MANUFACTURED HOUSING CONSTRUCTION VALUE USING THE ANALYTICAL HIERARCHY PROCESS

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ABSTRACT

Manufactured houses represent a large proportion of factory-built housing in the United States. There are as many variations in quality of materials used, construction techniques, and installation procedures, as there are manufacturers in this industry. This makes the decision of purchasing, given the variety of homes, difficult for the homebuyer. This study provides a framework for evaluation of manufactured houses based on a defined robust goal of construction (utility) value and utilizes the Analytical Hierarchy Process (AHP) to transform a qualitative process into a quantitative one. This AHP-based framework will aid manufacturers in determining construction value-adding features that should receive the highest priority such that value is delivered to prospective homeowners. The developed framework is inspired by current thinking in the Lean Construction literature and will especially inform the value generation focus area.

KEY WORDS

Value Creation, Value Generation, Value Management, Analytical Hierarchy Process

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INTRODUCTION

Manufactured houses represent a large proportion (about 18%) of the housing industry in the United States. Prior to 1974, manufactured houses were known as mobile homes and were provided with an intention for temporary and recreational housing. In 1974, the National Mobile Home construction and Safety Act, also known as the HUD code, was passed by Congress marking the birth of the manufactured housing industry.

A manufactured house is defined as a structure, transportable in one or more sections, which in the traveling mode, is eight body feet or more in width or forty body feet or more in length, or, when erected on site, is three hundred twenty or more square feet, and which is built on a permanent chassis and designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities, and includes the plumbing, heating, air-conditioning, and electrical systems contained therein.

There are as many variations in quality of materials used, construction techniques, and installation procedures, as there are manufacturers in the manufactured housing industry (Barshan et al 2003). This makes the decision of purchasing, given the variety of homes, difficult for the homebuyer. Within a specific price range, most homebuyers decide the purchase of a house based on its appearance or the reputation of the manufacturer, rather than on technical aspects, which later causes buyer's remorse. With a high competition level in the home building market, the manufacturer's challenge is to provide a durable and reliable house without affecting the unit cost of production. The challenge lies in identifying the value-adding features of a house and investing the time and effort to deliver them in lieu of features that add less value to the house.

Notwithstanding the many facets to the value of a house, or that of value in general (such as market value, utility value, historical value, perceived value, etc), this study focuses on the construction or utility value of a manufactured house which is defined as the proportion of the overall product value of the house that is obtained from the construction materials; the processes involved in putting them in place and the post construction assurances against structural or functional damages caused by materials and/or poor craftsmanship, excluding normal wear and tear (Barshan 2003). Because a house is made up of different subsystems such as, structural, mechanical, electrical and so on, each sub-system contributes differently to the construction value of the house. In addition, each sub-system is itself further affected by the choice of items that are combined to produce it.

To guide manufacturers in determining construction value-adding features that should receive the highest priority such that value is delivered to prospective homeowners, this study provides a framework for evaluation of manufactured houses based on a defined robust goal based on construction value and utilizes the Analytical Hierarchy Process (AHP) to transform a qualitative process into a quantitative one. The developed framework is inspired by current thinking in the lean construction literature and will especially inform the value management focus area The paper begins with a brief introduction to Lean Construction and value generation, followed by a discussion of the methods and tools used to achieve the objective of the paper.

LEAN CONSTRUCTION

In 1992, Koskela suggested that the construction production processes should be viewed as a transformation of inputs to outputs, a flow of material and information, and a value generation process. This formed the basis of his Transformation-Flow-Value (TFV) theory which is an integration of the efficacious qualities of Craft, Mass, and Lean Production paradigms, as well as the explicit inclusion of the Value Generation perspective. This latter view of production as a process of value generation was inspired by the over-reliance on the transformation and flow paradigms in existing production paradigms.

This tripartite view of production has lead to the birth of Lean Construction as a discipline that subsumes the transformation-dominated contemporary construction management (Koskela 1999, Koskela 2000, and Berteslen and Koskela 2002). Lean Construction is now being taught in undergraduate and graduate curriculums by instructors at institutions of higher education around the world (Ballard and Howell 2003). In addition, literature devoted to Lean Construction is now rich with explorations of the TFV theory itself as well as its implementation on project-based production systems, i.e., in construction settings (simple and complex), through the development and successful launching of TFV-based methods and tools.

