# Innovative Model for Forecasting Trailer Usage for Prefabricated Exterior Wall Panels

A. Rener<sup>*a,b*</sup>, A. Karatas<sup>*c*</sup>, M. Cole<sup>d</sup>

<sup>a</sup>Department Civil and Architectural Engineering, Lawrence Technological University, US <sup>b</sup> Centerline Prefab, LLC, US

<sup>c</sup> Department of Civil, Materials and Environmental Engineering, University of Illinois at Chicago, US <sup>d</sup> College of Business and Information Technology, Lawrence Technological University, US

E-mail: arener@centerlineprefab.com, akaratas@uic.edu, mcole@ltu.edu

#### Abstract -

With growing demand for large scale exterior envelope prefabrication solutions beyond precast concrete, Engineer-to-Order (ETO) prefabrication firms must develop reliable methodologies to manage finish goods inventory of large components. The imbalance between fabrication time and installation requires ETOs to forecast likely consumption of transportation resources at the proposal stage with only a conceptual understanding of the final project. Since 2019 US domestic trucking costs have increased due to demand. Therefore, ETOs need a reliable forecasting trailer usage model for estimating transportation costs at the proposal phase and mitigate the risks of an arbitrary approach. The proposed model was developed and evaluated by using a supervised machine learning algorithm on a large data set collected from completed exterior prefabricated panel projects in the US. The model was then tested and compared to estimations completed by a professional prefabrication estimator. The model can assist ETOs with projecting the quantity of trailers likely necessary for ิล prefabricated panel project with less variance at the proposal phase with limited information. The increased accuracy can reduce the financial exposure of the ETOs.

#### Keywords -

Prefabrication; Offsite Construction; Exterior Wall Panels; Logistics; Estimating; Supply Chain

# 1 Introduction

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 [1]. An accepted overarching term utilized throughout the construction industry is *prefabrication*. Adoption of prefabrication and offsite construction continues to increase to address challenges with schedules, quality, sustainability and manpower [2]–[4]. To meet this demand, most prefabrication companies deliver their products in an Engineer-to-Order (ETO) model [5], [6].

Prefabrication, as a concept, is not a new idea. The United States government utilized prefabrication techniques and planning during the Manhattan Project to rapidly construct communities that now are part of Oak Ridge National Labs [7]. There was a period in the 20th Century where companies like Sears and Roebuck sold "kitted" residential homes that were a form of prefabrication. However, the complexity of systems and components of buildings that are now being utilized are much more intricate for onsite prefabrication and offsite prefabrication. Onsite prefabrication can include constructing subassemblies while on the jobsite prior to the permanent installation. Offsite prefabrication is completed in a production facility focused on a specific building element, and requires consideration of new challenges in transportation, supply chain and logistics. Therefore, ETO's must examine other products and solutions that have evolved to address these challenges in the supply chain.

This study specifically focuses on examining prefabricated exterior systems, such as the panel systems fabricated by the ETO companies, that are multi-layered high-energy performance cladding systems that layer various building materials to create the panels [1]. For decades, precast concrete has been available to building owners 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. Whether its 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 [8]. 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 [9].

ETO companies develop project specific solutions to meet the needs of a given project. Often, this work is procured at the schematic or design development stage of the design process. As such, granular details about the panel products necessary to complete the project are not yet designed. However, ETO's regularly must provide a fixed price or Guaranteed Maximum Price to their clients that have to be cost competitive to warrant the inclusion of their products in the project. This requires preconstruction and estimating teams of the ETO to utilize their experiential knowledge to develop their proposal. At the point of proposal submission, the ETO generally has information regarding the orientation of the panels, the square footage of the project, a preliminary panel count, framing style and, aesthetic finishes. The experiential knowledge of the estimators is subjective and limited to their personal experience or the institutional knowledge of their organization. One area that shows large fluctuations in accuracy in the estimate is the estimation of the number of trailers necessary to transport the finished panels from the manufacturing facility to the jobsite. Since the onset of the COVID pandemic, over-the-road trucking costs have increased four to five-fold compared to 2019 for subcontracted over-the-road hauling services in the United States. This has magnified the financial impact of errors in the forecasting of trailers at the proposal stage. In the event the estimator errors too low, the costs quickly compound and erode profitability for the ETO. Conversely, overly conservative estimating of trailers may cause the ETO's proposal to be viewed as too expensive. To address this challenge, ETO companies must assess multiple strategies for addressing management of their finished goods inventories to align both installer and customer demands.

