MODULE ASSEMBLY CAPACITY
A Study of Alberta Module Constructors

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EXECUTIVE SUMMARY

The Canadian heavy industrial sector is facing an increase in international competition. A workshop was held at the Modular Offsite Construction Summit (in 2012 in Edmonton, Alberta), to discuss issues in Alberta heavy industrial modular construction. As a result of these discussions, a steering committee was built to oversee and coordinate activities on behalf of module constructors operating in the Alberta industrial construction sector.

Working with the University of Alberta NSERC Industrial Research Chair in Construction Engineering and Management, the committee began an independent study to establish the true module assembly capacity of Alberta module constructors, in order to better understand their competitiveness. The study targeted 18 major module constructor companies operating in Alberta, and 17 responded to the questionnaire. Although some participating companies indicated that they own and operate module yards outside Alberta, these modules were not considered in the analysis and results presented in this report. The report summarizes the findings of the survey.

Based on the collected data, the total determined resident module assembly capacity is 1,418 modules. Of these modules, 25.32% represented capacity from pipe rack, 20.52% process modules, 13.47% E-houses, 15.23% building modules, 11.71% stair modules and 13.75% electrical modules. Results indicated that each module yard has an average of 50.64 modules.

Data from participating companies revealed there is a minimum of 28 module yards operated in Alberta. These yards utilize a total of 947 acres of land. Results from the study further indicated that on average, module yards have been in operation for 9.97 years, have an average size of 32.66 acres, and have a resident capacity of 50.64 modules. The study further revealed module yards on average can hold 1.64 modules per acre.

Analysis of the data on the workforce engaged in module yards indicated during typical seasons, module yards have an average of 234 craft workers and 24 supervisors per yard. The analysis further revealed on average, to cope with the work load at peak times, the number of craft workers is increased by 54.27% and the number of supervisors is increased by an average of 66.67%.

The study established the most commonly fabricated module type is the pipe rack module, followed by equipment module. The least fabricated module type is the stair module. This trend could be attributed to the requirements and configurations of the projects the companies undertake and the nature in which these companies do business.
1.0 INTRODUCTION

The objective of this study was to obtain information regarding the module assembly capacity of module constructors operating in Alberta. Collection of this information is the first step in understanding and improving the competitiveness of Alberta module constructors, which is necessary in order to improve competitiveness, especially as international competition increases.

This report summarizes the analysis performed. Basic statistics about module yards, organized by geographic location, are presented. Then an analysis is run on all module yards collectively and statistics reported on different module yard attributes such as age, size, workers and resident capacity. Statistical distributions are also fitted to each of these parameters for the collective set of module yards. Finally, module yards are independently grouped based on module size criterion and then by resident capacity criterion. Characteristics of module yards within each group are then analyzed and reported.

An overview of module products and facilities are briefly discussed in the following sections before the findings of the study are presented.

1.1 MODULES AND MODULARIZATION

1.1.1 Definition

Modularization is the process of moving work from a construction site into a more controlled environment. This process is said to deliver productivity, safety and quality benefits to the construction industry. Modularization involves planning the design and construction of a facility in a broken-down approach; the entire facility is built from separate components that can be fabricated, shipped to site and assembled (erected) on site into the final product. These components are referred to as modules. Modules are unique in nature, so the type, size and components of a module change from project to project and also vary within the same project. The different types of modules are discussed in the following section.

1.1.2 Types of Modules

Modules used for erecting industrial facilities vary by type. They are categorized according to the components that make up the module. The components will vary depending on the type of construction and the part of the construction in which the module is intended for use. There are standardized categories of the components typically embedded into modules, and six main types of modules:

- Pipe rack module
- Equipment/process module
- Electrical module
- Stair module
- Building module
- E-houses
Examples of some of these typical module types are shown in Figures 1 through 4.

**Figure 1: Process Module**

**Figure 2: Equipment Module**
1.1.3 Evolution of Modules

Modules fabricated for erecting industrial facilities have evolved over time. This evolution has been driven by efforts to increase the number of work hours moved off-site to module yards. Another factor influencing this evolution is an attempt to reduce the footprint of the built industrial facility complexes\(^1\). The first generation of modules were predominantly comprised of

pipe racks. Second generation modular construction execution included first generation (pipe racks) plus equipment and pre-dressed vessels. Third generation modules focused on fabricating modules to optimize the layout and space occupied by the facility when erected on site. Third generation modularization reduced the amount of structural steel, piping, electrical and insulation work required.