A critical component of Koskela's TFV theory of production is value creation and generation. Its inclusion is a unique feature of the TFV theory and makes it a more robust and broader conceptualization than just the ideal production system embodied in the Toyota Production System. In fact, Lean Production as conceived by Toyota is not necessarily customer-value driven. At its core, the primary goal of the Toyota system is to accelerate/shorten the delivery of products to the market which translates to reducing the time of product development and production cycle. This is evident from Toyota's TPS publication which states: "Constantly Shorten the time it takes to convert customer orders into deliveries" (as quoted in Richards 2002). The emphasis on time is also clear in the following quote by Toyota's president, Hiroshi Okuda:

> *"The company that can identify what technologies are needed, introduce them quickly, and commercialize them will succeed."* (Business Week, June 15, 1998, As quoted in Richards 2002).

By focusing on time reduction, Toyota was able to break-away from the ubiquitous time-cost-quality tradeoff triangle while simultaneously improving cost and quality (through less inspections and rework). The focus on time reduction also explains the relentless pursuit of waste and the development of all the enabling techniques and tools such as JIT, Heijunka (production smoothing), Poke-Yoke (mistake-proofing), 5S, Total Productivity Maintenance, etc (Womack et al 1990, Womack and Jones 1996). This philosophy of time reduction versus value generation is most likely based on the realization that customer expectation is shaped by product developers. This may also be the influence of Dr. Deming himself. Consider, for example, the following quote from the last interview Dr. Deming gave:

> *"The customer invents nothing. The customer does not contribute to design of product or the design of the service. He takes what he gets. Customer expectations? Nonsense. No customer ever asked for the electric light, the pneumatic tire, the VCR,*

> *or the CD. All customer expectations are only what you and your competitor have led him to expect. He knows nothing else."* (Stevens 1994).

Dr. Deming was clearly suggesting that companies should be proactive in shaping customer expectation. He is admonishing companies for *overlying* on focus groups and product clinics to extract customer preferences. Helpful as these steps may be, companies should then analyze the feedback from customers and work on finding ways to provide a *surprise* and *delight* product experience even if this was at the expense of excluding some preferences.

Recognizing the different dynamics that govern the relation between customer and constructor, the value generation view as conceived by Koskela (2000) suggests that value is generated through the interaction between customer and supplier, wherein the customers provide the requirements and the supplier delivers it. The main principle being the elimination of value loss (realized outcome versus best possible) by ensuring customer needs and wants are captured and challenged. Another similar view on value generation is that of the Lean Construction Institute (LCI), which considers that value is generated when customer capabilities are expanded, creating new needs and purposes, and the facility better fulfills the purposes of customers/producers and demands of other stakeholders. Miron and Formoso (2003) utilized value generation principals developed by Koskela in establishing guidelines for managing client requirements in building projects throughout the product development process. For a detailed discussion on value generation, the reader is referred to Koskela (2000).

Notwithstanding the consensus in the Lean Construction community that value generation is a critical pillar, more research efforts are needed to better understand the concept of value generation and how to implement it. A major difficulty in research dealing with value is the fact that the term itself has escaped canonical definition. Wandahl and Bejder (2003) discuss this and other related issues as well as presenting Value-Based Management (VBM) as a framework for value generation. Essentially, VBM is an approach that recognizes the need for management of values and management by values (Wandahl and Bejder 2003). This concept considers two sets of values; product value and process value. Product value is comprised of market (exchange) value and utility (use) value, while process value represents the ethical value of the provider. This VBM approach will likely energize the research activity in the Lean Construction area of value generation.

In this paper, we concern ourselves with utility (use) value of a manufactured house; what we call construction value.

A MANUFACTURED HOUSE AS A CONSTRUCTION SYSTEM TREE

To facilitate the understanding of a manufactured house as a product, using systems engineering techniques a manufactured house was divided into its relevant sub-systems. Each subsystem was subsequently divided into its respective items and/or sub-items. Figure 1 shows such an example of division of a construction system such as a house, bridge, etc.

