five projects worth of panels in finished goods inventory, storage capacity can be an issue. On-site storage of finished panels for 75% of the respondents can pose space constraints that have resulted in half of the ETOs in the survey group slowing or halting production.

4.1.2 Centroid Method

To calculate a potential staging facility the Centroid Method (Jacobs and Chase, 2011) was utilized based on data collected from the previous 24 months of projects for a specific ETO fabricator located in Michigan. The available data spans fourteen projects shipping to 4 states. The states include Michigan, Tennessee, Missouri, and Georgia. Shipping of these projects required 235 loaded flatbed trailer trips. Figure 8 provides context for the locations of each of the projects utilized for the calculations.

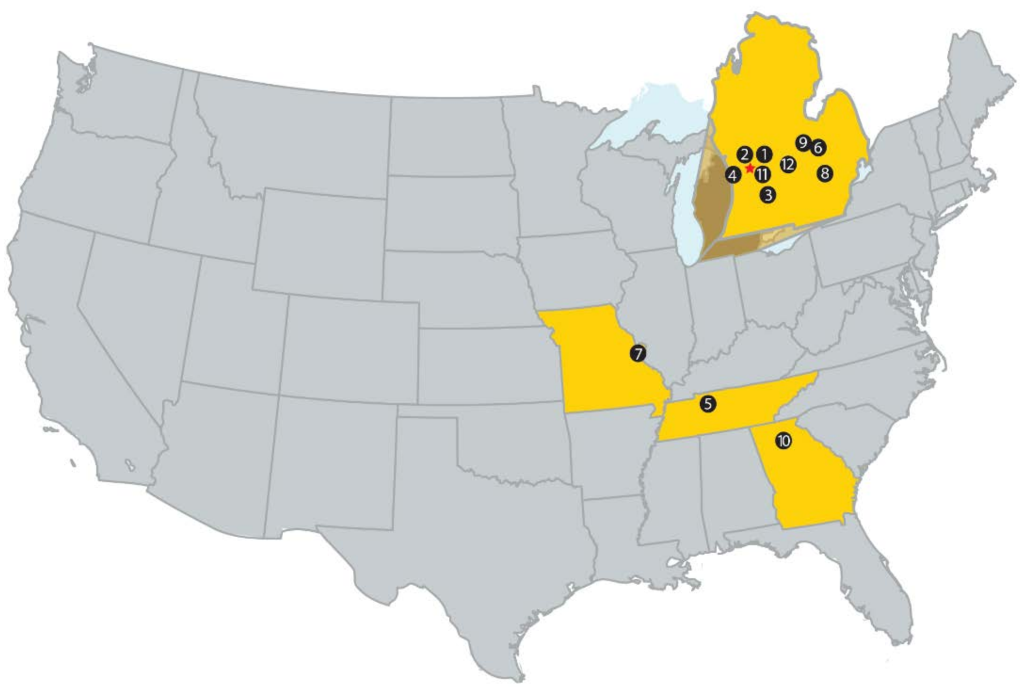

Figure 8. Project Locations Utilized for Centroid Calculation

Flatbed trailers are utilized for transport of prefabricated exterior wall panels. For the purposes of calculation, the typical total volume variable (V) was replaced with the total number of truckloads as shown in EQ 3. This approach is reasonable because of the high degree of variability of panel dimensions and relative weights dictates the quantity of panels that can be loaded onto a trailer.

$$C_x = \frac{\sum d_{ix}V_i}{V_i} \quad \text{and } C_y = \frac{\sum d_{iy}V_i}{V_i} \qquad (3)$$

In order to get the relative longitude and latitude values an online converter (www.coordinates-converter.com) was utilized to convert the actual project addresses and that of the factory to actual coordinate values. Those values were then normalized relative to the factory by defining the factory's coordinates at (0,0). Table 2 presents the relative coordinates, the number of trucks utilized for each project and the calculated values of $d_{ix}V_i$ and $d_{iy}V_i$.

