5th International/11th Construction Specialty Conference
5e International/11e Conférence spécialisée sur la construction

Vancouver, British Columbia
June 8 to June 10, 2015 / *8 juin au 10 juin 2015*

MEASURING HIGH-LEVEL PROJECT PRODUCTIVITY FOR ALBERTA CAPITAL PROJECTS

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Abstract: This paper contemplates the development of a single high-level productivity metric for Alberta capital projects in order to represent overall improvement over time. The Industry Leaders Roundtable would use this metric to challenge the status quo, and formulate "out of the box" thinking to improve Alberta Megaproject productivity. The measure would be most relevant for the owner; however, owners and industry need to be supportive to make it successful. For this purpose, the proposed study includes comparisons with data held by the Construction Industry Institute (CII) such as COAA (Construction Owner's Association of Alberta) and CII Performance Assessment Database. This paper establishes selection criteria for input/output variables for the high-level productivity metrics based on the comprehensive review of existing productivity metrics and create a high-level productivity metric. Data are collected from COAA and CII Performance Assessment Database. Descriptive and statistical inferential analyses are conducted for comparison of high-level project productivity between Alberta and U.S. capital projects. The results of this study are anticipated to provide a single high-level productivity metrics with informative quantitative analyses for Alberta projects.

1 INTRODUCTION

Construction industry has been a significant role in Alberta's as well as Canada's economy. In 2013, the construction sector represents 10.9% of $338.2 billion (CND) of total gross domestic product in Alberta (Alberta Government, 2015). Over the two decades, the construction industry in Alberta increases from $4.5 billion (CND) to $36.8 billion (CND). Especially, oil sands industry is a big portion of the construction sector in Alberta and more than $102 Billion (CDN) was spent on construction and operation capital necessary to develop oil sands resources (COAA, 2009). While the size of construction industry increases, the productivity performance and improvement in Alberta's construction industry have been declining. This decline in Alberta is consistent with the decline of construction productivity in North America region over the past three decades (Jergeas, 2009).

For improving performance of construction productivity, academic researchers and industry practitioners have tried to provide effective productivity measurements. In usual, construction labor productivity is measured in actual work-hours per installed quantity. This measurement has been widely adopted in existing productivity studies (Yi and Chan, 2014). However, this productivity measurement focused on micro-level measurement for construction productivity depending on disciplines and workers. In spite of outstanding contributions from the previous studies, a high-level project productivity measurement has been demanding to capture overall improvement of project productivity for capital projects over time. The

Industry Leaders Roundtable in Alberta seeks a comprehensive measurement of high-level project productivity to challenge the status quo, and formulate “out of the box” thinking to improve Alberta capital project productivity.

This paper contemplates and presents possible measurement of high-level project productivity for Alberta capital projects. This paper aims to identify the most appropriate single, high-level project productivity metric for Alberta’s capital projects in order to gauge overall status and trends across the industry based on pros and cons of each measurement. This paper also compares Alberta capital projects’ project productivity with those of U.S. capital projects as a benchmark.

2 RESEARCH BACKGROUND

2.1 COAA-CII Performance Assessment Initiative

As the principal industry association for capital projects in Alberta, the Construction Owners Association of Alberta (COAA) strives to provide leadership to enable its owner members to be successful in their drive for safe, effective and productive project execution. Since 2005, COAA and CII have had a collaborative partnership for the purpose of benchmarking capital projects in Alberta. Building on the collective expertise of COAA and CII, the COAA Benchmarking program has provided a comprehensive performance assessment system comprised of a customized questionnaire, a dedicated database, and a suite of individualized reports for each company submitting project data as shown in Figure 1. This program was funded by COAA with assistance from Alberta Finance and Enterprise, a component of the provincial government of Alberta, and operated by University of Calgary Performance Assessment Lab.