This study presents an automated forecasting model that ETO fabricators can utilize at the estimate stage of a project to forecast the quantity of over-the-road trailers necessary to transport a prefabricated panel project from its place of fabrication to the jobsite for final installation on the building. By drawing on a large data set compiled from completed projects of twelve ETOs the model can forecast likely trailer counts with less variance than a professional estimator. ETOs are generally limited to their own experiential knowledge from their data set of projects. The paper is organized to present the objective, followed by a literature review, then an overview of the model creation including data collection and validation. Conclusions drawn from the study, limitations of the current model and future research complete the paper.

# 1.1 Objective

The objective of this study is to develop an innovative automated model that is capable of forecasting trailer usage for prefabricated exterior wall panels with greater accuracy than current methods. The model utilizes supervised machine learning algorithms on a large data set collected from completed projects from multiple companies in the US. The model can be used by ETO fabricators at the estimate stage of a project to forecast trailers necessary to transport a project from its origin place of fabrication to the final destination (i.e., jobsite). The development of the tool can reduce the potential for financial risk associated with poorly predicting the number of trailers necessary for a project.

# 2 Literature Review

Studies have identified multiple factors that contribute to the complexity of the supply chain challenges in the construction industry [10]. The research determined there were four overarching categories that the challenges could be organized within. Those are: material flow, company communication, project communication, and complexity. The challenges identified by their respondents are wide ranging and require substantial management and planning effort to overcome successfully.

Communication between the project site and ETO companies can be challenging relative to demand needs. This creates a disruption in the production process. Panova and Hilletofth [11] used dynamic modelling 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. Utilizing buffer space for safety stock also minimized disruption of the production sequence and onsite activities, ultimately reducing the bullwhip effect [12], [13]. 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 at the factory or intermediate staging site.

The importance of thorough planning in construction supply chain is a critical step increasing the likelihood of a successful project and it becomes even more critical when utilizing ETO prefabricated components [6], [10]. There is 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 [8]. 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 [14].

Demand variability on construction sites for construction materials, such as precast products, can be an impediment to success due the demand of on-time delivery to keep the project on schedule [15]. The importance of thorough planning in construction supply chain is a critical step to increase the likelihood of a successful project and it becomes even more critical when supply is constricted [10]. A research study was conducted to attempt to optimize transportation costs and the quantity of trucks [16]. Although this research has some fundamental application, it considered weight and volume of prefabricated components as part of the characteristics of the products. However, there were no multi-dimensional attributes considered. It did not consider specific important transportation aspects inherent in building façade panels, such as precast, and the likelihood for oversized loads. This research also did not account for large variability in sizes that may result from custom nontypical building products.

On time deliveries of products to the jobsite are critical to maintain a project's flow. One approach to mitigate late deliveries caused by manufacturing challenges can be addressed through the managed incorporation of a buffer or safety stock. Implementation of a safety stock either at a permanent or temporary location can help to minimize disruptions [11]. Further research through surveys have examined preferences for buffer stock levels to mitigate disruptions [9]. Therefore, it is important to consider the costs associated with large buffer stocks which can become costly if there is not a contractual vehicle for billing for that material in a timely manner.

For full realization of the schedule benefits of prefabrication, the prefabricated components must arrive at the project site when the schedule demands. Late or early deliveries of prefabricated assemblies can cause disruption to the project site and can result in double handling [12]. The expectation of the prime contractor is the entity responsible for transportation plans for storage space to deal with slow site installation or bad weather.

Through a survey conducted of ETO exterior panel fabricators it was found that all the respondents store their finished goods inventory of panels on trailers prior to shipment to the jobsite [17]. Nearly 50% of the respondents reported slowing or halting production due to issues with storing finished good inventory. To address these aforementioned research gaps, this study focuses on the utilization of completed projects to develop a model capable of forecasting trailer resources for projects at the proposal stage.

# **3** Model Development

The automated forecasting model was developed in two steps. Data were collected on randomly selected prefabricated panel projects. In order to be included in the data set, the projects had to be completed so that characteristics of the project were actual and not estimated or theoretical. Data were analyzed, and validated using a supervised machine learning algorithm to assess the practical functionality of the model in forecasting trailer resources.

