LITTLE'S LAW FOR THE US HOUSE BUILDING INDUSTRY

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ABSTRACT

Although the housebuilding industry is a significant player in the housing supply pipeline, housing experts have paid little attention to this player and have focused more on the other players such as policy makers, financiers, and land developers. Research has tended to focus on house builders and individual housebuilding operations as the constructs of the whole house building industry. However, analysis of the dynamics of the whole industry as a single system has remained unexplored.

This research investigates these dynamics in the US housebuilding industry and explores the applicability of Little's law at the national level. The focus of the study is on single unit dwellings and the time span of the study is forty years between 1971 and 2010. Single unit dwellings made up seventy six percent of all dwellings completed in 2010. The analysis commences with the adaptation of the law for the house building industry. The industry's parameters such as number of house starts, completion time, and number of houses under construction are used as the proxies for arrival rate, cycle time, and work in process. A time factor is added, and the average house completion time is predicted using the law. The predictions are compared with the actual data using error metrics and visual comparisons.

The result shows that Little's law can predict the dynamics of the industry with 5 percent error. Thus, it is applicable in the house building industry and can be used for the analysis of the industry's dynamics. This research demonstrates that the US house building industry operates similar to a production line, and therefore offers industry practitioners and industry analysts powerful techniques for better understanding housing supply.

KEYWORDS

Little's law, work flow, work in process, production planning, US housebuilding industry

INTRODUCTION

Housing supply pipelines start with future urban designation and continue with zoning, structure planning, development and subdivision approval, civil works and building approval, and ends with housing construction. In this process, house building is the final stage of the pipeline and has an influence over the housing supply.

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Thus, to improve housing supply, one needs to understand the dynamics of this industry.

One approach for understanding these dynamics is workflow planning and the use of production planning principles (Gharaie et al. 2010). Little's law is one of these principles that explain the relationship between work in process, cycle time and arrival rate in a production line. This research investigates the applicability of this law in the US house building industry. The study is conducted at national level and the houses considered are single-family houses. This type of house made up seventy six percent of all dwellings completed in 2010. The time span for the study is forty years between 1971 and 2010.

The following sections include a review on the history of the law and its applications in construction as well as other industries. It continues with the adaptation of Little's Law for the house building industry and the analysis for its applicability validation. The default language for the proceedings is English; both UK English and American English are acceptable.

LITTLE'S LAW REVIEW

Little's law is a mathematical equation for dealing with queuing systems (Little 2011). It was proofed by Sir John D. C. Little in 1961 and since then, has been applied in different contexts and industries. The law says that the average number of items in a queuing system (L) equals the average arrival rate of items (λ) multiplied by the average processing time (W). Thus;

$$L=\lambda W \quad \textit{Equation 1}$$

This law holds for all production lines including those with variability (Hopp and Spearman 2008). However, it is not limited to production lines. It can be applied in any queuing system. For example, Harris (2010) suggests that Little's law provides a general framework for understanding the complex relationship between emergency department staffing and patients' length of stay. Further, the law has been used in the implementation of lean six sigma in manufacturing (George 2002). The other examples of Little's law applications include epidemiology and public health, stocks and flows, and counter terrorism (Kaplan 2011).

The application of Little's law in construction was introduced by Koskela (1999) as part of production management techniques that can be used in the construction industry. Little's law assumes that the input and output rate of the process is constant, production is under a steady-state condition and has long production runs. However, for normal construction productions, which are temporary and affected by learning curves and environmental influences, it needs to be modified (Walsh et al. 2007).

The applicability of Little's Law in residential production systems was examined by Bashford et al. (2005). They showed that the production variables such as work in process, cycle time and throughput are related and interconnected in this type of production. They conducted their research in the Phoenix, Arizona, housing market and concluded that the large variations in construction cycle time (completion time) can be explained by the changes in the production loading or work in process in this area.

The applicability of Little's law at national level has been introduced by Gharaie (2011). He has used Little's law to investigate the recent increase in the average house completion time in Australia and to explain the dynamics of the Australian house building industry. Following Gharaie's work, this paper uses the same principles to demonstrate the applicability of the law in the US house building industry and to investigate the relationship between average house completion time, number of houses under construction, and number of house starts.

LITTLE'S LAW ADAPTATION FOR THE HOUSE BUILDING INDUSTRY

Little's law in production planning is the fundamental law explaining the relationship between work in process (L), average processing time (W) and rate of starts (λ) in a production line. However, since Little's law is developed for manufacturing systems, it needs to be adapted for the house building industry. Therefore, this part of the study starts with this adaptation, and then the US house building industry is examined for applicability of the law.

In house building where houses are the products of the system, work in process is measured by number of houses under construction (NHUC), average processing time is measured by average house completion time (AHCT), and number of house starts (NHS) is the arrival rate of the system.