1.1.4 Module Yard

A module yard is a designated, flat open space used to assemble modules. Module yards are typically divided into work areas referred to as bays. Each bay is usually occupied by only one module being built. The layout of bays in a yard will typically change over time as the type and number of modules being fabricated changes. The major constraining factor to the resident capacity of a module yard is the size of the yard.
2.0 ASSUMPTIONS MADE IN THIS STUDY

A number of assumptions were made in order to facilitate the data analysis in this study. These included:

- Companies that participated in the study represent the major players in this industry within the Alberta region.
- The study focused on only module yards owned and operated within Alberta.
- The typical size of an Alberta-built module (24’×24’×120’ and 340,000 lbs) was used as a unit of measure for purposes of quantifying the capacity of module constructors. This standardization was done to facilitate the respondents in estimation of their module resident capacities. In reality, there would be significant variation in size of modules and scope of work involved.
- Responses provided regarding the percent of module types assembled in the company’s module yard were based on the following criteria: in-house experience, project type and profitability.
- In cases where respondents indicated they had full ability to fabricate all the types of modules, the distribution of their production profile was assumed to be equally divided amongst the module types.
3.0 METHODOLOGY

The responses obtained from the questionnaire survey were entered into and analyzed using Statistical Package for Social Scientists (SPSS). Statistics generated from some of the results were represented in the form of charts. These charts were also generated using SPSS.

In other cases, statistical distributions were fitted to the empirical data collected. These distributions were assumed to represent the population from which the data points collected from responses were generated. Continuous and discrete distributions were fitted depending on whether the parameter being dealt with was discrete or continuous in nature. Fitted distributions are represented as Probability Density Functions (PDFs) within the main body of the report and as Cumulative Density Functions (CDFs) within the Appendix. This representation was chosen so that the variations in the parameters of the aggregated data would be easily visually displayed to readers.

The data collected from participants was analyzed from three different perspectives: (1) company perspective, (2) module yard perspective using module size categorization and (3) module yard perspective using resident capacity categorization. This approach was used to highlight all possible trends.

In the first phase of the analysis, all data collected was aggregated and then statistics generated from them. Confidence intervals are also computed for these statistics. This phase represents an analysis at a company level. The second phase entailed categorizing module yards according to a module yard size criterion.
4.0 ANALYSIS AND RESULTS

This section of the report discusses and presents results on the module yards, and the different attributes of the module yards.

4.1 MODULE FABRICATION YARDS OPERATED BY EACH COMPANY IN ALBERTA

The study tried to establish the number of module yards within Alberta. Results of the study indicated that there are 28 module yards in total that are currently in operation within Alberta. Statistics were also generated for the number of module yards owned and operated by each company. These are summarized in Table 1.

<table>
<thead>
<tr>
<th>Statistic of the Number of Module Yards</th>
<th>Value for the Statistic (Number of Yards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.65</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Results indicated that companies operate between 1 and 3 module yards in Alberta. The average number of yards per company was found to be 1.65. The spatial distribution of these module yards within the province of Alberta was not tracked in this study but can be a parameter tracked in subsequent studies. A map showing their geographic location can then be generated.

Discrete statistical distributions were fitted to the data on the number of module yards that each company owns. A Poisson distribution showed the best fit for this data. A screen shot of the cumulative distribution function (CDF) for the data is shown in Figure 5.
4.1.1 Trendlines Showing Variations in the Number of Yards and Corresponding Module Fabrication Capacity

The study established the year in which the participating companies established each of their module yards. Based on this data, it was possible to indicate the changes in the number of module yards that occurred each year and the resulting change in the module fabrication capacity. This information was plotted on charts presented in Figures 6 and 7, respectively.
Figure 7: Chart Showing the Different Module Fabrication Capacity Increments over the Years

The years indicated experienced changes corresponding to the values shown on the charts. In the years not indicated, there was no change.

4.2 TOTAL MODULE YARD RESIDENT CAPACITY AND CAPACITIES BY MODULE TYPE

Results obtained indicated that Alberta has a total module residence capacity of 1,418 standard Alberta-size modules. The average number of modules per module yard was also found to be 50.64 standard Alberta-size modules. The data collected from participants was analyzed at a more refined level in order to determine the distribution of their residence capacity by module type. The results obtained are presented in Tables 2 and 3.