For a manufactured house, we will use the phrase 'construction system' to denote plant operations, transportation and installation at the desired location, and the warranty services provided during the warranty and callback period. A sample construction tree for a manufactured house is indicated in Figure 2. Brief descriptions of the various 'branches' are provided next

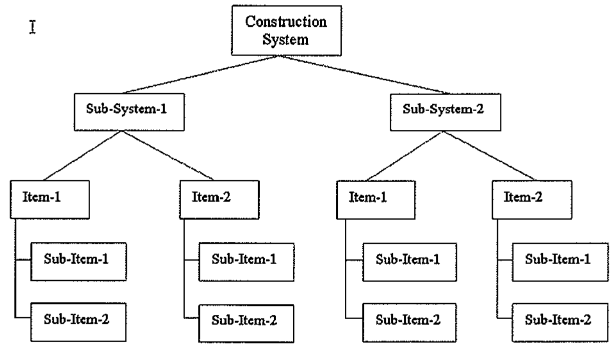

Figure 1 Construction System Tree

SUB-SYSTEMS

The first level of classification for the construction process tree is called sub-systems. These are the different parts of the manufactured house that uniquely contribute to the construction value of the house. Therefore the contribution of all the sub-systems under the construction system for the manufactured house will determine the overall construction value for that house.

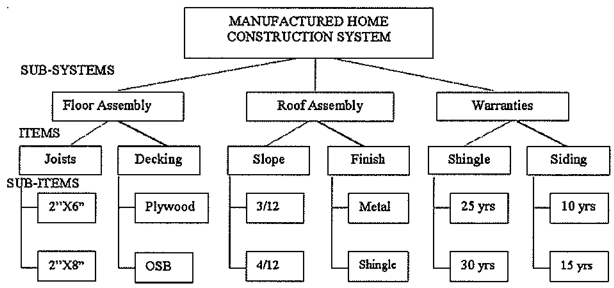

Figure 2 Sample Construction System Tree for a Manufactured House

Three sub-systems are portrayed in Figure 2 as an example. These are: floor assembly, roof assembly, and warranties. Floor assembly and roof assembly are important structural related components of a manufactured house that are design and material driven, whereas warranties are service related components that are quality driven with respect to the reliability and durability of the house. Because each of these components provides a major contribution to the construction value of the house, they are classified as sub systems. Barshan (2003) identified nine such important sub-systems.

ITEMS AND SUB-ITEMS

Items are components of a sub-system that form a complete sub-system. Every item under a sub-system independently contributes towards adding value to its sub-system. Moreover it is assumed that the items of one sub system are independent of the items of another sub system. This means that an item under a particular sub-system, e.g., joists under the floor assembly, is not affected by an item under another sub-system. This assumption is made to facilitate using the Analytic Hierarchy Process (AHP) model, which will be discussed shortly. In addition, every item under a sub-system contributes differently towards the construction value of the manufactured house. Figure 2 shows items of various sub-systems for the construction process of a manufactured house.

It can be observed from Figure 2, that joists and decking are components of a floor system (a sub-system discussed earlier) that when attached together will form a successful floor system for a manufactured house. Both these items are material and design driven, where different combinations could be used for different materials. Similarly slope and finish are components of a roof system that are also design and material driven. Shingle and siding, items for warranties, are time and material driven as the durability and service of the product would depend upon the type used and its useful life. Also, shingles and siding are required as items for roof and external wall protection respectively. Manufacturers provide different warranty durations on these items and hence it becomes essential to consider these as items adding to the construction value of the manufactured house.

Sub-items are the last level on the Construction System Tree. Sub-items represent the possible choices for constructing an item. For example, the item "joists" can be constructed using 2"X6" or 2"X8" members depending on the design as well as the manufacturer's choice. Also the material options for the decking item are plywood or oriented strand board (OSB). These sub-items are also shown in Figure 2.

In general the choice of sub-items is driven by the requirement set for the item (design, material, aesthetics, time, etc.). Also, in many cases, the choice of a particular sub-item depends on the manufacturer and the type of homes produced. The final sub-item choice directly impacts the quality of the constructed item, which in turn affects the sub-system level.

SELECTING SUB-ITEMS USING THE AHP MODEL

The main of the research that this paper is reporting on was to provide manufacturers with a quantitative approach to assess the contribution of the sub-items to the overall construction value of a manufactured home. A literature review into prior similar work revealed that modeling such unstructured problems can be performed using a technique knows as Analytic Hierarchy Process (Dias and Ioannou 1996). This technique was developed by Saaty in 1980 to address problems involving multi-attribute decision making in the economic, social, and management sciences. While money serves as the basis of measurement of all kinds of goods and services, the Analytic Hierarchy Process or AHP is also particularly suited for measuring social values (Saaty, 1980).