# 3.1 Project Data Collection

Data were collected from ETO prefabricators specializing in exterior wall panels for 107 completed projects that included characteristics of the panels along with the number of trailers utilized to transport the finished goods to the jobsites. This task needed an exhausting effort and meticulous organization to reach out to all ETO prefabricators in the US and create a dataset on the completed projects.

The project specific data spanned over a four-year period and were collected from multiple companies servicing different regions of US. It is noteworthy to mention that this research did not focus on transportation distance because it does not affect actual trailer trips to and from the factory and jobsite.

Data set created for utilization in this study included both macro and specific characteristics of the exterior panels fabricated for the project. Macro level characteristics included total square footage of panels and number of panels built for the project. Additionally, the respondents were followed up to gather more detailed information relative to the panels' structural configuration as part of the building skin as either a By-Pass, Infill or Load-Bearing configuration. Specific information on the panels fabricated for a project included panel finishes. The following variables were included:

- Cornice/Parapet Element
- Frame only
- Back-up
- EIFS
- Metal
- Thin Brick (with cast bed)
- Thin Brick (over foam)
- Fiber Cement Siding
- Aluminum Composite Panel (ACM)
- Acrylic Panel

#### • Other

The cornice/parapet element refers to a thickened architectural detail at the top of the panel. This has potential significance because it would create differing panel thickness that must be accounted for in the loading of panels. Frame only panels are comprised of only coldformed metal studs and no other materials. This would make them, potentially, the thinnest cross-section of any of the panel types. Back-up panels are comprised of studs, sheathing, and an applied air/vapor barrier. Exterior Insulated Finishing System (EIFS) panels have foam and an applied finish beyond that of a back-up panel. Metal panel finishes could include insulated metal panel, corrugated metal siding or machine bent formed panel assemblies. Thin brick over cast bed is a multilayered approach applied to the back-up panel that includes a slip sheet, lath/mesh and a cementitious cast bed applied to the panel prior the installation of commercially available thin brick materials. In contrast to the thin brick over cast bed, the thin brick over foam allows for the adhesion of thin brick materials to the cementitious base coat applied to foam that is adhered to the back-up panel. Fiber cement siding, along with attendant insulation, is applied to the back-up panel assembly per the manufacturer's instructions. This is often constructed in a rain-screen configuration. The aluminum composite panel is often fabricated out of sheets and machined into desired geometries prior to being installed on the back up panel with the attendant carrier system. The "Other" finish allowed for the respondents to provide data on projects that did not have any of the finishes provided as options. Respondents also provided the actual number of trailers that were utilized to transport the finished panels from their fabrication facility to the project site.

#### 3.2 Data Analysis and Validation

Dataset were analyzed using a supervised machine learning algorithm involving multiple data variables for analysis. The data was analyzed in Minitab V20.4 utilizing multivariate regression of the panel characteristics (predictors) regressed on the number of trailers (response) The results were evaluated along with the residuals to determine the reliability of the selectedmachine learning algorithm. To assist with evaluation and description of the resulting equation, the number of trailers was transformed to the log natural and the multivariate regression was then performed again [20].

To estimate the validity of the automated forecasting model, derived from the set of 107 completed projects, data from actual projects not in the data set were input into the equation and the forecasted trailer resources were then compared to the actual number of trailers utilized for that project. Furthmore, the developed model was also tested on a professional estimator. The estimator had no prior knowledge of the actual projects and was engaged to forecast the number of trailers necessary on the four sample projects utilizing their experiential knowledge. The variances from actual were then evaluated for practicality of the developed model.

# 4 **Results and Discussion**

#### 4.1 Numerical Results

#### 4.1.1 Data Collection

Data from 107 randomly selected completed projects was gathered and analyzed as part of this study. Table 1 summarizes the total data set by the 14 predictor variables (x) and the outcome variable (y).

It is noteworthy to mention that there were no respondents that provided data for acrylic panel finishes so that predictor was not considered in the evaluation as it would add no value. The square footage and number of panels predictors are continuous variables; the remaining predictors are binary categorical variables.

