STRATEGIC ISSUES IN STRESSKIN FOAM PANELS FOR RESIDENTIAL CONSTRUCTION

by

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SUBMITTED TO THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING

at the MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1990

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Prefabricated components are playing an important role in decreasing the costs and increasing the performance of single family housing. This thesis proposes that the performance, costs, and present market share of a component is a result of the following factors:
- the underlying characteristics and economic structure of the industry,
- the technological and performance characteristics of the component's design,
- the technological, economic, and organizational characteristics of the production, marketing, and installation processes associated with the component.

These factors are examined in detail for the stressskin foam panel industry and, on a general level, for components in residential construction. The technological aspects of stressskin foam panels are examined using a framework for understanding prefabrication introduced in this thesis. The economic structure of the stressskin foam panel industry is analyzed using a framework developed by Michael E. Porter for conducting a structural analysis of an industry. The technological, economic and organizational aspects of the processes associated with the production and sales of stressskin foam panels are analyzed using Porter's framework for conducting a value chain analysis. Possible strategic actions by individual producers and the foam panel industry as a whole are discussed.
ACKNOWLEDGEMENTS

The subject of this thesis arose from my involvement in a joint MIT-Industry consortium for developing innovative residential construction technology. Much of the information that contributed to this thesis resulted from a cost study I conducted over too many months in conjunction with the consortium's development of an improved roof panel system.

Acknowledgement and a sincere "Thank you" are owed to the following individuals who helped me with the cost study, this thesis, or both:

MIT faculty and staff: Professor Fred Moavenzadeh, who served as my thesis advisor and contributed many of the core concepts in this thesis; Mr. John Crowley, a Research Associate in Architecture who supervised my participation in the consortium and, for a time, served as my thesis advisor; and Professor Lorna Gibson, who provided moral support and academic guidance.

MIT graduate students: Tim Tonyan, whose knowledge, advice and friendship were very much appreciated, and Ron Sanchez, a superb teacher of strategic management who has contributed to my understanding of innovation in construction.

Industry: (producers of foam panels and other residential components, contractors, and kit home designers)
Amos Winter, President, Winter Panel Corp., Brattleboro, VT
Tom Martyn, Vice President, Winter Panel Corp.
Art Milliken, President, Acorn Homes, Concord, MA
Bob Sullivan, Foam Products Corp., St. Louis County, MO
Joe Solinski, NVR Building Products, Pittsburgh, PA
Leonard Silk, President, Shelter Systems, Hainesport, NJ
John Slayter, Ryland Homes
Reed Bergwall, President, Comfort Design Inc., White River Junction, VT
Henry Tainter, Cape Associates, Eastham, MA
Bo Foard, Autumn Builders, Brattleboro, VT

I appreciate the funds provided by the U.S. Army Research Office to MIT's Center for Construction Research and Engineering. As a result of my Program for Advanced Technology in Construction (PACT) fellowship I was able to accomplish significantly more research than would have been otherwise possible.
The love and encouragement of my wife, Amy, was critical throughout my research. Finally, I would like to acknowledge that the Lord God played a very big part in this thesis, as He does in all of our lives.

Unless the Lord builds the house
its builders labor in vain.
(Psalm 127:1)

This thesis is dedicated with love to my parents,
Tom Toole and Betsy Relin,
who have been so important in my life.
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CHAPTER ONE: INTRODUCTION TO PREFABRICATION

INTRODUCTION

In 1987, the cost of all products and construction associated with new residential construction in the United States was $194,772,000,000. New housing starts included 1,024,400 single family detached (SFD) homes valued at $114,463,000,000.¹

A prefabricated component in residential construction is a collection of pieces that is preassembled in a factory before being placed in its final location in the house. In this thesis, the term component refers to prefabricated wall, roof, floor, and foundation systems. Each of these systems are associated primarily with the structure of the house, not with aesthetic finishes, utilities, etc. Windows and doors are also examples of prefabricated components, but their production characteristics, histories and present market share are significantly different from the other component systems. Accordingly, components in this thesis will not include windows and doors.

Components have become an important part of the residential construction industry. According to Automated Builder magazine, of the SFD starts in 1988, 92% included one or more components. In that year there were over 2000 component manufacturers, with the top 100 achieving combined gross sales of $807,000,000. Many people in the residential construction industry believe that components represent the most promising concept for decreasing the cost and increasing the performance of housing.

Structural foam panels are an innovative residential component. While offering superior performance along several dimensions, they have yet to achieve their potential levels of performance, cost or market share. Three fundamental questions confronting observers of the foam panel industry (and anyone interested in understanding innovation in residential construction) are:

1) How can the performance of foam panels be improved?
2) How can the costs of foam panels be decreased?
3) How can the market share of foam panels be increased?

It is believed that these questions are also of fundamental importance to producers of foam panels. Although it could be argued that producers in general are more interested in increasing their profit margin and total profits than in improving the performance or lowering the cost of their products, the state of competition in residential construction is such that higher margins and total profits can only be achieved by increasing the performance, lowering the costs and increasing the market share of their product.

Answering the three questions above requires an understanding of how an innovation is adopted in the component market. A model is introduced at the end of this chapter that indicates how the performance, costs, and present market share of a component are a result of the following factors:

1) the underlying characteristics and economic structure of the industry,
2) the technological and performance characteristics of the component’s design, and
3) the technological, economic, and organizational characteristics of the production, marketing, and installation processes associated with the component.

The purpose of this thesis is to examine these factors in
detail for the stresskin foam panel industry and, on a broad
level, for residential components as a group. The goals of the
thesis are to provide the reader with a better knowledge of
stresskin foam panels as a product (with a heavy emphasis on
their use in roof systems rather than in walls), a better
understanding of the factors influencing the adoption of an
innovation in residential construction, and a practical method
for analyzing existing and future component systems.

In addition to the innovation model, this first chapter
includes a discussion of some key terms and relationships. A
brief history and discussion of prefabricated residential
construction is presented, including the factors that have
contributed to the development of the component market.

Chapter Two reviews the basic functions and characteristics of
the four most common residential roof framing systems installed
today. The technological aspects of stresskin foam panels is
examined in Chapter Three using a framework for understanding
prefabrication in components introduced in this thesis.

In Chapter Four, the economic structure of the stresskin foam
panel industry is analyzed using a framework developed by
Michael E. Porter. The economic, technological, and
organizational aspects of the processes associated with the
production and sales of stresskin foam panels is analyzed in
Chapter Five using Porter’s framework for conducting a value
chain analysis. In addition to the analyses themselves,
Chapters Three, Four and Five include suggestions for strategic
actions by individual producers and the foam panel industry as
a whole that are based on the results of the analyses. Chapter
Six summarizes the strategic actions suggested in earlier
chapters and discusses the application of the methodology used
in this thesis to other component systems.
The Appendices include the details and results of a cost study of the four roof systems I conducted as part of my involvement with the Advanced Housing Construction Technology consortium at MIT.

BASIC TERMS AND RELATIONSHIPS

TECHNOLOGY is the set of quantifiable physical attributes\(^2\) that contributes to the physical qualities of a product. Each attribute may be a result of progress in one or more scientific or technological fields. For example, the maximum unsupported span of an innovative material is a function of various aspects of its mechanical strength, which may have been developed or optimized by material scientists.