AHP is a method for using pairwise comparisons to compare the elements of a certain level of a hierarchy with respect to an element in a higher level of the same hierarchy to show the relative importance of each element of the lower level with respect to that element in the higher level. According to Saaty, the pairwise comparison process can be an asset for problems where there is no scale to validate the result. Pairwise comparison is the process of comparing pairs of elements as opposed to comparing all the elements in a single step. These features of AHP make it especially pertinent to the development of a quantitative approach to assess the contribution of the sub-items to the overall construction value of a manufactured home. Figure 3 is a flowchart portraying the AHP-based methodology developed for performing this assessment.

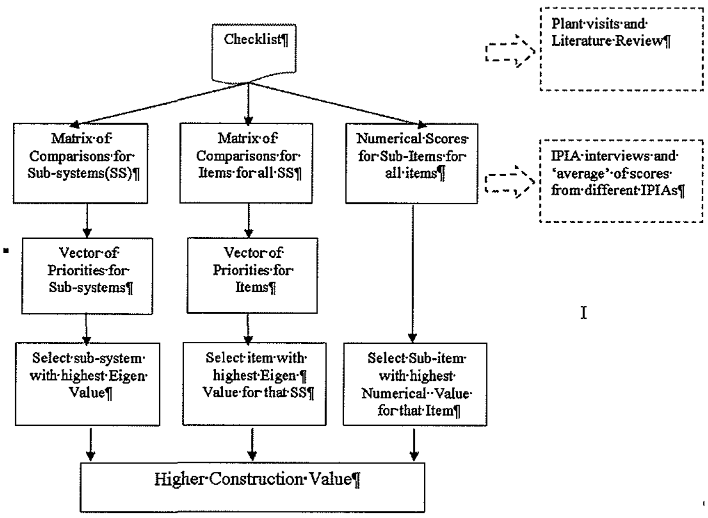

Figure 3 Model for assessing the contributions of house attributes using AHP

The methodology is basically comprised of a simple four-step process as follows:

1. Develop a checklist based on the construction system tree developed in the earlier section
2. Formulate a matrix of comparisons for sub-systems and items under every subsystem. Assign numerical scores to sub-items for every item.
3. Determine the relative importance of contribution each sub-system and each item under that sub-system provide towards the construction value of a manufactured house. This is obtained by calculating the vector of priorities for sub-systems and items.
4. Select the sub-systems with higher Eigen value and determine the items within that sub-system with higher values. For those particular items select the sub-item with higher numerical score.

The mentioned steps are explained next using a sample checklist and information provided from Barshan (2003).

The acronym IPIA shown in Figure 6 stands for Inspection Primary Inspection Agency. This third-party agency evaluates the ability of manufacturing plants to follow their own approved quality control procedures as well as providing ongoing surveillance of the manufacturing process. They are regarded as the 'police' in the manufactured housing industry. They are responsible for inspecting every unit being manufactured before leaving the plant and provide HUD labels indicating that the house is inspected and ready for installation.

It is critical to note that the AHP is considered in this research because it was found to be more suitable for guiding manufacturers in determining construction value-adding features that should receive higher attention during the production phase. This research was neither focused on improvement of the design management phase of manufactured housing nor on the identification and translation of client's expectations to design targets. Consequently, the use of the Design Structure Matrix (DSM) and the Quality Function Deployment (QFD) techqniues were entirely out of the research scope (see Browning 2002, Koskela et al (2002), and Eldin and Hikle (2003) for coverage of theses techniques). Future projects will address the utilization of these two techniques.

Step 1-Checklist

The system tree is used mainly to classify the various aspects of the manufactured house construction process into sub-systems, items and sub items. It also provides a framework to visually organize the construction process. However this does not facilitate documentation of the sub-items that are actually used for a particular house. A checklist is one apparatus that can resolve this issue. A checklist will also facilitate the development of the AHP model. Figure 4 shows the format used for the checklist, which follows the same classification levels used in the construction system tree.