Table 1. Summarized Data Set of Panel Projects

Variable	Total	% of
		Total
Square Footage (x1)	5,020,976	100
Number of Panels (x2)	43,722	100
Bypass (x3)	71	66
Infill (x4)	12	11
Load-Bearing (x5)	26	24
<b>Cornice/Parapet (x6)</b>	9	8
Frame Only (x7)	26	24
Back-up (x8)	22	21
EIFS (x9)	44	41
Metal (x <sub>9</sub> )	4	4
Thin Brick (cast bed)	3	3
( <b>x</b> <sub>10</sub> )		
Thin Brick (over foam)	3	3
(X11)		
Fiber Cement Siding (x <sub>12</sub> )	2	2
Aluminum Composite	1	1
(X13)		
Other (x <sub>14</sub> )	6	6
Number of Trailers	2,559	100
( <b>v</b> )		

#### 4.1.2 Data Analysis

To analyze the collected data, the forecating model was developed by using a upservised machine learning algotirhm. The panel characteristics (predictors presented in Table 1) were regressed on the number of trailers (outcome). Equation 1 presents results from the analysis, that represents the unstandardized regression coefficients ( $R^2 = 79\%$ ):

 $\begin{aligned} Trailors &= -6.23 + 0.000411x_1 - 0.01204x_2 + \\ 17.2x_3 + 18.11x_4 + 11.58x_5 + 0.4x_6 - 10.06x_7 - \\ 5.45x_8 - 0.69x_9 + 25.73x_{10} - 1.09x_{11} - 2x_{12} + \\ 44.95x_{13} - 1.08x_{14} \end{aligned} \tag{1}$ 

Examination of residuals suggests a few data points are outliers. Figure 1 presents the Normal Probability Plot of the residuals and Figure 2 shows the Versus Order Plot of Observation Order and Residuals.



Figure 1. Normal probability plot of residuals versus percentage



Figure 2. Versus order plot of observation order versus residuals

To help interpret the unstandardized regression coefficients from Equation 1 in terms of the estimated percent change in the number of trailers as a function of a one unit change of the predictors, trailers was transformed to its natural log (LN transformation) and the regression equation was recalculated. As an example, for every 1,000 square feet of panel  $(x_1)$  there is an estimated 1.3% increase in the number of trailers needed (see Equation 2):

$$LN \ Trailers = 1.158 + 0.000013x_1 - 0.000118x_2 + 1.191x_3 + 0.835x_4 + 0.695x_5 + 0.066x_6 - 0.688x_7 - 0.233x_8 + 0.019x_9 + 0.775x_{10} + 0.066x_{11} + 0.104x_{12} + 1.358x_{13x} - 0.133x_{14}$$
(2)

To evaluate the functionality and accuracy of the applied machine learning algorithm, four randomly

selected projects were evaluated that were not part of the original data set. The characteristics for the model were gathered for each of the projects. Utilizing Equation 1, predictions were made relative to the number of trailers and then compared to the actual number of trailers utilized. The predictors for the four sample projects are presented in Table 2. The square footage and panel count are presented as integer numbers. The balance of the predictors is presented as binary number because they either are part of the panels of the selected project or are not.

Utilizing Equation 1, project predictors were regressed on the number of trailers. The results of the application of the model equation are presented in Table 3 along with the actual number of trailers utilized in the sample projects.

As a practical matter, there are no partial trailers so the resultant prediction can either be rounded up for conservative purposes or the practitioner can choose to round down the predicted number and manage their efforts to meet that goal. Results across the four projects found the regression model produced reasonable results for three of the four sample projects. In the case of project 2, the results exceeded the actuals by approximately onethird.

Table 2. Sample Projects with Attendant Predictors

Predictor	#1	#2	#3	#4
Square Footage	10,942	11,507	40,658	92,500
Number of Panels	70	33	109	287
Bypass	1	1	1	1
Infill	0	0	0	0
Load-Bearing	0	0	0	0
Cornice/Parapet	0	0	1	1
Frame Only	0	0	0	0
Back-up	1	1	1	0
EIFS	0	0	1	0
Metal	0	0	0	1
T Brk (cast bed)	0	0	0	0
T Bck (ovr foam)	0	0	0	0
Fiber Cmt Siding	0	0	0	0
ACM	0	0	0	0
Other	0	1	0	0