PERFORMANCE is the set of quantifiable system attributes that are related to the system's ability to serve its functions.\(^3\) These attributes may actually contribute to the desired functions once installed--such as the physical properties of the system--or they may be associated with the process of achieving the installed system--such as its design, purchase, installation, etc. Figure 1 is a list of typical performance attributes, not all of which will apply to every component system.

PERFORMANCE AND MARKET SHARE: There are two main issues in this relationship. The first issue is the extent to which consumers recognize performance advantages. For example, if a wall system provides an R-value of 38, do most consumers


\(^3\) Ibid, p. 3.
recognize that this is significantly more desirable than a wall system that provides an R-value of 25? The second issue is the extent to which consumers are willing and able to pay for higher performance. For example, consumers may acknowledge an R-38 wall is more desirable than an R-25 wall but not be willing to pay a price premium for the R-38 wall.

Physical properties:
- thermal insulation (R-value) *
- maximum unsupported span *
- load bearing capacity for a given span *
- life of entire system except finishes
- life of finishes (interior and exterior)
- fire safety *
- moisture resistance (chance of leaking) *
- reliability of system (warranty, reputation)
- architectural flexibility

Aesthetic:
- interior and exterior visual appearance of the unit itself
- contribution to the overall appearance (ditto)
- flexibility/range of finishes

Installation:
- speed of installation (may include intermediate milestones, such as house close up)
- number of trades required and their interaction
- skill level required
- total labor hours required
- maximum number of workers required at one time
- number and type of special tools required
- number and type of equipment required
- safety aspects

Sales:
- total ordering/installation time
- time required by purchaser during sales process
- ability to ensure timely delivery

Note: An asterisk * denotes attributes for which a minimum or maximum are specified in the model building codes.

Figure 1: TYPICAL PERFORMANCE ATTRIBUTES FOR COMPONENTS
While the value attributed to a higher level of performance in any of the attributes listed in Figure 1 will vary with each consumer and with the type of component system, many residential construction consumers recognize superior performance and are willing to pay for it. Inasmuch as a home is such a large purchase, however, consumers are not always able to afford physical performance above the code-specified minimum or a product or brand with a high-end reputation. The segments that are willing and able to pay for superior performance are generally the Luxury and Custom homes market segments. A producer of a product offering superior performance may therefore initially price the product high and earn profit margin in the Luxury and Custom segments; however, the product's initial market share will be limited since the majority of new houses fall under the Starter and Move-Up segments. Eventually, the producer will probably "step-down" (reduce) the price of the product to appeal to the Move-up segment, where it will be readily accepted due to its acceptance in the custom market.

PERFORMANCE AND COSTS: The relationship between cost and performance varies with the component. Sometimes improved performance is accompanied by increased costs, which is the case with stressskin foam roof panels and with most of the differences between a starter home and a luxury or custom model. In other cases, performance is increased while cost is decreased, as is the case with roof trusses and—if the life cycle costs are considered—thermal insulation. A product offering decreased performance with increased costs obviously has no market value unless necessitated by environmental or other special conditions.

MARKET SHARE AND COSTS: The concept of reduced costs is not restricted to lower initial purchase or installation costs.
Additional cost parameters that may influence a purchasing decision are expected annual energy costs, maintenance costs, and replacement costs. The term life cycle costs is often used to sum up all aspects of cost. Costs are similar to performance in that the actual number for an attribute may not be as important as the perceived future value of the actual number. For example, low energy costs may be very important to a homeowner, yet he/she may refuse to place a high value on a system providing low energy costs due to the chance that the cost of higher insulation would not be reflected in the purchase offers if the house were sold.

THE FOUNDATIONS OF PREFABRICATION
The term prefabrication has meant differing things to different people over the years in residential construction. While prefabricated systems have been pursued in very different ways, there have been six primary goals:
1) increased performance
2) increased predictability
3) decreased development and construction times
4) decreased number and skill level of labor required on site
5) decreased seasonality
6) decreased costs

Increased Performance: Prefabrication can increase the performance of part or all of a house by making it possible to use a wider range of materials and designs. For example, the reconstituted wood beams and joists that have become popular over the past ten years allow longer spans in roofs and walls than conventional sawn lumber. It would not be practical to produce a reconstituted wood product on a jobsite. Even items

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that used to be produced on site could not be produced on site today if they had to meet the performance and quality of those produced in a factory. For example, homeowners and homebuilders are so used to the performance and quality of factory produced windows and doors that they would not tolerate any attempts to produce them on site again.

Increased Predictability: There are three aspects of predictability that homeowners and homebuilders tend to value: time, quality and costs. Variability in these three aspects result from variability in labor productivity, quality control inspection, and material availability and unit costs. Prefabrication makes each of these elements less variable, and therefore more predictable, than they are in conventional construction. Controlled environmental conditions, mechanized production, closely supervised, operations research-type management and quality control, and volume purchases of materials are some of the characteristics of factory production that allow increased predictability.

Decreased Time: Development time for a homebuilder or developer is the time between when a firm commits to building a speculative house or housing tract and the date of completion. Decreased development and construction times are desirable for homebuilders and developers because, as the saying goes, time is money. Time savings means reductions in overhead and financing costs. Development time for a homebuyer may be considered the time between when he arranges to have a house built and the date of completion. In the 19th century, when portable prefabricated houses were often built along frontiers, savings in construction time meant less time without a permanent shelter overhead. While this is not the case with custom homebuyers today, they are nonetheless often anxious to move into their new homes.
Development time is decreased by having most of the architectural and engineering design performed at some earlier date, based on a standardized product. Less design is therefore necessary after the buyer orders the house. In addition, since much of the design is standardized, site preparation work can often begin while the design is being modified for the buyer's specific needs. Construction time is reduced since much of the work is performed quickly in a factory.

Decreased Labor: Decreasing the number and skill level of labor required to erect a house on site is desirable to reduce costs, increase safety and performance, and allow construction of housing in remote locations, in locations experiencing temporary local labor shortages, and in locations facing a long term shortage of labor (as is predicted for the U.S. starting later this decade). Whether homebuilders would agree that decreasing labor requirements is desirable probably depends on who is asked. Management would agree with the homeowner. Laborers, who no doubt would otherwise enjoy higher wages, might disagree.

On site labor requirements are reduced by having most of the work accomplished in a factory. There is therefore less work to be performed on site and, if the components are properly designed, the skill level required to install them is reduced.

Decreased Seasonality: It is desirable for homebuilders to reduce the impact of weather on construction since it allows them to build houses throughout the year, thus maintaining a steadier income. Society also benefits by reducing the inefficiency resulting from discontinuous production, and, on a less theoretical level, by reducing the amount of unemployment.
compensation paid to idled labor. Seasonality is reduced through prefabrication by reducing the amount of work that must be accomplished on the jobsite open to the weather. Most of the work is accomplished in an environmentally controlled factory.

Decreased Costs: Decreasing the costs of housing has many benefits. Microeconomic theory tells us that decreasing the cost of any product benefits society as a whole and increases the supply of the product (unless the product has a price elasticity curve that is 100% inelastic, which housing does not). It seems that lowering the cost of housing here in the United States is more important than ever before. Harvard University reported in 1989 that the cost of homeownership for first time homebuyers as a percentage of their income rose from 17.0% in 1970 to 33.0% in 1988.\(^5\)

Prefabrication decreases the cost of homebuilding in many ways. The labor wage rate is considerable lower in a factory than on site due to the lower skills generally required, year round employment, safer and more pleasant working conditions. The labor and equipment costs per output is lower due to the lower wage rate, better supervision and control, and the fact that mechanized equipment is less expensive than manual labor providing volume is above a minimum threshold. As mentioned under "Increased Performance", less expensive innovative materials and designs can be used. Economics of scale may occur in some aspects of production. Volume purchasing may provide significant discounts. As mentioned under "Decreased Time", decreased development and construction times reduce overhead and financing costs. Loss of materials on site due to

\(^5\) Harvard University, Joint Center For Housing Studies, *The State of the Nation's Housing*, (Cambridge, MA: Harvard University Press, 1989).
theft or weather damage is reduced. Finally, design and engineering costs should be reduced since the costs of standardized design can be spread over a large number of units.