Table 2: Total Alberta Module Residence Capacity by Type

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Total Resident Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe rack module</td>
<td>359</td>
</tr>
<tr>
<td>Process/Equipment module</td>
<td>291</td>
</tr>
<tr>
<td>E-house module</td>
<td>191</td>
</tr>
<tr>
<td>Building module</td>
<td>216</td>
</tr>
<tr>
<td>Stair module</td>
<td>166</td>
</tr>
<tr>
<td>Electrical module</td>
<td>195</td>
</tr>
<tr>
<td><strong>Total Capacity</strong></td>
<td><strong>1418</strong></td>
</tr>
</tbody>
</table>
Table 3: Percentage Contribution of Each Module Type to Total Residence Capacity

<table>
<thead>
<tr>
<th>Module Type</th>
<th>Percentage Contribution to Total Resident Capacity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe rack module</td>
<td>25.32</td>
</tr>
<tr>
<td>Process/Equipment module</td>
<td>20.52</td>
</tr>
<tr>
<td>E-house module</td>
<td>13.47</td>
</tr>
<tr>
<td>Building module</td>
<td>15.23</td>
</tr>
<tr>
<td>Stair module</td>
<td>11.71</td>
</tr>
<tr>
<td>Electrical module</td>
<td>13.75</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100</strong></td>
</tr>
</tbody>
</table>

These results were plotted on a bar chart and a pie chart, respectively. This was done to provide a visual display of the data to facilitate its interpretation. The charts generated are shown in Figures 8 and 9.

Figure 8: Module Resident Capacity by Module Type
The analysis of the module mix according to type revealed that pipe racks are the most predominant type of module fabricated within Alberta while stair modules are the least fabricated.

Discrete statistical distributions were fitted to the data of the residence capacity of the module yards. The geometric distribution showed the best fit. The CDF and parameters of the fitted geometric distribution are summarized in Figure 10.

An important parameter to establish in future similar studies is the average time that each type of module stays resident within the module yard.
The study also tried to establish details of the resources required to sustain these reported fabrication capacities. In order to do that, statistics were generated for the module yard sizes in acres and total numbers of craft workers and supervisors engaged in these yards in typical and peak work conditions.

4.3 SIZES OF THE MODULE YARDS

Module yard size is a variable that plays a role in influencing the module yard residence capacity. The study performed basic statistics on data collected from participants for this variable. Results obtained are summarized in Table 4.

<table>
<thead>
<tr>
<th>Module Yard Size Statistic</th>
<th>Value for the Statistic (Acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>32.66</td>
</tr>
<tr>
<td>Maximum</td>
<td>80.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>4.00</td>
</tr>
<tr>
<td>Sum</td>
<td>947.00</td>
</tr>
</tbody>
</table>

These results show that 947 acres of land in Alberta is currently being utilized for module fabrication for industrial projects. The average module yard size was found to be 32.66 acres while the smallest and largest were found to be 4 and 80 acres, respectively.

Continuous distributions were fitted to the data on module yard sizes. The Gamma distribution showed the most suitable fit. The CDF and parameters for this distribution are shown in Figure 11.
Figure 11: CDF for the Sizes of Module Yards in Alberta (Unit of Measure is Acres)

4.4 DETAILS OF WORKERS IN THE MODULE YARDS

It is known that craft workers are a critical resource required for the fabrication of modules for industrial construction. As these workers perform their task, they are closely monitored and at times guided by their supervisors. This study set out to determine the number of craft workers and supervisors engaged in the fabrication process at each module yard during typical and peak work seasons. The values obtained are summarized in Table 5.

Table 5: Workers Engaged in Module Yards

<table>
<thead>
<tr>
<th>Worker Category</th>
<th>Work Conditions</th>
<th>Average Number of Workers</th>
<th>Total Number of Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supervisors</td>
<td>Average/Typical</td>
<td>24</td>
<td>602</td>
</tr>
<tr>
<td></td>
<td>Peak</td>
<td>40</td>
<td>1033</td>
</tr>
<tr>
<td>Craft Workers</td>
<td>Average/Typical</td>
<td>234</td>
<td>6552</td>
</tr>
<tr>
<td></td>
<td>Peak</td>
<td>361</td>
<td>10105</td>
</tr>
</tbody>
</table>

Results indicated that worker numbers in peak work seasons are just over 1.5 times the number of workers utilized in average work seasons.
4.4.1 Supervisor – Craft Worker Ratio

The study set out to establish the supervisor/worker ratios engaged at module fabrication yards during average/typical and peak seasons. Results obtained are summarized in Table 6.