Table 2. Number of Trucks, Relative Latitude and Longitude and Centroid Component

Project #	**Number of Trucks**	**Latitude**	**Longitude**	$d_{ix}V_i$	$d_{iy}V_i$
Factory	N/A	0.000	0.000		
1	9	-0.025	-0.330	-0.225	-2.970
2	2	-0.023	0.051	-0.046	1.102
3	115	0.668	-0.058	76.820	-6.670
4	4	-0.303	0.609	-1.212	2.436
5	3	6.644	1.095	19.932	3.285
6	8	-0.128	-1.963	-1.024	-15.704
7	12	4.254	4.629	50.940	55.548
8	5	0.346	-2.306	1.730	-11.530
9	15	-0.131	-1.967	-1.965	-29.505
10	12	8.843	-1.590	106.116	-19.080
11	30	-0.128	0.007	-3.840	0.210
12	20	0.185	-1.175	3.700	-23.500

The relative centroid of X is then calculated utilizing EQ 3:

$$\frac{(-0.225) + (-0.046) + (76.820) + (-1.212) + (19.932) + (-1.024) + (50.940) + (1.73) + (-1.965) + (106.116) + (-3.84) + (3.7)}{235}$$

Relative Centroid X = 1.067

The relative centroid of Y is then calculated utilizing EQ 3:

$$\frac{(-2.970) + (1.102) + (-6.670) + (2.436) + (3.285) + (-15.704) + (55.548) + (-11.530) + (-29.505) + (-19.080) + (0.210) + (-23.500)}{235}$$

Relative Centroid Y = -0.207

The calculated centroid values for X and Y were then converted back into actual coordinates based on the location of the current factory.

Actual Centroid X = (42.889-1.067) = 41.821

Actual Centroid Y = (-85.654-(-0.201)) = -85.452

Utilizing the same coordinate converter software, the result of this analysis would suggest a location in or around Sturgis, MI for a staging facility. As shown in Figure 9, Sturgis, MI is located near the border between Indiana and Michigan. Its nearest major interstate is I-80/90 to the South. There are no major North-South interstates in close proximity.

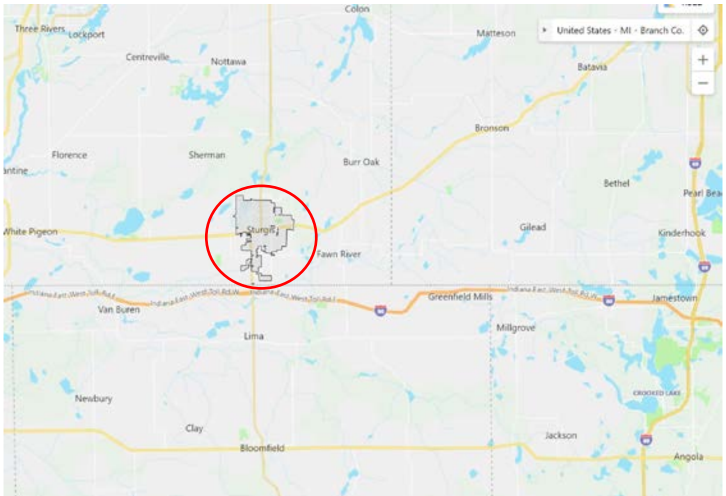

Figure 9. Map of Sturgis, MI (Google Earth, 2020)

4.1.3 Purchase versus Lease/Rent of Trailers

Regardless of staging facility location, each ETO must carefully manage flatbed trailer availability to ship their final products. Deadlines are critical to maintain the overall construction schedule and often there are large pieces of equipment and specialty tradesmen on site to receive delivery of the panels, so delays are costly. Due to the finished nature of the panels, relative cost, and desire to minimize damage air-ride trailers are generally the preferred method of transport.