THE HISTORY OF PREFABRICATION

1820 - 1900: Prefabrication is a concept that has been around longer than many people realize. The manufacturing of prefabricated structures on a large scale basis began in the 1820s.

From...the specialized manufacturers of Britain, the continent of Europe, the United States of America, eventually even the countries of the colonial empires, there was a considerable outflow of buildings and structures in component form. These were destined for assembly and erection, occasionally in the home market, but predominantly in an astonishingly variety of export markets embracing Europe, Africa, Asia, the Americas, and Australia. There was an impressive range of products: hospitals and schools, warehouses and factories, market buildings and stores, churches and meeting halls, barracks and blockhouses, lighthouses and bridges, theaters and exhibition pavilions, offices and arcades, conservatories and farm buildings, gasworks and railway stations. They were produced in small workshops and large industrial plants employing a thousand men....

Despite the impressive range of buildings that were being prefabricated in the nineteenth century, single family houses remained the predominant prefabricated structure. People settling in new areas sought to get a roof over their head before they worried about buildings associated with commerce and culture. The following is a quote from an 1830 pamphlet advertising a prefabricated house.

"...A comfortable Dwelling that can be erected in a few hours after landing, with windows, glazed doors, and locks, bolts, and the whole painted in a good and secure manner, carefully packed and delivered at the Docks, consisting of two, three, four or more roomed Houses, made to any plan that may be

1900 - 1960: The industrial revolution brought much improvement in manufacturing and commerce yet did little to improve the living conditions of the urban masses necessary to support the economy. Prefabricated housing in the twentieth centuries shifted from portable houses for remote areas to low cost houses for urban dwellers. Leading or accompanying this shift in target homeowners was the entrance into prefabricated housing by architects, many of whom enjoyed international prominence.

This was the period when the great masters, Le Corbusier, (Walter) Gropius, Frank Lloyd Wright, found it necessary to deal with the technological imperatives and social ideology of mass housing, when each in his own manner...explored the potentials of industrialized building. This is the period when European architects of standing in the modern movement...engaged with enthusiasm in designing prototypes for industrial production....In this crusade they were joined by...many notable architects in the United States. ¹

Despite this formidable array of creativity and genius, prefabricated housing achieved only limited success during the first half of this century. Reviewing the many books and documents authored by famous architects such as those named in the quote above, there is a plethora of brilliant concepts, some of them seemingly practical. Yet history records few concepts that were successfully developed. Steel houses were produced in significant numbers in the United States and the United Kingdom. Copper houses were produced in Germany in the Thirties and many were shipped to Palestine. The General Panel Corporation, started by Walter Gropius and Konrad Wachsmann, seemed positioned to capitalize on the urgent need for prefabricated, low cost housing immediately after WWII ended.

¹ Ibid, Prologue

² Ibid, p. 5.
Yet none of these systems were produced for longer than a few years, and none enjoyed even a small portion of the large demand envisioned by the system designers and manufacturers.

1960 - PRESENT: The late 1960s marked a new era of prefabricated housing in this country. Operation Breakthrough was a massive housing program initiated by the United States government. Operation Breakthrough sought to increase the supply of housing by lowering the cost of multi-family construction through quantum technological and organizational innovation. America's largest corporations were encouraged to propose residential systems that took prefabrication to the limit.

A slew of literature on prefabrication appeared during this period as professionals from many different fields saw the potential that recent technological advances held for improving the performance and reducing the costs of housing. The concept of systems was embraced—that is, improvements in the collection of individual pieces that make up the house as a whole—rather than merely improvement in individual pieces. The majority of Operation Breakthrough prototypes were attempts to make systems improvements, many through the use of modular concrete construction. The term "industrialization" was often heard during this period, although it had been used in previous years.

Once again, despite formidable talent and apparently good ideas—and even sufficient capital—a set of prefabricated systems did not achieve the success envisioned them. The twenty-two Operation Breakthrough systems selected for prototype never made it to mass production. Experts and not-so-experts alike have proposed a number of explanations for Breakthrough's lack of total success, including this comment:
During the Operation Breakthrough, many companies entered the modular housing field for the first time, and with much fanfare. Large and powerful corporations...entered the arena with the supposition that sophisticated corporate management techniques would prove successful in housing as they had in other fields. Wrong! Housing is a tight-budget, low-overhead quick-decision industry that proved totally elusive to Fortune 500 companies. 9

One of the most common complaints heard about the Breakthrough prototypes was the negative feelings associated with a totally prefabricated home. The boxy, bland appearance of many of the systems certainly did not help. The vast majority of firms simply did not successfully interpret the preferences and behavior of homeowners. 10 It seems that a comment made about the prefabricated systems common in the nineteenth century applies equally as well to the Breakthrough systems.

The function of the home is to conserve, to protect privacy, family life, cultural and social values, traditions. It is a reflection of very deep needs, for security, continuity, conformity, in an area of emotional intensity, dealing as it does with one's personal immediate environment, rich in symbolic meaning. The early prefabricated house challenged and denied most of these attributes... 11

Another factor proposed as inhibiting successful development of industrialized housing was transportation restrictions, specifically involving highways. Cited were narrow width limits, overly restrictive times when it was permissible to transport a wide unit, and the requirements for expensive


11 Herbert, p. 19.
escort vehicles and signs to warn adjacent motorists.  

Organized labor was often cited as one of the main barriers to prefabricated systems. Union leaders claimed they fought against prefabrication only when jurisdictional disputes occurred or when a prefabrication plant was established specifically to obtain lower wage rates on a nearby project. Individuals on the other side of the issue claimed that unions were fanatically and selfishly against all innovation, particularly prefabrication.

Perhaps the most significant factor behind the demise of the Operation Breakthrough prototypes is the fundamental economic conflict of prefabricated housing. High overhead costs are a liability in the cyclical housing industry, yet are unavoidable in prefabrication due to the expensive equipment required and other high fixed costs. Another way of viewing the conflict is to acknowledge that requirement of prefabricated systems for continuous production in order to achieve satisfactory cost and quality directly conflicts with the housing market's discontinuous demand.

Besides stimulating technological innovation, the subsidies of Operation Breakthrough were intended to allow the firms to aggregate the housing market to ensure continuous production even during periods of low demand. Pellish pointed out that even if sufficient annual demand was achieved, manufacturers would still have trouble ensuring that a steady supply of land, capital, labor and materials, and technical information was

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available.\textsuperscript{14}

Despite the apparent lack of success of Operation Breakthrough and the slow growth in complete prefabricated homes since then, progress has indeed been made in prefabrication since the early 1970s—arguably at a faster rate than ever before. There are many trends in society and the homebuilding industry that have contributed to the significant growth rate in prefabrication over the past thirty years. Several of these were mentioned earlier, such as the growing shortage of skilled labor in this country and the cost of housing increasing beyond the ability of many homebuyers to pay for it. Also, regardless of whether it was ever as big an obstacle as some claimed, the strength and rigidity of union resistance has certainly decreased.