<table>
<thead>
<tr>
<th>Statistic of Supervisor-Craft Ratio</th>
<th>Value for the Average/Typical Season(s)</th>
<th>Value for the Peak Season(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1:10.52</td>
<td>1:10.74</td>
</tr>
<tr>
<td>Maximum</td>
<td>1:5</td>
<td>1:5</td>
</tr>
<tr>
<td>Minimum</td>
<td>1:20</td>
<td>1:20</td>
</tr>
</tbody>
</table>

These results indicated that there is no significant change in the supervisor/craft worker ratios as the work load for module yards fluctuates. The results also show that on average, each supervisor is responsible for approximately 11 craft workers.

4.5 AGE OF THE MODULE YARDS

Results of the study indicated that there is a wide range of fabrication modules, with respect to age, in existence. The oldest module yard was found to be 39 years old and the newest just 1 year. Statistics of the years of operation of module yards in Alberta are summarized in Table 7.

<table>
<thead>
<tr>
<th>Statistic of Module Yard Age</th>
<th>Value for the Statistic (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>9.97</td>
</tr>
<tr>
<td>Maximum</td>
<td>39.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.00</td>
</tr>
<tr>
<td>Sum</td>
<td>289.00</td>
</tr>
</tbody>
</table>

Results also indicated that companies operating within Alberta have a combined total of 289 years of experience fabricating modules for industrial construction projects.

Continuous distributions were fitted to the data on the years that the module yards in Alberta have been in operation. The Weibull distribution showed a good fit. The CDF and parameters for this Weibull distribution are shown in Figure 12.
4.6 MODULE DENSITY AND WORKER DENSITY IN THE MODULE YARDS

4.6.1 Module Density in the Module Yards

Data collected on the residence capacity and size of module yards was used to compute the density of modules within yards in Alberta. Results obtained are summarized in Table 8.

Table 8: Statistics of Module Density in Yards

<table>
<thead>
<tr>
<th>Statistic of Module Density in the Yards</th>
<th>Value for the Statistic ( Modules Per Acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.64</td>
</tr>
<tr>
<td>Maximum</td>
<td>3.75</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.75</td>
</tr>
</tbody>
</table>

The results of this analysis showed that on average, there are approximately 2 Alberta standard size modules per acre in module yards within Alberta.
4.6.2 Worker Density in the Module Yards

The study set out to establish the statistics of the number of module yards within each acre for each module yard. The results for this analysis are summarized in Table 9.

Table 9: Worker Density in the Module Yards

<table>
<thead>
<tr>
<th>Statistic of Worker Density in Module Yards</th>
<th>Craft Workers</th>
<th>Supervisors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average/Typical Season</td>
<td>Peak Season</td>
</tr>
<tr>
<td>Mean</td>
<td>7.90</td>
<td>12.14</td>
</tr>
<tr>
<td>Maximum</td>
<td>18.75</td>
<td>32.00</td>
</tr>
<tr>
<td>Minimum</td>
<td>2.00</td>
<td>3.00</td>
</tr>
</tbody>
</table>

Results indicated that on average, there are approximately 8 and 13 craft workers per acre engaged in module fabrication in a typical and peak work season, respectively. The results also indicated that there are approximately 1 and 2 supervisors per acre in a typical and peak work season, respectively.

4.7 ANALYSIS BASED ON THE CATEGORIZATION OF THE MODULE YARDS

Responses received from participating companies were categorized two times. The first categorized module fabrication yards by the resident capacity of the yards. The second categorizes module yards by their size. Categorization is based on the 25th, 50th and 75th quartiles.

4.7.1 Categorization of Module Yards by Resident Capacity

The data obtained from participants was categorized into 4 categories using a resident capacity criterion. Basic statistics were computed for the different variables for these categories, and are summarized in Table 10.

Table 10: Attributes of the Modules in Each Residence Capacity Module Category

<table>
<thead>
<tr>
<th>Module Yard Category by Residence Capacity</th>
<th>Number of Module Yards</th>
<th>Mean Resident Capacity</th>
<th>Mean Module Yard Size (Acres)</th>
<th>Mean Age (Years)</th>
<th>Typical Mean # of Supervisors</th>
<th>Typical Mean # of Craft Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - &lt;15.00</td>
<td>6</td>
<td>14.29</td>
<td>6.50</td>
<td>8.67</td>
<td>15.80</td>
<td>134.00</td>
</tr>
<tr>
<td>15.00 - &lt;47.50</td>
<td>8</td>
<td>28.38</td>
<td>21.88</td>
<td>9.63</td>
<td>16.00</td>
<td>128.38</td>
</tr>
<tr>
<td>47.10 - &lt;71.50</td>
<td>6</td>
<td>62.17</td>
<td>44.50</td>
<td>12.17</td>
<td>35.60</td>
<td>375.00</td>
</tr>
</tbody>
</table>
Results indicated that module yards with higher residence capacities are generally larger in size and have been in operation for a longer period of time compared to those with small residence capacities. The yards with larger residence capacities also have approximately twice the number of skilled direct human resources engaged in the work compared to those with low residence capacities.