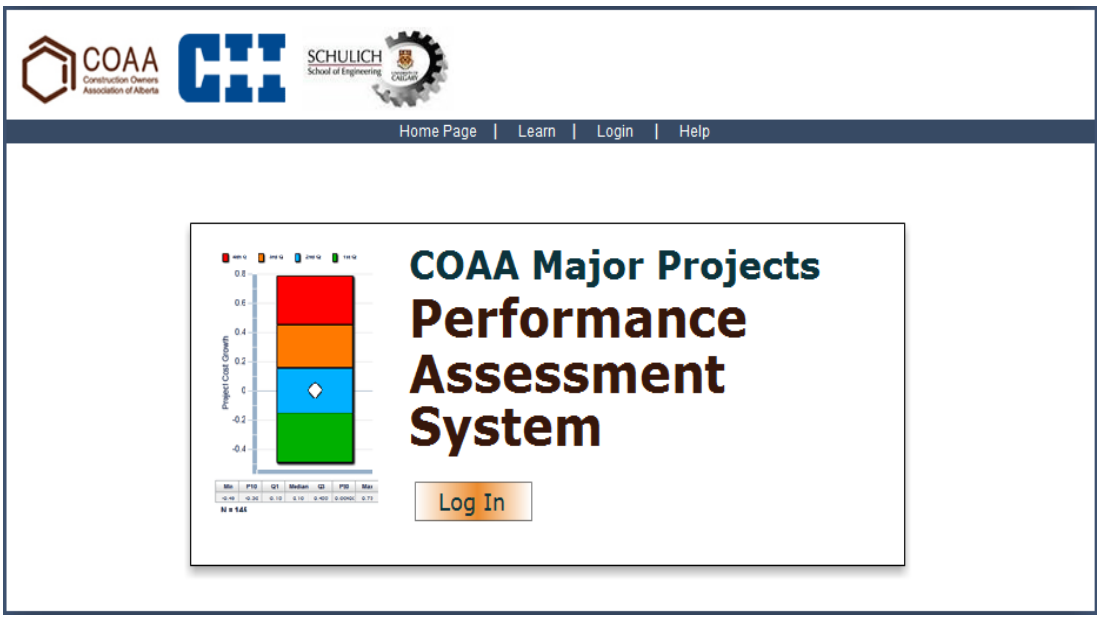

Figure 1: COAA Major Performance Assessment System

Since 2005, the collective effort of COAA and CII has focused on exploring the performance and productivity concerning the execution of capital projects in Alberta. This collaboration was premised on the extensive experience of CII in researching and benchmarking industrial facilities in the United States and around the world. Extending CII’s reach into Alberta permitted tremendous understanding of the performance of these projects, especially when compared with similar projects in the United States. In the line of this efforts, this study develops a high-level project productivity metric for Alberta capital projects.

2.2 Macro-Economic Level Workforce Productivity

Statistics Canada, Canada's national statistical agency, measures labor productivity as an economic indicator across the world, which is calculated by real gross domestic product per hour worked. Real gross domestic product (GDP) (or real value-added) is a chained Fisher quantity index of GDP at basic prices. According to the definitions from the Statistic Canada (Statistic Canada, 2015), the number of hours worked in all jobs is the number of all jobs times the annual average hours worked in all jobs. According to the retained definition, hours worked means the total number of hours that a person spends working, whether paid or not. The hours worked generally includes regular and overtime hours, breaks, travel time, training in the workplace and time lost in brief work stoppages where workers remain at their posts. On the other hand, time lost due to strikes, lockouts, annual vacation, public holidays, sick leave, maternity leave or leave for personal needs are not included in total hours worked. Statistic Canada has adopted this measure to calculate workforce productivity as well as international economic organizations and other countries. Figure 2 was created using annual labor productivity by province and industry that Statistics Canada announced (Statistics Canada, 2015)

Figure 2: Labor Productivity in Construction Sector (2007-2013)*

*Courtesy by Statistic Canada (2015)

Figure 2 indicates that the labor productivity trend in the construction sector over the past seven years since global economic recession. During the pre-recession (2007-2009), the labor productivity in the construction sector had declined in both Alberta and Canada. After recession, Alberta's labor productivity in construction sector has been increasing 20.7% from 2009 to 2013 while the labor productivity in Canada tends to be steady during the same period. In 2013, Alberta's labor productivity in the construction sector was 1.3 times than overall labor productivity in Canada. This remarkable improvement of the labor productivity in Alberta's construction sector is consistent with the economic development in Alberta's economy over the last years.

This labor productivity, which is announced by the government, is representing national and regional economic indicator and is used as a fundamental data when the government develops an economic policies and makes capital investment decisions. However, this indicator has a limitation not to show project-level productivity that can be used for improving performance of owners and contractors. Thus, this paper contemplates the measurement of high-level project productivity metrics that can be applied to individual capital projects.