Changes in consumer preferences have occurred. Homeowners in all segments of the market increasingly demand quality construction. Buyers in the Starter segment may not be able to afford many of the features and expensive finishes found in the more expensive segments, but they still demand a well built house. Similarly, most consumers increasingly demand performance—not bells and whistles, but simple performance like decreased sound transmission through interior walls. More consumers are looking for the kind of livable space not found in traditional tract designs.

As is discussed in Chapter Three, technological progress has also favored increased fabrication. The past thirty years has seen automated machinery start to replace crude mechanized equipment. The availability of inexpensive computer-aided-design and drafting (CADD) systems for the personal computer has made them more common in prefabrication plants. The same

\textsuperscript{14} Dietz and Cutler, eds., pp. 138-140.
is true for information technology systems. All three of these trends have contributed to the slow progress being made towards flexible manufacturing in prefabricated homebuilding. A final technological factor is the increasing performance and acceptance of innovative engineered wood products, such as oriented strand board (OSB) and laminated veneer lumber (LVL).

The factors discussed above explain why prefabrication has been growing in homebuilding but do not indicate the direction of the growth. Prefabricated houses--generally referred to as "manufactured housing" these days--are typically divided into four groups: HUD-code (also called mobile), modular, panelized and precut.

HUD-code homes are called such as a result of the federal agency that originated the code. Passed in 1976, the U.S. Department of Housing and Urban Development Manufactured Homes Construction & Safety Standards established national building codes for mobile home-type houses that supersede state and local building codes. Single section HUD-code homes leave the factory 100% complete while double section units require one to three weeks of finish work to connect the two sections. Most mobile homes include a metal chassis system in the floor. HUD-code homes are sold through local dealers and generally resemble plain, one-story stickbuilt construction. Statistics obtained from Automated Builder magazine indicate that there were 272,000 units sold in 1988, which was 15% of the total single family home sales.

Modular homes are similar in concept to many of the Operation Breakthrough systems except that the majority are made out of wood, not concrete, and are intended for single-family detached homes, not multi-family. In effect, most modular units are partial stickbuilt homes assembled in a factory,
including the finishes and utilities. Like mobile homes, modular units can be joined and finished on site in one to three weeks and generally offer limited flexibility in sizes, styles and finishes. Automated Builder reports that there were 109,000 modular homes and apartments sold in 1988, which was 6% of the housing market.

Panelized houses are pre-designed home packages that include most of the components referred to in this thesis—wall, floor, and roof panels or trusses. In addition, a panelized home package may include a utility core and finishes. Panelized systems may be open or closed. An open wall does not have the interior sheathing or wall board installed in the factory. Instead, the wall surface is installed on site after insulation and utilities are installed. While closed systems provide quicker on site completion, they are sometimes resisted because the materials and construction between the faces cannot be inspected on site. Automated Builder’s figure for 1988 sales of panelized homes was 653,000 units (35%), but this includes precut and log homes.

Precut houses generally consist of conventional materials that are cut and labelled in a factory before being shipped to the site for standard installation. There is really little manufactured about them. As is mentioned in Chapter Two, whether precut house can be installed faster than conventional construction is debatable. As one might expect, however, precut houses offer a wide range of architectural flexibility and finishes.

TRENDS TOWARDS COMPONENTS: While all four prefabricated housing types described above have continued to gain market share over the past fifteen years, they have yet to achieve the market share or sales growth of components sold outside of a
home package. Roof trusses were used in nine out of every ten stickbuilt homes built in 1988. The growth in sales of floor trusses, wall panels, and gable ends (of roofs) has also been significant. Fifteen years ago, nearly all component manufacturers produced only roof trusses. In 1988, 92% produced roof trusses, 76% produced floor trusses, and 20% produced wall panels.

The exceptional growth of components compared to the four prefabricated systems is a result of three fundamental differences between components and the other three systems. First, the other three types are all complete house packages and therefore limit the architectural flexibility in sizes, shapes, styles, and finishes more than most homeowners desire. Second, components have the most desirable amount of work performed in the factory given the levels of technology available in manufacturing systems today. Modular and mobile homes have too much performed in the factory while precut houses have too little. Third, components benefit from systems improvement while the other three types have undergone very little systems-type improvement over conventional construction. These three fundamental characteristics of components, along with three additional elements, will be discussed in detail for roof systems in the Chapter Three.

Many in the industry more knowledgeable than this author also believe that components represent the most promising type of prefabrication. Dietz saw the advantages of components some twenty-one years ago and introduced issues that are still quite relevant today.

The term "pieces" refers to smaller units...assembled at the site to provide the structure into which are inserted infilling nonstructural panels or field-fabricated parts such as partitions. The line between industrialization and traditional construction can easily become blurred. The objective may be greater flexibility or arrangement with a
smaller number of different units that might be possible with big panels, or it may be simpler fabrication equipment in the shop, or simpler and lighter erection equipment, or pieces small enough to be handled by manpower alone. More joints are usually required than with boxes and large panels, but the joints may be simplified by being put at points of low stress. The amount of field finishing and incorporation of utilities is generally greater than with boxes and big panels, but this can be reduced by careful and ingenious design.¹⁵

Perhaps the simplest way to sum up the predicted growth in components is to say there has and will continue to be a substantial, but not entire, transfer of value from the jobsite to the production plant. In other words, most but not all of the economic activity and value creation associated with a new home will occur in a factory instead of on the site that the new house is located. The implications of this partial transfer of value will be discussed in Chapter Six.

A MODEL FOR UNDERSTANDING INNOVATION IN THE COMPONENT MARKET

While the growth in market share of components has been relatively high compared to other forms of prefabrication, it has been quite low compared to their potential growth, given the advantages they offer over conventional construction. There are various factors in the homebuilding market that have kept the theoretical superiority of components from achieving their potential in reduced costs, increased performance and market share.

The model below seeks to describe the typical process of adoption of an innovation in residential components to identify the many factors that have contributed to the characteristics

and market share of individual components. It was developed
from literature by Shaw (1987), Sanchez (1989), Amsden and Bar-
Or (1989), Porter (1985), and the prefabrication concepts and
trends discussed in this chapter. Like many models, it is
sufficiently comprehensive and detailed to be cumbersome while
sufficiently general to omit several factors that may apply in
specific cases. Nevertheless, it is believed that the model is
of value in that it accurately captures the majority of
processes, participants, and other factors involved in the
adoption of an innovation in the residential component market.

A model such as this one deserves more explanation and
verification of each premise through case studies. (Indeed, a
proper discussion would be a thesis in itself.) Unfortunately,
space does not permit. The purpose of outlining the model here
is to ensure the reader has the "big picture" of innovation in
residential components. Further, the strategies presented in
this thesis for decreasing the costs and increasing the
performance and market share of stresskin foam panels are based
on this model.

The reader may note the following themes:
1) the successive stages of technological discovery,
evaluation, application, acceptance, and adoption
2) the discounts applied to cost, performance, and competitive
advantages by risk adverse participants
3) the relationships between:
   a. the underlying characteristics and economic structure of
   the component industry,
   b. the technological and performance characteristics of the
   component's design,
   c. the technological, economic, and organizational
   characteristics of the production, marketing, and installation
   processes associated with the component,
d. and the resulting market share of the component.