SUB SYSTEM-1:	☐		☐	
Item-1	☐	Sub item-1	☐	Sub item-2
Item-2		Sub item-1		Sub item-2
SUB SYSTEM-2:	☐		☐	
Item-1	☐	Sub item-1	☐	Sub item-2
Item-2		Sub item-1		Sub item-2

Figure 4 Checklist format for Construction Systems of a Manufactured House

The categories as seen in Figure 4 are sub-systems that are further classified into items, against which a selection of sub-items are available. The blank boxes are provided for checking the appropriate sub-item relevant to the item being considered. A sample checklist is shown in Figure 5, which is only showing one sub-system; the roof assembly. As illustrated in Figure 5, the sample checklist, a space for an additional sub- item is provided in case the manufacturer uses a sub-item different from those listed. Once completed, the checklist is a very useful tool for systematically recording information about manufactured homes.

ROOF ASSEMBLY:			
Design Load	☐ 20 Lb	☐ 30 Lb	☐ I
Roof Slope	☐ 3 / 12	☐ 4 / 12	☐
Insulation R-value	☐ R-21	☐ R-19	☐
Eave Projection	☐ 3”	☐ 8”	☐
Eave Position	☐ Front and back	☐ All around home	☐
Roof Underlayments	☐ Rolled out and stapled	☐ Only rolled out	☐
Roof Finish	☐ Metal	☐ Shingles	☐
Roof Sheathing	☐ Plywood	☐ OSB	☐

Figure 5 Sample checklist for Construction Systems of a Manufactured House

A detailed checklist can be found in Barshan et al. (2003). The checklist was developed from data collected from manufactured house plant visits and literature reviews on manufactured homes. Using this checklist, a manufactured house of any brand can be evaluated based on its construction related attributes.

Step-2a Matrix of comparisons for sub-systems and items

A matrix of comparisons is a matrix in which a pair-wise comparison process is performed. Assume that there is a certain criterion, say x, which is divided into three sub-criteria, and the objective is to find the strength of those sub-criteria on the main criterion. The sub-criteria; say a, b, and c; are pair wise compared in their strength of influence on the main criterion, x. In this research, the matrix of comparison was developed for the sub-systems and items using the Analytic Hierarchy Process (AHP) model. Table 1 shows the entries to the matrix of comparison. In Table 1, (A, B) represents the value of comparison between A and B that is based on the following criteria (Saaty 1980):

- If A and B are equally important, then insert value for (A, B) as 1.
- If A is weakly more important than B, then insert value for (A, B) as 3.
- If A is strongly more important than B, then insert value for (A, B) as 5.
- If A is demonstrably or very strongly more important than B, then insert value for (A, B) as 7.
- If A is absolutely more important than B, then insert value for (A, B) as 9.
- (A, A) is a diagonal element representing the comparison between A and itself and thus (A, A) is always 1.
- (B, A) represents the element opposite to (A, B) with respect to the main diagonal. (B, A) is the reciprocal of (A, B). For example, if (A, B) is 5, then (B, A) is 1/5.

Table 1 Entries to the Matrix of Comparisons

	A	B	C
A	1	(A,B)	(A,C)
B	(B,A)	1	(B,C)
C	(C,A)	(C,B)	1

In Table 1, only the values in the white cells have to be provided, as the values in the shaded cells are the reciprocal values of the white cells. The main diagonal of the matrix is always equal to unity.

The values for the comparison matrices for sub-systems and items were obtained by interviewing third-party agency inspectors (IPIAs) because they are knowledgeable in the construction process of manufactured houses. During these interviews, the IPIAs were introduced to the term construction value first and then for every white cell in the matrix of comparisons, they were asked the following questions:

- How important is sub-system A compared to sub-system B in terms of contributing to the construction value of the manufactured house?
- How important is item A compared to item B in terms of contributing towards the value of sub-systems?

A sample sub-systems matrix of comparisons is shown in Table 2. It can be observed from Table 2 that the comparisons between floor system and roof system have a value of 1/5, which means that the floor system is strongly less important than the roof system in terms of contributing towards the overall construction value of a manufactured house. Similarly, other comparisons are made between the different sub-systems.

Table 2 Matrix of Comparisons for Sub-systems

	Floor assembly	**Roof assembly**	**Warranty**
Floor assembly	*1*	*1/5*	*1/3*
Roof assembly	*5*	*1*	*1/3*
Warranty	*3*	*3*	*1*

Table 3 shows a similar matrix of comparisons for the various items comprising the sub-system Floor Assembly. For example the comparisons between axles and tires indicate that axles are strongly more important than tires in contributing to the overall construction value of the manufactured house.