3 METHODOLOGY

3.1 High-Level Project Productivity Metrics

To develop high-level project productivity measurement, the reasonable input and output need to be defined to meet the purpose of measurement. This study adopts two approaches for exploring high-level productivity measurement in Alberta capital projects.

First, a quantity-based approach is applied which aggregates construction productivity in major construction disciplines including concrete, structure steel, piping, equipment, electrical, insulation, and instrumentation. Construction productivity of each discipline is measured based on actual work-hours per installed quantity. When using this manner, lower productivity values indicate better productivity performance. Using this quantity-based approach, the CII developed project-level engineering and construction productivity metrics to measure high-level project productivity of capital projects. This approach was applied to measure project-level productivity through standardization and aggregation of productivity metrics of engineering and construction disciplines (Liao, 2012; Chanmeka, 2012). Similarly, the project-level construction productivity metric was calculated through the following procedures:

- Transformation: For calculating project-level productivity metric, the productivity data first needs to be assessed on normality of the distribution because the standardization is conducted based on the assumption of normal distribution of the data. This study checked the normality and skewedness on the distribution of productivity values and applied natural log transformation to transform the skewed productivity data for standardization.

- Standardization: The transformed productivity values of the disciplines were standardized to z-score which standard score which means the number of standard deviations. In practice, the absolute value of this metric represents the distance between the productivity value of one project and the population mean of the productivity values in units of the standards deviation. A value is negative when the productivity is below the average, positive when above.

$$z_i = = \frac{p_{ij} - \mu_i}{\sigma_i}$$

  where: z_i = z score of ith construction discipline's productivity; p_i = the transformed productivity metric value of ith construction discipline's j^{th} project; μ_i = mean value of the transformed productivity metric value of ith construction discipline; σ_i = standard deviation of the transformed productivity metric value of ith construction discipline.

- Aggregation: Through the standardization of the productivity values, the variability of productivity values in different disciplines was neutralized and calibrated in the same scale suitable for aggregation. The standardized productivity values of construction disciplines are aggregated using work-hours as the weights because work-hours is usually considered as a common parameter amongst different disciplines (Liao, 2012). The standardized productivity values in different disciplines are aggregated using the following equation:

$$\textit{Project Level Productivity Metric} = \frac{\sum_{i=1}^{n}(WH_i \times z_i)}{\sum_{i=1}^{n} WH_i}$$

where: z_i = z score of ith construction discipline's productivity; WH_i = work hours of the ith construction discipline.

Second, a cost-based approach is also used which considers costs for construction activities as an output. Total site work-hours is considered as hours worked in construction field. All costs have been normalized in terms of currency, location, and time. The normalized cost are value in 2013 Chicago. Similarly, this approach is applied to high-level productivity measurement. The following costs were considered as output.

- The total constructed cost includes all costs, direct and indirect, inherent in converting a design plan for material and equipment into a project ready for start-up or commissioning, but not in production operation; the sum of field labor, supervision, administration, tools, field office expense, materials, equipment, and subcontracts. Therefore, this study uses sum of procurement and construction cost as total constructed cost.
- The construction phase cost includes the costs of construction activities from commencement of foundation or driving piles to mechanical completion. The costs include construction project management, construction labor, and also equipment and supplies costs that are used to support construction operations and removed after commissioning. The CII defined construction direct and indirect costs for detail of typical cost elements in construction phase.
- The equipment cost is the total cost of major equipment. The major equipment is commonly used interchangeably with engineered equipment. It is generally defined as tagged/numbered process or mechanical equipment including drivers.

When using this cost-based approach, larger productivity values indicate better productivity performance because the costs indicate amount of construction works that have been done as output. For calculating cost-based productivity metrics, the following simple equation is applied.

$$\textit{Project Productivity Metric} = \frac{\textit{Cost for construction activities}}{\textit{Work-hours}}$$

In addition to that, the ratio of construction phase cost to procurement cost is also considered as a high-level productivity metric. This metric indicates that how much construction cost is larger than procurement cost considering major equipment and large modularization. If major equipment or modularization is larger, the value of this metric would be smaller.

Based on these two approaches for measuring high-level project productivity, this study investigates the following five candidate as high-level project productivity measurement.