Deliveries less than 200 miles from the factory can be facilitated through the use of rental trailers that are under contract with the ETO. However, the availability of these trailers can become limited during the fall peak harvest periods for farmers who utilize them for delivering their products to market.

An evaluation of the cost to purchase trailers versus continually leasing was undertaken. The current market rate for a 52’ air-ride trailer is $690/month. Rather than purchasing an unused new model the evaluation looked at used models as the trailers sit idle the majority of the time empty, loaded with finished goods, or being offloaded at the jobsite. A simple financing analysis, utilizing the formula in EQ 4, (https://www.wikihow.com/Calculate-Loan-Payments) was undertaken to determine the cost, on a monthly basis, to purchase a used trailer.

$$M = P * (J / (1-(1+J)^{-N})) \qquad (4)$$

Where M is the monthly payment amount, P is the principal of the loan, J is the effective interest rate and N is the total number of payments. An internet search of available used trailers meeting the desirable criteria showed the average sale price of $35,000. To determine the monthly loan installment cost an interest rate of 3.5% for a period of 5 years was utilized.

$M = 35,000 * (0.00291 / (1 – (1+0.00291)^{-60}))$

M = $636.58

The monthly installment cost to purchase a trailer of $636.58 does not account for the general maintenance or yearly certification costs. The average rental rate is $690/month for a trailer for an on-demand basis. Maintenance items such as tires, breaks and bushings can be expensive to repair with some of the parts being proprietary to the OEM. Table 3 presents a cost comparison of rental versus purchase including estimates for costs beyond monthly rental or loan payments.

Table 3. Cost Comparison of Rent Versus Purchase

	Rent	**Purchase**
Monthly Cost	$690.00	$636.58
Estimated Yearly Maintenance/Insurance	N/A	$2,200.00
Estimated Yearly Recertification	N/A	$300.00
Expected Yearly Cost	$8,280.00	$10,318.95

In addition to the estimated yearly fixed cost of the purchase price over the period exceeding that of the rental option it does not provide the flexibility to reduce the commitments if there is a slowdown in demand. The survey of other ETOs when specifically asked about if they owned the trailers necessary to fulfill their transportation needs versus other lease/rent options all responded that they either lease or use rental options. These findings validate that leasing and rental options are the most desirable structure for trailer needs of ETO panelizes.

4.2 Proposed Improvements

4.2.1 Based on Survey Results

Of the surveyed firms, all of the respondents want to have a large portion of the project complete or underway prior to the installation activities commence. The large dimensions of the panel products and the buffer hedge most of the ETOs plan to have complete, results in storage capacity issues. The ETOs need to evaluate, when establishing their operation, a location that can accommodate the volume of finished goods inventory on hand. This is also a consideration when the business grows. With all respondents storing their finished panels outside and on trailers, a location that can house dozens of trailers is necessary. ETO's should consider a secure storage lot in a location that is advantageous to their projected project locations and ample supply of trailers.

4.2.2 Recommendations from Centroid Method Results for Offsite Storage Facility

As a result of the survey, respondents indicate that storage of finished goods (panels) is a problem that can result in them slowing or stopping their production line to address the problem. The result of the Centroid analysis determined a location for an offsite staging yard to be located in or near Sturgis, MI. The resultant location is approximately 90 minutes from the factory. Evaluation of Sturgis as a community for a staging yard does not seem to be ideal due to its distance from major freeways. A location that is closer to a major east-west and north-south freeways would allow the ETO more efficient distribution of finished panels.

The Centroid method calculation was based on the previous 24-month period and does not consider future project locations. A forward-looking analysis based on revenue projections along with weighted probabilities would allow for evaluation of the solution location's longevity.

4.2.3 Fleet Management from Trailer Purchase vs. Rent Analysis

The monthly installment cost to purchase a trailer of $637 compared to an average rental rate of $690 does not account for the general maintenance or yearly certification costs. Maintenance items such as tires, breaks and bushings can be expensive to repair with some of the parts being proprietary to the OEM. Notwithstanding the estimated yearly costs of purchase exceeding rental, the ETO should strongly consider the rental option of the trailers over purchasing even though they may have less control on trailer availability. They can minimize this risk through multiple vendors with rental fleets and do thorough projections of their project needs more than six months in advance.