A General Model of Innovation in the Component Market:
1. The underlying characteristics of the component market are:
   A. The economic environment of the component market is characterized by extreme cyclical demand that is tied to the general economic conditions within the United States.
   B. The industry structure of the component market is fragmented and includes strong competitive forces exerted by substitutes, suppliers and the threat of entry.
   C. The component industry has numerous Producers, with many small firms started by individuals with backgrounds in homebuilding or manufacturing, who may not possess the skills or vision to establish effective operating and competitive strategies.
   D. Products in the component market involve lumber or wood products, are in the early to middle stages of the product life cycle, and are innovative in their degree of prefabrication.
   E. Consumers and channels (homeowners, distributors and homebuilders) in the component market are generally risk adverse and do not understand how a product can improve their own value chain.

2. Advances in various technologies create the potential for improvement in components. Examples of these technologies include materials, manufacturing systems (including computer aided machinery (CAM)), structural design, information systems, computer aided design and drafting (CADD), telecommunications, and audio-visual systems. As there is very little R&D in the component industry, the advances in technologies that are pertinent to components occur outside the industry. Since adoption within the component industry is not attempted until a potential producer sees a promising application, innovation
tends to be market pull rather than technology push.

3. Improvement that results from technological advances can be in the form of increased performance, additional services, reduced costs, or a combination of two or more. Advances can be applied in either new or improved components or in one or more of the processes (production, sales, installation, etc.).

4. A technological advance that offers potential improvements in the component industry may or may not be attempted to be applied there. Whether a manufacturer attempts to apply an advance depends on the following factors:
   A. whether the manufacturer is aware of the technological advance
   B. the manufacturer’s expected value of the economic or competitive advantage he may gain as a result of applying the technological advance. This value, which Sanchez termed the perceived net economic benefit, depends on:
      i. the manufacturer’s perception about potential consumer valuation of the cost or performance advantages that may result from applying the technological advances. Could it increase his market share or establish a profitable market niche?
      ii. the manufacturer’s perception of potential barriers to achieving economic or competitive advantage after attempting to apply the technological advances. There are several elements of this development risk:
         a. the risk that applying the technological advances may not result in cost or performance improvements. In other words, what is the risk that the technology just will not pan out?
         b. the risk that improvements will not be accepted into the market due to various compatibility problems such as
unregulated competitive forces resulting from the structure of the industry, such as entry barriers that would prevent the innovation from entering market and switching costs that would prevent the use of different supplies needed for innovation

unregulated forces resulting from the nature of the industry, such as incompatibility with existing construction methods, materials and processes

regulated forces resulting from the nature of the industry, such as incompatibility with codes

c. the risk that consumers will not place a high value on the improvements
d. the risk that an improved product would be beaten out by a competitor reducing the price of an existing product or introducing a product offering even greater improvement

C. the manufacturer’s ability to finance development of the improvement, particularly if the potential manufacturer is now a homebuilder.

5. A technological advance that is applied in a manufacturing firm may or may not actually lower the cost of the component. The degree to which the costs are actually reduced is a result of the following factors:

A. the organizational and financial ability of the manufacturer to apply technology to reduce costs through developing new products or modifying existing products

B. the match between the manufacturer’s production characteristics and the industry’s cost behavior drivers:

i. what portion of the plant’s capacity the firm operates at

ii. how fast manufacturer can move down the cost learning
iii. how well the manufacturer is able to benefit from economies of scale
iv. how well the manufacturer capitalizes on linkages between production activities and linkages between the value chains of the manufacturer and of suppliers and/or distribution and installation channels
v. whether the manufacturer can benefit from interrelationships with horizontally or vertically integrated businesses
vi. whether the manufacturer capitalizes on economies related to timing
vii. the location of manufacturing relative to suppliers, installers and buyers

C. the effectiveness of firm/industry in value activities other than the one(s) most affected by the technology

D. whether the innovation is differentiated, such as offering improved performance or services, that offset the cost savings from the new technology

6. In a similar way to reduced costs, a technological advance that is applied in the component industry may or may not actually achieve improved performance. The degree to which performance of a component is improved is a result of the following factors:

A. the organizational and financial ability of the manufacturer to apply technology to improve performance in design and production through developing new products or processes or modifying existing
B. the organizational and financial ability of the manufacturer to apply technology to improve performance in activities other than production, such as distribution, sales and service
C. how fast the manufacturer can move down the performance
learning curve, which depends on:

i. the slope of the curve

ii. the market share of the new or improved product

iii. the total demand for the product

D. whether the manufacturer emphasizes low cost rather than improved performance

7. A product that offers improved performance and/or reduced costs may or may not achieve a large market share, particularly in the period immediately following its introduction. The product’s actual market share, i.e. the degree that the industry actually adopts the innovation, is a result of:

A. various characteristics of the product:

i. how large are the performance differences between the new product and alternative products (i.e. products that have been on the market for some time or new products introduced by competitors)?

ii. how obvious are these performance differences?

iii. how large are the cost differences between the new product and alternative products?

iv. how obvious are these cost differences?

v. how easy is it for buyers to understand how the product functions?

vi. if the product failed, how significant are the consequences? For example, is the product part of an integrated system such that failure would cause major loss to the manufacturer, installer, or homeowner?

vii. how easy is it to test the innovation on a trial basis?

viii. what switching costs are necessary?

B. various characteristics of the manufacturer’s distribution, marketing and sales activities:

i. what is the background and training of the manufacturer’s sales force?
ii. how effective is the sales organization?
iii. how effectiveness is the sales process?
iv. how effective is the overall marketing program?
v. how effective is the support services?

C. various characteristics of the buyers (homeowners and homebuilders)
   i. how well do they understand their own value chain? In other words, can they perceive all the ways a product may provide concrete improvements to their lifestyle or business?
   ii. what is their propensity to change?
   iii. how strong is their need to improve in the areas in which the innovation provides improvement?
   iv. how cost sensitive are they?

D. various characteristics of the homebuilders as distribution and installation channels:
   i. what economic or competitive advantage results from adopting the innovation?
   ii. what is their background and training?
   iii. how well do they understand their own value chain?
   iv. what is their propensity to change?
   v. do they have any brand or manufacturer loyalty?
   vi. what is the nature of their relationships with the manufacturer and with the homeowner?

E. various characteristics of the interface between the manufacturer and the buyers:
   i. is the sales force interfacing with the actual decision maker?
   ii. do the buyers understand the innovation's advantages over existing products?
   iii. do the buyers have an accurate perception of the risks and switching costs involved with changing to the new product?

F. various characteristics of the environment:
i. sudden external events that increase the cost or performance appeal of the innovation (such as a temporary "energy crisis") or affect the availability of existing products

ii. government regulation that affects the cost or availability of existing products
In this chapter various aspects of roof systems are discussed, including their physical environment, physical performance and other functional requirements, individual parts that make up the system, and traditional styles. Each of these aspects are discussed in this chapter for foam panel systems and for their more traditional competitors: conventional and precut rafter systems and truss systems.

ROOF FUNCTIONS

The roof is the most important element in any dwelling. Houses are sometimes built around the world without all four walls, windows, doors, or a floor, but they are never built without a roof. The primary function of a roof is to serve as a barrier between the living space of the home and the environment. Depending on the geographic location and time of the year, a roof must keep out rain, sun, cold or heat, noise, wind, and the glances of neighbors, while keeping in heat or air conditioning. In addition, roofs must be sufficiently stiff to prevent unsightly or damaging deflections due to loads. Finally, roofs must be sufficiently durable such that the structural system lasts at least 50 years, the weather-resisting exterior surface lasts at least 20 years, and minimal maintenance is required.