1. Project Level Construction Productivity
2. Total Constructed Cost/Total Site Work-hours
3. (Total Constructed Cost – Equipment Cost)/Total Site Work-hours
4. Construction Phase Cost/Total Site Work-hours
5. Construction Phase Cost/Procurement Cost

3.2 Data Sources and Collection

This paper uses the data extracted from CII Performance Assessment Database and COAA Major Project Benchmarking Database. The CII Performance Assessment has collected capital projects data into its database through the collaboration with more than 130 industrial partners including leading construction owners and contractors around world. As of 2014, CII Performance Assessment Database suppressed 2,300 projects in its database, exceeding over $300 Billion (USD) of cumulative capital project investment since 1995 (CII, 2014).

By 2014, 60 Alberta capital project data has been collected in the COAA Major Project Benchmarking system which mainly consisted of oil sands projects including oil sands SAGD, oil sands upgrading, oil sands mining/extraction, oil and gas exploration, pipeline, and so on. The project data were extracted in

the databases if the middle point of construction phase of the projects was 2001 and later conducted in United States and Alberta.

3.3 Analysis Methods

Once the high-level project productivity measurements are determined, this study calculates each project productivity metric and compares its mean between Alberta and U.S. projects. To compare the mean of high-level productivity metrics and their distributions between two regions. An independent sample t-test was applied to project productivity comparisons. The independent sample t-test is a parametric test and two-sample test. This analytic method tests if the means between two groups are same or not. Thus, this study applied the independent sample t-test to test if the mean value of project productivity between Alberta and U.S capital project during the given period at 0.05 significant level. If a *p*-value of the t-test is less than 0.05, the result indicates the mean value of two groups are significantly different. Using this statistical analysis, this paper presents comparing means of project productivity between Alberta and U.S. capital projects.

4 HIGH-LEVEL PROJECT PRODUCTIVITY BENCHMARKS

4.1 Quantity-based High-Level Project Productivity

As a quantity-based high-level project productivity, the project-level construction productivity developed by CII was applied to comparison of project productivity between Alberta and U.S. capital projects. The value of the project-level construction productivity metric indicates that smaller productivity value indicates better productivity performance. In this study, the zero (0) value indicates the mean of productivity values of capital projects built in North America region.

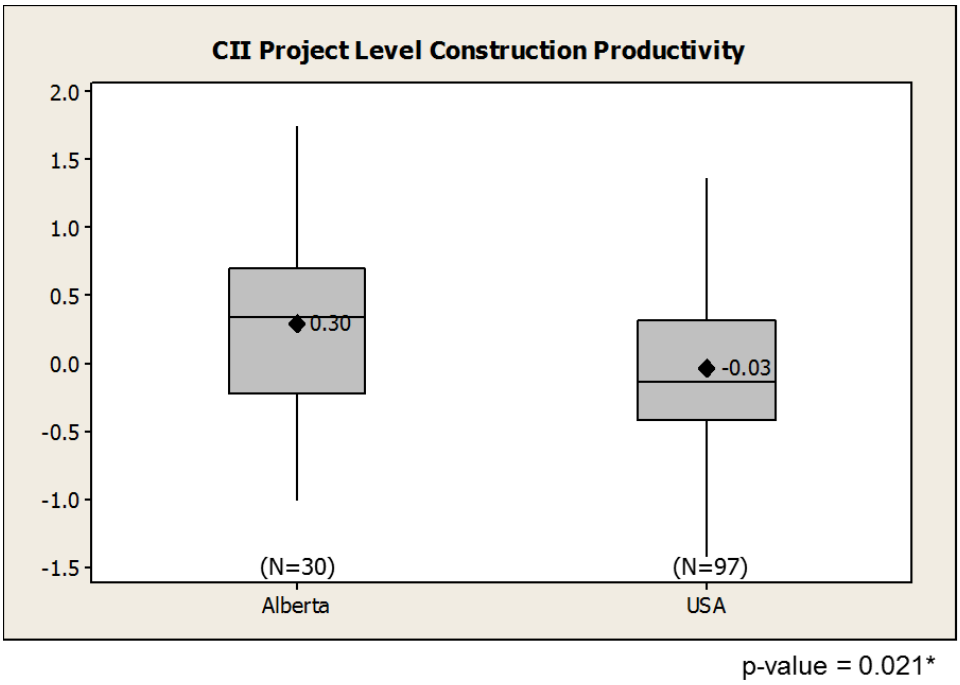

Figure 3: Project-Level Construction Productivity Trends (2001-2011)