Table 3 Matrices of Comparisons for Items

FLOOR ASSEMBLY:		1	2	3	4	5	6	7	8
Axles	1	*1*	*5*	*1/5*	*1/3*	*1/7*	*1/5*	*1/5*	*1/3*
Tires	2	*1/5*	*1*	*1/7*	*1/7*	*1/9*	*1/3*	*1/7*	*1/5*
Joist Size	3	*5*	*7*	*1*	*1*	*1/3*	*3*	*5*	*7*
Joist Spacing	4	*3*	*7*	*1*	*1*	*1/3*	*3*	*5*	*7*
Joist System	5	*7*	*9*	*3*	*3*	*1*	*5*	*7*	*9*
Insulation R-value	6	*5*	*3*	*1/3*	*1/3*	*1/5*	*1*	*5*	*7*
Decking material	7	*5*	*7*	*1/5*	*1/5*	*1/7*	*1/5*	*1*	*3*
Type	8	*3*	*5*	*1/7*	*1/7*	*1/9*	*1/7*	*1/3*	*1*

It should be noted that the values shown in Table 2 and Table 3 are provided for demonstration purposes only. Therefore, the reader should avoid any rationalization of these values. The actual values obtained for the research are detailed in Barshan (2003). It is also important to stress that the intent of obtaining values for sub-systems and items was not to capture the decision criteria or the thought process of the experts – we were not trying to develop an expert system. Rather the intent was to elicit the judgment of these experts with regard to the construction value of a manufactured house.

Step 2b-Assign numerical scores to sub items

For a given item, there could be many sub-items. Hence the checklist was designed with a blank third option for any other sub-items that may be used by the manufacturer. Because the number of sub-items for any item is not fixed, developing a matrix of comparison quickly becomes an intractable endeavor. If we fixed the number of sub-items in a checklist, the options would be limited and if a manufacturer happens to use a sub-item different from the ones mentioned in the checklist, the comparison becomes infeasible. We also found that pair- wise comparison for several sub-items quickly wears out the respondent.

Consequently, an alternative approach was adopted for assigning values to sub-items. A numerical scale from 1 to 10 was used, with 1 being a lower score and 10 being the highest. The scores for all sub-items in the checklist were assigned by the third-party agency inspectors. As an illustration, a completed checklist for the sub-items of Floor Assembly is shown in Figure 6. Again, these scores are provided for illustration purposes only.

FLOOR ASSEMBLY:						
Axles	10	New	8	Old and Certified		
Tires	10	New	6	Old		
Joist Size	6	2"X6"	8	2"X8"		
Joist Spacing	10	16" o/c	6	24" o/c		
Joist System	6	Longitudinal	10	Transverse		
Insulation R-value	6	R-11	8	R-21		
Decking material	10/6	Plywood / OSB	8	Novadeck		
Type	10	Water-resistant	5	Non water resistant		

Figure 6 Numerical scores for sub-items

The main criteria used to arrive at the numerical scores for sub-items was durability, which refers to the longevity for any particular sub-item. The IPIA inspectors were asked "On a scale from one to ten, and according to its durability, what score would you assign sub-item A". The scoring can be explained with an example from the sample checklist. Consider the item 'Joist Spacing', shown in Figure 6, with its sub-items 16″ o/c (on center) and 24″ o/c. These two sub-items were assigned the respective scores 10 and 6, indicating that 16″ o/c are better.

Step 3- Vector of Priorities for sub systems and items

A normalized principal eigen vector is the vector of priorities for any matrix of comparisons. The vector of priorities delineates the relative weights of the elements of the matrix considering their strength on influencing the main criterion with respect to which they are being compared. Estimates of that vector can be obtained by dividing the elements of each column by the sum of that column (i.e., normalize the column) and add the elements in each resulting row and divide this sum by the number of elements in the row. This is a process of averaging over the normalized columns. This method is recommended by Saaty (1980).

Table 4 Column normalization and vector of priorities for sub systems

	Floor assembly	Roof assembly	Warranty	Vector of Priority
Floor assembly	0.11	0.05	0.20	0.12
Roof assembly	0.56	0.24	0.20	0.33
Warranty	0.33	0.71	0.60	0.55

Table 4 is an example for column normalization and vector of priorities for sub systems and Table 5 is an example for column normalization and vector of priorities for items under the sub-system Floor Assembly – the other items under the different sub-systems are also subjected to the same calculations but are not shown here to save space. In Table 4 the vector of priorities is calculated as follows:

1. Divide the elements of each column of the matrix of comparison by the sum of that column (see Table 2). Hence, the first element in the new matrix after normalization will be $\frac{1}{1+5+3}$=0.11. This is the first value as observed in the matrix of normalization shown in Table 4. Other values were obtained in a similar way.