### 4.7.2 Categorization of Module Yards by their Size

The data in the study was also categorized into 4 categories using module yard size criteria. Statistics for the variables of each yard category were calculated and are presented in Table 11.

<table>
<thead>
<tr>
<th>Module Yard Category by Residence Capacity</th>
<th>Number of Module Yards</th>
<th>Mean Resident Capacity</th>
<th>Mean Module Yard Size (Acres)</th>
<th>Mean Age (Years)</th>
<th>Typical Mean # of Supervisors</th>
<th>Typical Mean # of Craft Workers</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;= 71.50</td>
<td>8</td>
<td>102.57</td>
<td>55.13</td>
<td>10.13</td>
<td>31.43</td>
<td>357.14</td>
</tr>
</tbody>
</table>

Results in this table indicated that large size module yards have higher values of residence capacity compared to small yards. Likewise, larger-size module yards have higher numbers of craft workers and supervisors. This was the expected trend. The results indicated that module yards that are larger in size have generally been in operation for a shorter period compared to smaller module yards.
5.0 CONCLUSIONS AND RECOMMENDATIONS

This study was designed to cover a limited scope of issues existing within the module fabrication industry in Alberta, and aimed at gathering the basic properties of the yards of the participating companies. The findings presented in this report are based on the data collected in the questionnaire survey from the 17 participating companies.

Data received indicated there is a total resident capacity of 1,418 modules for fabricator companies operating in Alberta. Contributions to this overall capacity by the different module types were as follows:

- Pipe rack modules – 25.32%
- Process/equipment modules – 20.52%
- E-houses – 13.47%
- Building modules – 15.23%
- Stair modules – 11.71%
- Electrical modules – 13.75%

The study established that there is a minimum of 28 module fabrication yards in Alberta that occupy a total of 947 acres. Companies that participated in the study indicated on average that they operate 1.65 module yards each.

It was established on average, module yards:

- have been operated for 9.97 years,
- have a size of 32.66 acres,
- have a resident capacity of 50.64 modules, and
- can hold 1.64 modules per acre.

The study revealed useful information about the number of workers and supervisors with the following details:

- Typical work season conditions:
  Average craft – 234 workers with 24 supervisors.
- Peak work season conditions:
  Average craft – 361 workers with 40 supervisors.
- Supervisor to craft worker ratio in typical work season: 1:10.52.
- Supervisor to craft worker ratio in peak work season: 1:10.74.

The values for the various parameters (yard sizes, age of yards, and number of workers) were represented as statistical distributions to facilitate any subsequent simulation-based studies that may be intended in follow-up studies.
There was some ambiguity in the participants’ responses to the module type question. In future studies, it is recommended to use design documents (drawings and specifications) of a typical industrial project that requires the fabrication of different types of modules. Participants in the study could be informed to assume they have an infinite work load of the type specified in the design documents. These design documents could then be useful to the respondents in two ways, namely:

- To serve as a basis for participating companies to estimate their production rate for the different types of modules.
- To serve as a basis for companies to estimate the mix of module types they would configure their operations to produce, given availability of work in each type is not a constraint.

It is recommended that subsequent studies strive to quantify the module fabrication capacity of companies in Alberta based on both a resident capacity and throughput capacity criteria. Furthermore, these studies should establish the utilization rates of these installed modules to illustrate potential capacity shortages or surpluses.
ACKNOWLEDGEMENT

The NSERC Industrial Research Chair in Construction Engineering and Management would like to express thanks to those who supported this research project. Thank you to all the companies who participated through completion of the survey – the research would not be possible without your provided data.

ETHICS APPROVAL

An Assessment of the Steel Fabrication Capacity in Canada, Study ID: Pro00032564, has undergone independent ethics review through the University of Alberta Research Ethics Office and been approved.
APPENDIX – CUMULATIVE DENSITY FUNCTION CHARTS FOR THE DIFFERENT ATTRIBUTES OF THE MODULE YARDS

Discrete PDF for the Number of Module Yards for Each Company

Discrete PDF for the Resident Capacity of Module Yards in Alberta
Continuous PDF for the Sizes of Module Yards in Alberta (Unit of Measure is Acres)

Continuous PDF for the Number of Years of Operation of Module Yards in Alberta