With these definitions, Little's law for the house building industry would be as follows:

Little's law in manufacturing: $L=\lambda W$ *Equation 2*

Substitutions:

$$L \rightarrow NHUC$$
$$W \rightarrow AHCT$$
$$\lambda \rightarrow NHS$$

$\Rightarrow$ *Little's law for house building industry:* $NHUC = NHS * AHCT$ *Equation 3*

It should be noted that house completion time is influenced by the NHUC and NHS at the start of a house. However, the completion of the house may be reported in the year after. In this case, the NHUC and NHS are associated with the AHCT in the next year. For example, the AHCT reported in 1992 may be associated with the NHUC and NHS in 1991. This adds the effect of time to Little's law presented above and its mathematical representation is:

$$NHUC_{(t)} = NHS_{(t)} * AHCT_{(t+l)} \quad or \qquad AHCT_{(t+l)} = \frac{NHUC_{(t)}}{NHS_{(t)}}$$ *Equation 4*

Where *l* in the term *l+t* represents the lag and has the same dimension as AHCT.

In the US house building industry, the average house completion time is less than one year and the NHS and NHUC are reported annually. Therefore, the assumed value for *l* in the Little's law is 1. The validity of this assumption is tested in the following section.

DATA COLLECTION AND DEFINITIONS

There are some terms used in this research that can affect the understanding of the results. Following are the definitions of terms used in this work. Note that since the data for this research were collected from the U.S. Census Bureau database, the definitions are the exact quotes from the Censes Dictionary.

House:

House in this study is a single unit dwelling and includes fully detached, semidetached (semi-attached, side-by-side), row houses, and townhouses. Note that the buildings with two or more units are not included in this study.

Start:

"Start of construction occurs when excavation begins for the footings or foundation of a building. All housing units in a multifamily building are defined as being started when this excavation begins." (U.S. Census Bureau 2012a).

Completion:

"A house is defined as completed when all finished flooring has been installed (or carpeting if used in place of finished flooring)." (U.S. Census Bureau 2012a)

Average house completion time:

This is the length of time from start of construction to completion. Considering the start and completion definitions, average house completion time is the time between the first physical building activity and readiness of the building for occupation. This definition helps this study specifically focus on the house building industry. The approval process and the activities before the start, and after finish, of the construction process are excluded. The average house completion time data were obtained from the US Census bureau. These data are collected on a monthly basis and are annually reported.

Number of house starts:

The number of house starts is the number of houses started in one year. This set of data is collected monthly by the US Census Bureau and is reported monthly and annually. For the purpose of this research, the annual data were obtained from the Bureau.

Number of houses under construction:

This is "the estimates of housing units started, but not yet completed" (U.S. Census Bureau 2012a). These data have also been obtained from the US Census Bureau.

THE VERIFICATION OF LITTLE'S LAW APPLICABILITY

The applicability of Little's law that shows the relationship between average house completion time, number of houses under construction, and number of house starts in the US house building industry, is a hypothesis that needs to be verified. This verification is undertaken by comparison of the actual and predicted AHCT using the law. The time series for all three parameters of NHUC, AHCT and NHS are obtained from US Census Bureau (2012b). Thus, if AHCT is predicted by the law and compared with the actual data, the level of errors would show the validity of the law in the industry. In other words:

$$\left.\begin{array}{l} AHCT_{pred\,(t+l)} = \dfrac{NHUC_{act(t)}}{NHS_{act(t)}} \\ \\ AHCT_{act(t)} \textit{ is available from US Census Bureau} \end{array}\right\} \Rightarrow \text{Comparison of } AHCT_{pred} \text{ and } AHCT_{act} \text{ would show applicability of the law}$$

Equation 5

The comparison is made using two methods. The first method is a visual comparison of the trends of actual and predicted data on the same graph. The second method uses mean absolute percentage error (MAPE) as an error metric, which shows the level of error between the prediction and the actual data.

VISUAL COMPARISON

The first method to test the prediction accuracy is visual comparison. To see the conformity of the predicted and the actual AHCT, the two graphs are drawn on Figure 1. This stage of the verification is done with the assumption that *l* equals to one in the law. The closeness of the prediction and the actual data shows the applicability of the law in the house building industry. This figure shows that the predicted data follow the same trend as the actual data. The prediction is accomplished with very small error, demonstrating its predictive strength. Further, the assumption of one year lag is shown valid for the Little's law in the US house building industry.