5. Conclusion

The results of the survey confirmed that ETO panel fabricators all believe that they must commence fabrication and have a large portion of the project in finished goods inventory prior the installation process starting. The majority of the panel fabricators store their finished goods inventory on trailers at their facility. Half of the respondents stated they have had to slow or stop their production line because of storage constraints of finished goods inventories. This finding is substantial and undoubtedly shows that there is a cost impact for the forced shutdown or slow down to not run out of space. The findings stress the need for an ETO panel fabricator to develop a plan or method for address storage related issues of finished goods inventory such as an off-site storage facility while being mindful of the costs associated with trailer usage and availability.

The detailed investigation of a Michigan-based ETO panel fabricator's preceding projects utilizing the Centroid Method to determine a location for off-site storage resulted in a reasonable determination. ETO panel fabricators can utilize this method to identify geographic areas to search out temporary, or even permanent, staging facilities for their finished goods inventory. If there is not consistency in the general locations where they ship finished goods, an off-site location may not prove to be beneficial for an extended period of time. It may be advisable to plan for ample storage capacity when determining the location of the fabrication facility.

All of the respondents to the survey utilize trailers for storage of finished goods inventory of panels. While the costs of ownership compared to lease on a monthly incremental basis may appear close, maintenance costs are often borne by the lessor. In this arrangement the ETO panel fabricator can better estimate their costs in a forward-looking manner through a lease arrangement versus a purchase scenario. Additionally, most ETO panel fabricators do not have in-house maintenance staff qualified to complete the necessary maintenance on the trailers. If the ETO panel fabricator services a large geography, some of the contract carriers may provide their own trailers for deliveries outside of 150 miles.

5.1 Limitations

Of the 235 trailer trips utilized in the analysis, 208 went to destinations within Michigan. The disproportionate quantity of trailer trips in Michigan did offset the long-haul trips to other states that resulted in a calculated storage facility in Michigan. Shipping costs were assumed to be equal and the calculation did not take into consideration oversized load definitions or costs associated with special permits that vary from state to state. Trailer pricing analysis was based on interest and lease rates as of November 2020. The cost of trailer ownership does not factor in depreciation value that companies may look to maximize as part of their decision process.

5.2 Future Research

Additional research should be conducted eliminating some of the furthest locations in the previous 24-month period if the investigated ETO believes there is a small probability of future projects in those areas. Future research should focus on developing a forward-looking tool for ETO's to project both trailer needs, and location of offsite staging facilities based on revenue projections or backlog. Additionally, further study on techniques to improve productivity for the ETO panel fabricators could alleviate some of the storage capacity if their throughput was greater.

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Biography

Andrew Rener serves as President of Bouma Group, a west Michigan specialty contracting firm, and as Managing Member of Centerline Prefab, LLC, a west Michigan prefabrication operation. He also serves as a board member for a prefabrication consulting, product development and engineering company called PeerEngine. He is a member of the StoPanel Technology Executive Committee. Andrew is a licensed Professional Engineer in the State of Michigan, is a licensed residential builder in Michigan and holds commercial general contracting licenses in nine states. He has taught as an adjunct at Lawrence Technological University in the Department of Civil and Architectural Engineering for 14 years teaching graduate and undergraduate courses in construction engineering. During that time, he was awarded Outstanding Adjunct Faculty Award by the students. Andrew also taught for three years in the Civil Engineering Department at University of Detroit Mercy teaching graduate courses in construction engineering. Andrew has served on multiple national committees for the American Society of Civil Engineers and is a Fellow of the society. He has served on the advisory board for the Department of Civil and Architectural Engineering at Lawrence Technological University for more than two decades and remains a member of the board as an Emeritus member.