Figure 3 shows the comparison of the results of project-level construction productivity of Alberta and U.S. projects. The average of project level construction productivity in Alberta projects was 0.30 while that was -0.03 in U.S. projects. The 0.3 of the mean values of Alberta projects indicates 0.3 standard deviation above the mean of North America's construction productivity. On the other hand, the average of U.S.

projects is -0.03 that indicates the average of construction productivity of U.S. projects is below the mean of North America's productivity. As the results from the t-test, there was a significant difference in the project level construction productivity for Alberta projects (Mean=0.30, SD=0.69) and U.S. project (Mean=-0.03, SD=0.66) at the 0.05 significant level (p = 0.021). This result indicates that Alberta projects' construction productivity was above the average of capital projects' construction productivity in North America. Also, the average of Alberta projects' construction productivity was statistically significantly worse than that of U.S. projects.

4.2 Cost-based High-Level Project Productivity

High-level project productivity values measured by cost-based metrics were compared between Alberta and U.S. projects as can be seen in Figure 4. The value of the productivity metric developed based on cost-based approach indicates that larger productivity value indicates better productivity performance. That is, the larger value indicates that more amount of construction works has been done during one hour.

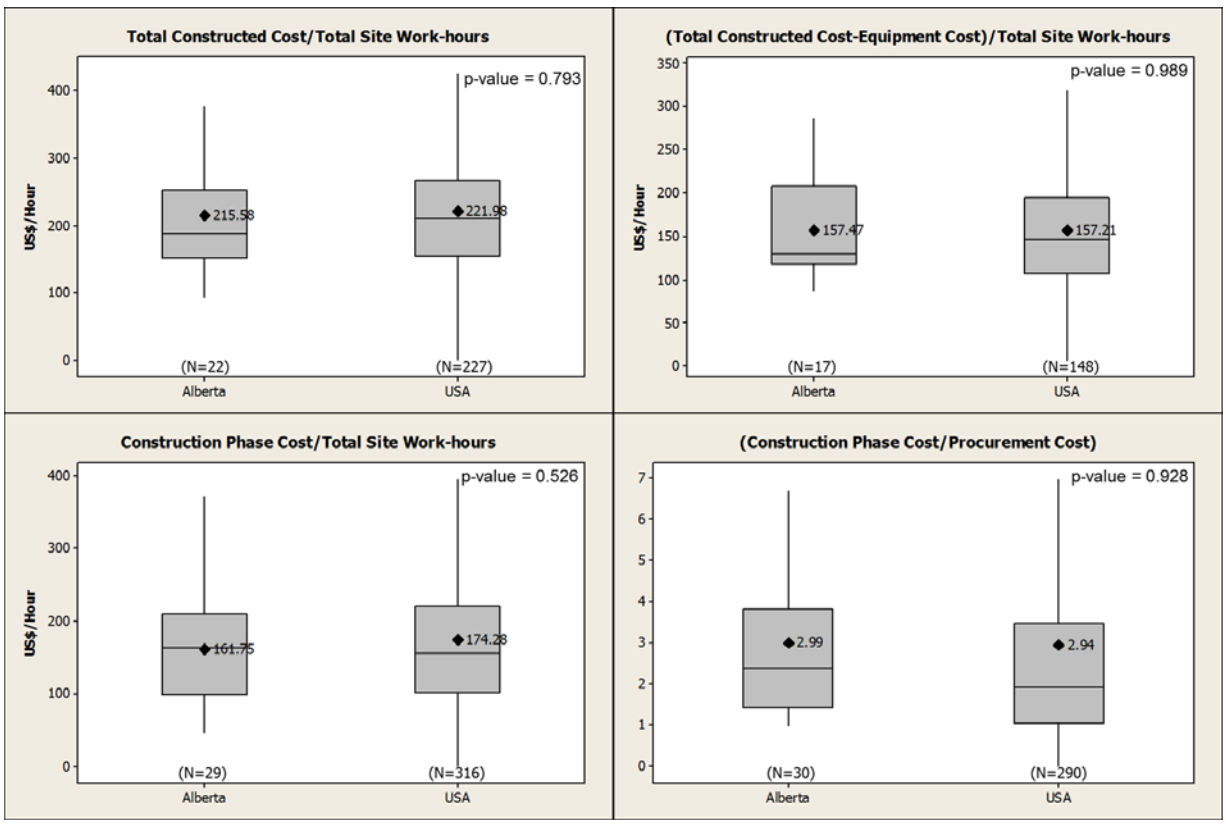

Figure 4: Cost-based High-Level Project Productivity

- Total Constructed Cost/Total Site Work-hours: The project productivity metric "Total Constructed Cost/Total Site Work-hours" means that the sum of procurement and construction cost per one hour worked in a capital project. The mean value of the project productivity of Alberta projects was US $215.58 per hour while that of U.S. projects was US $221.98 per hour. Thus, the U.S. projects' productivity was slightly better than that of Alberta projects but the t-test results shows that there was no significant difference between Alberta and U.S. projects (p-value=0.793).

- (Total Constructed Cost – Equipment Cost)/Total Site Work-hours: The project productivity metric "(Total Constructed Cost-Equipment Cost)/Total Site Work-hours" means that the total constructed cost excluding major equipment cost per one hour worked in a capital project. The mean value of the project productivity of Alberta projects was US $157.47 per hour while that of U.S. projects was US $157.21 per hour. Thus, the Alberta projects' productivity was slightly better than that of U.S. projects but the t-test results shows that there was no significant difference between Alberta and U.S. projects (p-value=0.989).
- Construction Phase Cost/Total Site Work-hours: The project productivity metric "Construction Phase Cost/Total Site Work-hours" means that the amount of construction phase cost per one hour worked in a capital project. The mean value of the project productivity of Alberta projects was US $161.75 per hour while that of U.S. projects was US $174.28 per hour. Thus, the U.S. projects' productivity was slightly better than that of Alberta projects but the t-test results shows that there was no significant different between Alberta and U.S. projects (p-value=0.526).