Roofs serve purposes other than physical properties. As a shell, the area under roofs are increasingly required to be habitable (which requires that the majority of floor space under the roof be at least 7′ high) and finished. A roof must be aesthetically appealing, both as an element by itself and as part of the overall exterior appearance of the house. Roofs are increasingly being called upon to allow light and
ventilation to pass through small areas, such as dormers and skylights.

Of course, all these functions must be accomplished at a total life-cycle cost that does not make house ownership impossible for the majority of society.

Being the surface of the house shell furthest from the ground and generally the only one possessing an orientation that is at least partially horizontal, roofs must be substantially more robust than walls. Although it is uncommon for roofs to support interior floors as exterior walls do, roofs are often subject to significant snow and wind loads, including suction. A strong sun on a hot day can result in roof surface temperatures over 160°. Roofs must shed every drop of water that falls as rain or melts from snow.

PARTS OF A ROOF
Residential roofs are generally composed of five sub-systems: framing, roofing, flashing, insulation, and trim. Each subsystem generally serves one of the basic roof functions discussed above. The framing system provides the vast majority of structural strength to resist dead and live loads. It consists of a truss or rafter skeleton with structural sheathing on top. The roofing system, usually some sort of shingle over an asphalt felt, is the first and most important line of defense against the weather over the vast majority of roof area. It must deflect the wind and stop and channel rain off the roof. The flashing system also stops and channels rain but is found around roof penetrations and at the eaves. Flashing has traditionally been sheet metal but synthetic polymers are slowly gaining in market share. The insulation system decreases the convective and conductive flow of heated or air conditioned air through the framing and roofing systems.
The most common forms are fiberglass batts or loose organic particles. Finally, roof trim provides an important aesthetic element to the roof at and under the rake and eaves.


FLAT ROOF

SHED OR LEAN-TO ROOF

GABLE ROOF

HIP ROOF

GABLE ROOF & DORMER

GABLE & VALLEY ROOF

HIP & VALLEY ROOF

MANSARD ROOF

BUTTERFLY ROOF

GAMBREL ROOF

"DUTCH" HIP

Figure 2: COMMON ROOF STYLES

This paper evaluates innovation only in the roof framing system. The other sub-systems that make up roofs are addressed only to the extent that they are affected by the choice of framing system.

TRADITIONAL ROOF STYLES
Roof designs in the U.S. have run the whole gamut of architectural complexity over the years, ranging from a single pitched surface to over thirty surfaces differing in size and pitch to a parabolic curve. Common styles include shed, gable end, hip roof, hip and valley, gambrel, mansard, and dutch hip. See Figure 2. Many roofs feature more than just the planar roof surfaces themselves. Dormers, turn gables, and skylights are added to provide additional habitable space under them, for light and ventilation, and to improve the interior and exterior appearance. See Figure 3.

Except in the custom designs, the trend in recent years has been towards the simpler designs. Gambrel, mansard, and dutch hip styles are rarely built by production builders. Dormers and houses with more than one pitch seem to be decreasing in number also.

COMMON ROOF FRAMING SYSTEMS
CONVENTIONAL AND PRECUT RAFTERS (see Figure 4)
Parts of a Rafter System: Until perhaps twenty years ago, the vast majority of residential roofs installed in the U.S. this century were framed with conventional rafters, i.e. 2x6 or larger solid lumber spaced 16" or 24" on center. Sheathing is the sheet material installed over the rafters to provide a continuous shell for nailing shingles and structural strength. It used to be thin pieces of solid lumber, such as tongue and groove siding, but is now almost always plywood or waferboard, 1/2" to 3/4" thick. Rafters are attached to the walls by
nailing metal framing anchors into the top plate. Solid lumberbridging is generally nailed between rafters over the plate to prevent lateral torsional buckling and as a nailing surface for the frieze or siding. Rafters are attached at the ridge by nailing into the ridge board, often with rafter straps. A rafter under load will tend to kick out at the eave unless restrained by either a collar beam stretching between the rafters on opposite sides of the ridge beam or a tied floor joist system.

Insulation is typically provided in rafter systems by placing batts or loose fill in between the floor joists, or—if the attic is heated or should be kept somewhat warm—in between the rafters. With either location, significant heat is lost due to radiation loss through the framing members unless the
insulation extends over them. In other words, the framing members act as thermal bridges.

Figure 4: TYPICAL RAFTER SYSTEM


Distribution and Sales: The solid 2x and 3x lumber that conventional rafters are made from can be purchased from any lumberyard. Medium and large homebuilders that install rafter roofs often purchase lumber in large quantities directly from mills. Precut rafters are generally sold as part of a complete precut or precut and panelized house package. Sales may be through a distributor/dealer, a homebuilder/dealer, or direct from the package producer.

Installation: Rafter systems are one of the most difficult parts of the house to install. Comparing their installation process to that of walls can put things into proper perspective. While the structural principles of a rafter-sheathing system for roofs is similar to the stud-sheathing system for walls, rafters are much more difficult to construct.
The biggest factor is the abundance of miter (angled) cuts found in rafters. There is always a miter cut at the ridge beam and usually three additional miter cuts at the eave end—two at the "birds mouth," so the rafter sits correctly on the top plate, and one at the actual eave. The difficulty of rafter installation also results from its location within the house. Entire stud walls can be constructed on the ground and tilted in place. Rafters must be positioned and nailed into place one at a time, usually twenty or more feet off the ground. Finally, the geometry of roof shells are usually more complex than walls. The walls of a house typically consist of four to eight rectangular planes. Roofs, on the other hand, typically have four to twenty planar surfaces, most of which are triangles. There is no such thing as a hip or gambrel wall.

The difference between conventional and precut rafter systems lies in where the rafters are cut to the proper length and angles. Rafters in conventional systems are cut on the job site; rafters in precut systems are cut off site in a factory. The implications of this shift in part of the work on cost and performance will be discussed in the next chapter.

The two notorious characteristics of roofs—they bear the brunt of mother nature and are among the most difficult parts of a house to build—explain why the MIT housing consortium chose to focus on improving roof systems before any other portion of the house.

TRUSS SYSTEMS (see Figure 5)
Parts of a Truss System: In the past twenty years, trussed systems have replaced rafter systems as the predominant method for framing a house. The two systems differ only in that prefabricated trusses replace the actual rafters. Trusses are
typically spaced 24" to 36" on center, which is slightly more than rafters. Sheathing is also typically plywood or waferboard, although slightly thicker sheets are needed if the spacing is greater than 24". The attachment of trusses to the walls is similar to that of rafters. In addition to the bridging installed over the top plate, lengths of wood or metal is often run on top of the bottom chord and below the top chord to prevent lateral torsional buckling. A ridge board is therefore not needed.

Common types of trusses are shown in Figure 6. The most common type are the W and King Post trusses. Note that neither of these provide habitable space under them. Consequently, unlike rafters, the area just under the roof shell is essentially useless.

The materials and method used to provide insulation in trussed systems are similar to those in rafter systems. Again, a significant thermal bridge can occur unless the insulation extends over the framing members.
Distribution and Sales: Standard W and Kingpost trusses are sometimes stocked in a several sizes and pitches by largelumberyards. Some lumberyards will also special order different types and sizes. Most homebuilders order their trusses directly from truss producers. There are over 1800 truss producers in the U.S. so most building sites have a plant within 100 to 200 miles. Many of the large homebuilders have
their own plants for producing roof trusses and other components.