To assess the practicality of the model an estimator in the prefabrication space was interviewed. The estimator stated that the challenge of trucking costs of finished panels has caused financial challenges on some projects due to the cost impact related to the estimated trailer quantities and the actuals necessary to complete the project. The estimator has started to utilize a rate of \$2,000USD per trailer load compared to \$500USD per trailer load 3 years ago. The estimator was then asked to evaluate the 4 sample projects to predict the trailer usage necessary for those projects and was provided the same project characteristics as presented in Table 2. The results of the estimator's forecast along with potential cost impacts, utilizing \$2,000USD per trailer load cost, are presented in Table 3. Negative cost variance values represent a loss or expense to the ETO and positive variances are savings compared to estimate.

The forecasts for both the model and the estimator compared to actual resulted in a likely loss on transportation costs for the ETO. However, the utilization of the model with the same data set as provided the estimator improved the accuracy of the estimate by nearly 400% in terms of dollars saved. The estimated value for each trailer load can vary by location, region, and available resources. Total haul distance (milage) can also have an impact on per load cost. However, the magnitude of the variance is significant enough to be a potentially desirable solution for ETO's as a risk mitigation tool for cost overruns relative to trailer usage on project compared to arbitrary means.

Tab	le 3. Comparis	on of Model a	and Estime	itor Prediction	is to Actual wi	th Attendant Co.	st Variances
Project	Model Prediction	Estimator Prediction	Actual	Variance by Estimator	Variance by Model	Effective Cost Variance (Estimator)	Effective Cost Variance (Model)
1	9.17	4	10	60%	8%	-\$12,000	\$0
7	8.77	5	9	17%	32%	-\$2,000	\$6,000
ŝ	20.62	16	18	11%	12.8%	\$4,000	\$6,000
4	71.66	30	96	69%	25.4%	-\$132,000	\$48,000
				Tot	al Variance =	-\$142,000	-\$36,000

# 5 Conclusion

Statistical analysis of 107 completed prefabricated panel projects was conducted to evaluate whether specific characteristics of the project can be utilized to forecast the number of trailers necessary to transport the finished panels to the jobsite. A predetermined but broad set of predictors were analyzed using a supervised machine learning algorithm to estimate the number of trailers. The resulting equation can be utilized to forecast the number of trailers required to ship panels from the ETO's facility to the project site. Project specific information of four additional projects not included in the original data set were utilized to validate the model by comparing actual number of trailers to the estimated quantities of trailers determined by a professional estimator in the prefabrication industry. The comparison shows that the model can provide forecasts of necessary trailers with less variance to actual compared to an experienced estimator. ETO's are incentivized to utilize a data driven approach to forecasting compared to historical arbitrary approaches due to the high costs of transporting the finished panels and the potential for adverse financial outcomes.

Dimensional data of the panels utilized in the data set was not solicited due to the custom nature of the solutions provided by ETOs and the variability in modern architectural aesthetics coupled with structural systems of buildings to meet specific project requirements. Panel dimensions and packing methodologies of each ETO can vary resulting in more or less panels being loaded onto a given trailer for transport. By way of example some ETOs may prefer nominal 4" dimensional lumber compared to others that may use 2" high density foam for dunnage. Variation in different states over-the-road load restrictions may also affect the number of trailers necessary to complete a project.

No consideration was given to the availability of trailers for an ETO as a potential constraint. It is presumed that acquisition of the necessary quantity of trailers is possible.

#### **5.1 Limitations**

Results of this study may be limited by size and validity of the sample of 107 projects submitted by ETO's for the purposes of this study. For example, residuals plots suggest some data points were outliers, and some predictors only occurred a few times (e.g., metal, thin brick, fiber cement siding, aluminum composite). Additionally, the regression analysis did not account for projects that have multiple finish characteristics such as EIFS, Metal or Fiber Cement to achieve the architectural aesthetic. Users should separate dissimilar finishes and utilize the supervised machine learning algorithm as if there was a separate project, with correlating square footage, for each variation in finish type.

# 5.2 Future Research

Ongoing collection of completed project data from the original study participants will be utilized to further refine and optimize the forecasting model as a userfriendly tool to help practitioners in the panel prefabrication space use data-driven forecasting of trailer resources. Future research will also create a simple user interface to allow the practitioner to quickly input the know predictors and receive a response from the model.

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