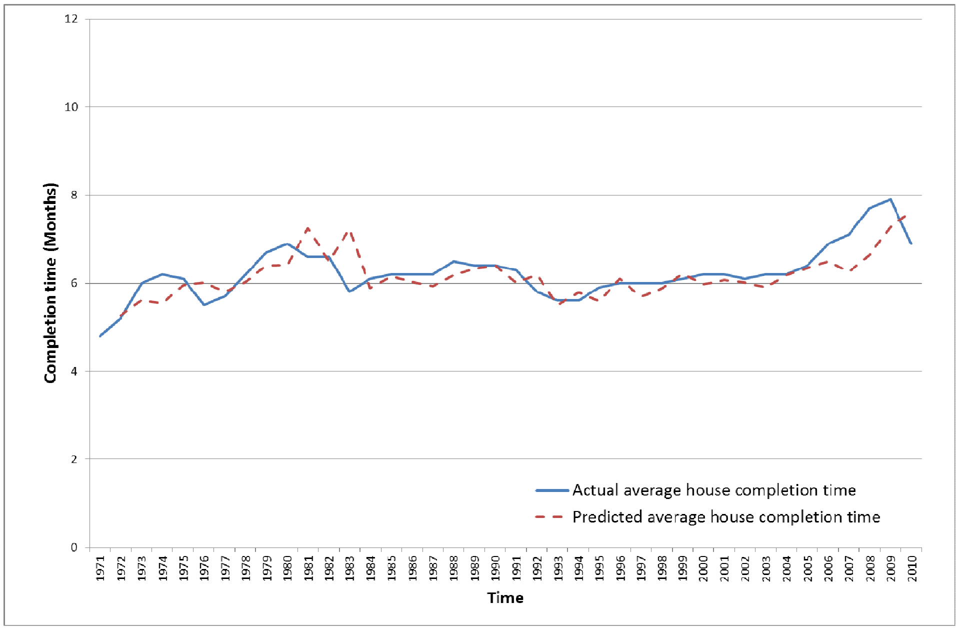

Figure 1: The comparison between predicted and actual average house completion time

MEAN ABSOLUTE PERCENTAGE ERROR

The error in a forecast is the deviation of predicted data from actual data. To analyse the accuracy of a forecast there are some error metrics that quantitatively compare the predictions with the actual observations. Mean absolute percentage error is one of these metrics (Evans 2010).

Mean absolute percentage error (MAPE) is the average of the absolute error divided by the actual data. This metric does not have a scale and can show the accuracy of a prediction regardless of its scale. The formula for MAPE is as follows:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{A_t - P_t}{A_t} \right|}{n} \times 100 \qquad \text{Equation 6}$$

Where A_t is the actual data for the time *t*, P_t is the predicted data for the time *t* and *n* is the number of forecast data.

For house production:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{AHCT_{act(t)} - AHCT_{pred(t)}}{AHCT_{act(t)}} \right|}{n} \times 100 \qquad \text{Equation 7}$$

The MAPE resulted from the above formula is 5%. This is an acceptable level of error in predicting the dynamics of an industry. Since this prediction is undertaken using the assumption of one year lag in the Little's law, the assumption is shown valid.

LITTLE'S LAW FOR THE US HOUSE BUILDING INDUSTRY

The analysis undertaken in this section shows the applicability of Little's law in the US house building industry. The prediction had an error of 5%, which is very low, and the visual comparison strengthened the proposition that Little's law is applicable in the US.

It was shown that the prediction should be made with a one year lag. Thus, Little's law for the US is, as follows:

$$NHUC_{(t)} = NHS_{(t)} * AHCT_{(t+1)} \qquad \textit{Equation 8}$$

The applicability of the law shows that the US house building industry approximates a production line. The same relationship that exists between work in process, cycle time and arrival rate in a production line exists in the house building industry between number of houses under construction, average house completion time, and number of house starts. This result is a platform for further analysis of the industry using workflow-based planning approaches. The verification of Little's law in the house building industry leads to the conclusion that the workflow-based planning approach can predict and explain the dynamics of the house building industry. This law is a platform for decreasing waste and increasing productivity in manufacturing. Therefore, it can be used for the same purposes in the house building industry. The applicability of this law also opens a new perspective to the industry and can lead to better understanding of its dynamics.

CONCLUSIONS

This research investigated the applicability of Little's law in the US house building industry. Since this law is designed for a manufacturing process, it was modified to suit the house building industry. The modification included the amendment of a time factor in the law. The investigation was undertaken through the prediction of the average house completion time using the law. Then the results of the prediction were compared with the actual data. The comparison was made using error metrics, and visual comparisons. It was shown that the errors between the result of Little's law and actual data are very small. MAPE was 5% which is an acceptable error for a prediction. Therefore, it was concluded that Little's law is applicable in the US house building industry.

Applicability of Little's law in the US house building industry demonstrates the similarities between the industry and production lines. This can be used as a platform for the adoption of techniques and methods used by production managers, in house building industry and in housing policy making.

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