Installation: Although it is possible to assemble trusses on a job site, the vast majority are manufactured in truss plants and shipped to the site on large custom trucks. The trusses are then placed on top of the walls and swung up into position. Some homebuilders position the trusses on the ground, install the sheathing and roofing, and lift the entire assembly into place.

As discussed in Chapter Three, complex roof geometries present problems for trusses. Trusses are generally not cost effective for complex roofs, such as those with varying pitches, ends other than gable or hip, and more than three or four functional dormers, turn gables, chimneys, or skylights.

STRESSKIN FOAM PANEL SYSTEMS

GENERAL:
Definition: There are many forms of prefabricated panels available on the residential market today. In this paper the terms "stresskin foam panel" and "foam panel" refer to residential panels that have a lightweight foam core in between two faces and are, at least to some degree, structural. (The term "stresskin" is used since the majority of resistance to various stress modes is provided by the "skin," i.e. faces. It is sometimes spelled "stressed-skin".) Foam panels that serve as insulation or as a finish surface alone do not fall under this definition because they are not structural, nor do structural panels with wood ribs (with or without foam) since they are not stresskin.

Origins: Structural foam panel systems were apparently first developed by the Koppers Corporation with research conducted by

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Rensselaer Polytechnic Institute (RPI) in the late 1950s. The National Association of Home Builders successfully installed prototype foam panels in their 1957 and 1958 demonstration homes. Although Koppers conducted a substantial marketing program and sold licenses to several homebuilders, sales did not exceed 800 homes the first two years and Koppers redirected their efforts to refrigerator panels. A few homebuilders and small manufacturers continued to offer foam panels throughout the 1960s and 1970s. While a few more manufacturers entered the industry after the Arab Oil Embargo of 1973, the number really started to grow after the second "energy crisis" in 1979.16 Andrews attempted to determine the growth in foam panel production over the past few years. The aggregate growth of the eighteen producers who responded to his survey showed annual growth rates of 66% and 79% in 1986 and 1987, respectively, with 58% projected for 1988.17

Like many new products, a number of technology-push and market-pull mechanisms contributed to their development and growth. The innovations in materials, system design and production that made structural panel systems possible are described in Chapter Three. Increases in the costs of labor and energy relative to other cost factors, such as materials and equipment, have made panels fairly cost effective. Needs emerged for a system requiring less skilled installation, tight, well-insulated design, and a system serving as a shell over Post and Beam framing18 that could be erected quickly. Finally, sociological

16 Andrews, pp. 6-7.
17 Ibid, p. 16.
18 Post and beam framing, also called timberframing, is making a comeback as an alternative system to conventional stickbuilt framing. Timberframed walls and rafters consist of 6"x6" or larger solid wood posts spaced every 4’ to 8’ and displayed prominently.
changes--primarily in energy awareness--have contributed to foam panels' growth.

Figure 7: THE TYPICAL PRODUCT LIFE CYCLE

PRODUCT LIFE CYCLE: Although the commercial aspects of foam panels will be analyzed in detail in Chapter Four, the product life cycle model provides a means of introducing one commercial aspect of foam panels. The product life cycle is represented by a graph of sales over time. The length of curve is divided into four stages: Introduction, Growth, Maturity, and Decline. See Figure 7. (The Growth stage is frequently divided further into Early Growth and Late Growth stages.) Each stage has certain characteristics for various commercial aspects associated with it. The product life cycle model is used primarily for formulating marketing strategy and predicting the sales curve over time for typical products or industries. In addition, the model has been used to suggest managerial styles,
investment strategies and other operational tactics most appropriate for each stage.

Porter lists typical characteristics for each stage. The majority of characteristics indicate foam panels are in the GROWTH stage. The buyer group is widening and will accept uneven quality. Products have some technical and performance differentiation; reliability is key; quality is generally good; competitive product improvements are being made. Marketing involves high advertising costs. Manufacturing has been shifting to mass production. The key function of most firms’ overall strategy is marketing. There are numerous competitors. Finally, margins and prices are both fairly high relative to substitutes.

Uses: Foam panels are used in the construction of residential walls, roofs, and foundations. They can be deployed over two distinctive framing systems, conventional and timberframing. Figures 8 and 9 show two common timberframing systems. For short spans and minimal loads, panels can also be deployed with few additional framing members, as shown in Figure 10. Regardless of the framing system used, panels replace the insulation and sheathing materials found in conventional construction and increase the maximum allowed spacing between main structural elements.

PHYSICAL CHARACTERISTICS:
Core and Face Materials: Cores are either expanded polystyrene or urethane. (Actually, urethane cores are made of either polyurethane or polyisocyanurate. The two materials are similar in nearly all respects and will hereafter be referred

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19 Porter, Competitive Strategy, p. 159.
Figure 8: PANEL RAFTER FRAMING SYSTEM
Source: Winter Panel Corp., Brattleboro, VT

Figure 9: PANEL RAFTER–PURLIN FRAMING SYSTEM
Source: Winter Panel Corp., Brattleboro, VT
Panels are commonly available with 1/2" or 5/8" thick structural wood (waferboard, plywood, or oriented strand board) as both faces or with a wood product on one face and gypsum board on the other. Several producers offer panels with aluminum kraft foil, 26 gage steel, 3/32" glassboard, or attractive 3/4" tongue & groove (T&G) siding.

Sizes: Panels typically are available in 4' and 8' widths and lengths ranging from 8' to 28'. Core thicknesses range from 3 1/2" to 6 1/2" for urethane cores and 3 1/2" to 9 5/8" for polystyrene. R values range from 19 - 41 for urethane and 11 - 44 for polystyrene. Panel unit weights vary from 2.3 - 6.23 pounds/square foot of panel.
SYSTEM INFORMATION

Framing: Structural panels--i.e. with two wood faces--can be deployed without additional framing for spans up to 17', assuming L/240 maximum deflection and a thirty pound live load. Panels with gypsum board serving as one face are known as "curtain wall" panels. The maximum unsupported span for these panels are approximately one-half of true structural panels.

Finishing: All panels require some finish work after installation. The interior finish work required depends on the inner facing. Wood facings generally have gypsum board installed on them to provide the 15 minute rated barrier between the interior space and the panel core that is required by fire codes. Curtain wall panels manufactured with a gypsum board face require only proper taping and spackling. Exterior finish involves installing flashing (around a chimney or other roof penetration), a perimeter drip cap, conventional asphalt or wood shingles, and wood trim. Some firms recommend base felt be used; others recommends that seams be sealed with roofing cement.

Ventilation: The ability of panels to provide an extremely tight house (i.e. little chance for cold air to move through the exterior shell) necessitates a higher level of forced ventilation than conventional construction to expel stale air and excess moisture. Air-to-air heat exchangers are required to minimize the heat loss accompanying the fresh air intake. Ridge vents are sometimes installed to vent the surface between the shingles and the panels. They do not contribute to ventilating the interior space.

Building code acceptance: Although larger panel manufacturers have pursued and achieved approval by the three building code
agencies, most producers recommend potential buyers verify that the panels are accepted by their local code. Producers are occasionally asked by a local building department to submit calculations stamped by registered engineer, particularly if the producer designed the entire frame.