2. Add the elements in each resulting row of the normalized matrix and divide this sum by the number of elements in the row. Thus, the first value for the vector of priorities for the first sub system in Table 4 is computed as $\frac{0.11+0.05+0.20}{3} = 0.12$.

The same calculations in step 1 and 2 above are also used to build the vectors of priorities shown in Table 5 for items.

Table 5 Column normalization and vector of priorities for items

FLOOR ASSEMBLY:		1	2	3	4	5	6	7	8		Vector of Priority
Axles	1	0.03	0.11	0.03	0.05	0.06	0.02	0.01	0.01		**0.04**
Tires	2	0.01	0.02	0.02	0.02	0.05	0.03	0.01	0.01		**0.02**
Joist Size	3	0.17	0.16	0.17	0.16	0.14	0.23	0.21	0.2		**0.18**
Joist Spacing	4	0.1	0.16	0.17	0.16	0.14	0.23	0.21	0.2		**0.17**
Joist System	5	0.24	0.2	0.5	0.49	0.42	0.39	0.3	0.26		**0.35**
Insulation R-value	6	0.17	0.07	0.06	0.05	0.08	0.08	0.21	0.2		**0.12**
Decking material	7	0.17	0.16	0.03	0.03	0.06	0.02	0.04	0.09		**0.08**
Type	8	0.1	0.11	0.02	0.02	0.05	0.01	0.01	0.03		**0.05**

Step 4 Value added Sub-systems, items and Sub-items

The matrices shown in Table 4 provide evidence that the most contributing subsystem to the construction value of a manufactured house is warranties (at 55%), followed by roof assembly (33%) and floor assembly (12%). In addition, within warranties, the item 'general' warranties is the most contributing factor to warranties (at 62%) followed by 'structural system' (26%), and siding and shingles at 6% each.

A manufacturer should consider the subsystems that provide a significant value towards the overall construction value of the manufactured house. Table 6 is a summary of sub-systems, items and sub-items that are arranged in the order of increasing sub-system Eigen Values. Thus in this example, the manufacturer can consider warranty as the most important sub-system and contributes around 55% of the construction value to the manufactured house. To improvise on this sub-system the manufacturer should items affecting the value of this sub-system must be considered which are the general warranty (62%) and the structural warranties (26%). The sub-items governing these items should next be evaluated and in this case it is 2 years for general warranty, which increases with higher warranty duration.

Table 6 Summary of Value added sub-systems, items and Sub-items

Sub-systems	Items	Sub-items
Warranty (55%)	General (62%)	2 years
	Structural Systems (26%)	5 years
Roof Assembly (33%)	Design load (42%)	30 Lbs
	Sheathing (14%)	Plywood
Floor Assembly (12%)	Joist System (35%)	Transverse
	Joist Size (18%)	2"X8"

CONCLUSION

This paper described a framework for evaluation of manufactured houses based on a defined robust goal based on construction value and utilizes the Analytical Hierarchy Process (AHP) to transform a qualitative process into a quantitative one. The framework can guide manufactures in determining construction value-adding features that should receive the highest priority and attention such that value is maximized for and delivered to prospective homeowners.

Reactions to the model have been positive by third-party inspectors who participated in the study as well as by manufacturers themselves. Space limitations prevented the presentation of a comprehensive example application of all house systems. A detailed presentation is available in Barshan (2003) for interested researchers. Future research will involve investigation of whether houses built based on the framework presented are of better quality. In spite of the inherently subjective nature of multi-attribute decision models, the AHP-based model will be validated using indirect techniques such as predictive validation, axiomatic validation, and convergent validation (see von Winterfeldt and Edwards 1986).

In general, additional research is needed to develop value management enabling techniques and procedures. Other researchers may choose to further develop the AHP-based framework presented with more advanced multi-attribute decision making tools or find other methods from other disciplines or industries. Regardless of the approach, efforts to develop new tools and ideas aimed at enhancing value management in Lean Construction should be guided by the VBM approach presented in Wandahl and Bejder (2003).

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