- Construction Phase Cost/Procurement Cost: The project productivity metric "Construction Phase Cost/Procurement Cost" means that the ratio of construction phase cost to procurement cost for a capital project. The mean value of the project productivity of Alberta projects was 2.99 while that of U.S. projects was US 2.94. The value of Alberta projects (2.99) means that the construction phase cost is about three times more than procurement cost. The larger metric value indicate that the project spent smaller amount of procurement cost including equipment cost compared to other projects. Alberta project procures engineered modules Thus, the Alberta projects' productivity was slightly better than that of U.S. projects but the t-test results shows that there was no significant different between Alberta and U.S. projects (p-value=0.793).

5 CONCLUSIONS AND PATH FORWARD

This study contemplates a high-level project productivity metrics that can be used for achieving stable planning and engineering to provide the baseline estimates of planned performance. Five measurements for high-level project productivity were developed and investigated through comparison between Alberta and U.S. projects. These metrics can be used to fill the gap between country- and industry- level labor productivity calculated by government and activity- and discipline-level productivity. As the results from the t-test analysis of the productivity between Alberta and U.S. projects, Alberta projects' project productivity tends to be lower than that of U.S. projects and can be more improved. The relatively lower productivity of Alberta's capital projects, especially large oil and gas construction projects causes various factors such as the apparent management deficiency in management scope, time, quality, cost, productivity tools, scaffold, equipment, materials, and lack of leadership, and others (Jergeas, 2009).

For capturing high-level project productivity, the measurement requires to be easily understandable and accepted as a measure of macro-efficiency of construction execution, dis-aggregatable to figure out causes, and practical to tract and record. Based on these requirements against high-level project productivity metric, only project-level construction project productivity metric developed at CII can be dis-aggregatable. So, it can be used for the high-level productivity measurement for Alberta capital projects. However, the high level productivity measurement needs to more elaborated and improved for capturing impact of off-site costs and module costs that are very significant component of capital projects. Although the COAA-CII collective efforts lead about 60 Alberta's projects in the COAA Large Major Benchmarking System, the number of the submitted projects is not enough to create time series trend over the time with statistical significance. Therefore, the more data collection of Alberta's projects may be required to develop better productivity measurements.

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