PRODUCTION:
The production process depends on the core material. Polystyrene cores are either purchased from external sources or produced in-house from beads in a steam/heat process. Panels are assembled by automated application of an adhesive between the faces and the core, followed by pressure on both faces. Urethane cores are produced in-house from liquid urethane. The panels may be assembled in a process similar to the polystyrene panels--separate core production followed by gluing--or produced in an integrated batch process in which the liquid urethane expands to form the core while simultaneously bonding to the faces. Cutting and routing for non-standard panels, if done by the producer, is then performed manually or with automated equipment.

MARKETING AND SALES:
Promotion: Most panel producers have had to actively pursue a more aggressive level of promotion and marketing than conventional construction since many homeowners and some homebuilders have never heard of foam panels. Promotion generally has take the forms of sales literature, advertising in various housing and residential construction magazines and booths at regional home and construction shows. Although a few firms include in sales literature vague references to lower initial cost, panels' advantages over conventional systems are based on performance, not purchase and installation cost. Typical sales literature emphasize panels' tremendous insulation value and resulting lower energy costs, speed and
ease of installation, strength and stiffness, and ability to provide vaulted (cathedral) ceilings. Actual performance and cost aspects are discussed at the end of this chapter.

Pricing: Most producers have 2-5 price lists, depending on the buyer's annual purchases. The difference between the maximum unit price (for one-time homeowners) and the minimum unit price (for homebuilders who purchase typically 50,000 square feet of panel each year) ranges between 15% and 70%, depending on the firm.

Distribution: There are three primary modes of distribution. The balance among the three modes is different for each manufacturer. One mode is to sell directly to the homeowner. Installation is then by the owner himself, by a contractor hired by the owner, or by a contractor hired by the manufacturer. A second mode is to sell to the contractor doing the installation for an owner or on a "spec" house. A third mode is to sell through dealers, sometimes a designer or contractor who may end up playing a direct part in the housebuilding process.

Scope of services: Several firms offer a design and material package for the complete house shell (walls and roof). Other firms will take responsibility for panel installation if there is a contractor in the buyer's area they have used before. Nearly all firms will furnish on site training to a homeowner or contractor installing panels for the first time. Most manufacturers will rent the special router and large saw, described under "Services" below, that are required for installation. Several firms sell accessory materials, such as sealant, spikes, connection hardware, and thermally broken headers.
Geographic Distribution: There are an estimated 60-100 producers of foam core panels throughout the United States.\textsuperscript{21} Like roof trusses and other prefabricated components, distribution and, therefore, competition tends to be regional. There are two reasons, both related to price: First, any price difference between the closest and next closest producers may be offset by transportation costs; second, many manufacturer prices include a site visit by a factory representative within a certain distance of the plant. It should be noted that several manufacturers with established reputations occasionally ship 1000 miles or more. Also, the majority of both producers and buyers tend to be located outside of major metropolitan areas.

Shipping: Panels are generally transported to the jobsite on flatbed trucks owned by the manufacturer. Some trucks are outfitted with small crane arms to offload and help with installation. Transport to a jobsite over 500 miles away is through a contract shipper, with the responsibility for unloading falling on the installer.

\textbf{INSTALLATION}

Equipment: Panels require special equipment frequently not owned by conventional homebuilders. A forklift is needed to unload the panels from the delivery truck if the truck is not rigged with a hydraulic arm. A small (12 ton) crane is strongly recommended for installing all but the smallest panels. A truck strap or other winch and strap system is often needed to ensure panel edges are butted tight against each other. A router and special bits are often required on perimeter panels or panels with an opening in them. Finally,

\textsuperscript{21} Andrews, p. 15.
an extra-large circular saw is required for cuts not perpendicular to the faces, as is required at the roof ridge.

Labor: A three person crew typically works most efficiently to install panels on a roof. No special skills are required, although there is a definite learning curve associated with production speed and quality. Some manufacturers do not discourage homeowners from performing their own installation provided at least one person on the crew is an experienced carpenter.

Figure 11: TYPICAL SPLINE JOINING SYSTEM
Source: Winter Panel Corp., Brattleboro, VT

Construction details: Required construction details vary with the manufacturer and the panel configuration. Some of the basic connections are described below:

Standard panel-to-panel connection: Some systems have two
1"x3" splines in routed channels, nailed to each panel face with 1 1/4" drywall screws or 6d nails, 6" o.c. See Figure 11. Other systems have one 2"x4" spline nailed as above. One system has an unusual steel "cam-action locking arm." Most producers recommend a bead of expansive sealant in a routed channel. Some manufacturers route the panels in the factory; others require field routing.

Figure 12: TYPICAL DETAIL AT TOP PLATE
Source: Winter Panel Corp., Brattleboro, VT
Eave and Rake connections: Most systems involve nailing through panels into a bevelled top-plate with 6"-12" ring nails or spikes at 6"-16" o.c. See Figure 12. Some systems require various steel straps to supplement nails. All systems can be finished with various soffet and fascia combinations. See Figure 13. Rake connections are similar to eave connections.

Figure 13: TYPICAL FINISHES AT EAVE

Source: Winter Panel Corp., Brattleboro, VT
FASTENERS AT 16" O.C. AT EACH PANEL ON EACH SIDE OF RIDGE (*)

5/8" FOAM CORE = .90 D SPIKES
7/4" FOAM CORE = 1" STL. SPIKES

16 D NAILS AT 16" O.C. EA. SIDE OF RIDGE THRU END MEMBERS TO TIE PANELS TOGETHER (*)

2x RIPPLED BRG. PRO - NAIRED TO BEAM OR WALL AT 16" O.C. WITH 10D NAILS (*)

WOOD BEAM OR BEARING WALL (*)

1/2" DRYWALL (*)

WIRE CHASE (*)

3 1/2" MIN.

**STANDARD RIDGE PANEL CONNECTION**

(*) DENOTES ITEMS NOT SUPPLIED BY FOAM PRODUCTS CO. AND TO BE FIELD INSTALLED.

Figure 14: TYPICAL ANGLED RIDGE DETAIL

Source: Foam Products Corp., St. Louis County, MO
Ridge connection: Most producers recommend nailing the panels to a ridge beam with spikes at 12"-16" o.c. Some producers recommend 90° ends with a special ridge piece. Other producers recommend bevelled ends with bevelled splines. See Figure 14.

Dormers and Skylights: All systems require some sort of framing under the panels that form the faces of the dormer. Skylights 4'x4 or smaller require 2x nailers around the perimeter and appropriate caulking and interior trim, but do not require any support framing.

Plumbing and Electrical: Most manufacturers recommend against installing plumbing in the roof panels due to exposure to freezing temperatures. Each system has a different method for handling electrical wiring. One firm pre-drills a 1 1/4" chase in the same location of every panel in the factory. Another firm will precut a chase along one edge only when requested, while another recommends installing wiring in a chase between built-up purlin members.

PERFORMANCE:
As stated in Chapter One, the performance attributes of foam panels or any residential component encompasses more than the physical properties of the installed system. Also, the value placed on a specific performance attribute will vary from consumer to consumer. Figure 15 is the list of typical performance attributes that consumers may value in residential components, with an indication of how panels compare to rafter and truss systems for each attribute.

Controversy: Several performance aspects of foam panels are controversial. The effective, long term R-value is one of them. A properly and recently installed foam panel system with R-30 cores provides significantly superior thermal insulation.
KEY:
A = panels offer an advantage over both rafter and truss systems
D = panels offer a disadvantage over both rafter and truss systems
E = panels are equal to both rafter and truss systems or offer an advantage over one system and a disadvantage over the other
? = How panels compare to rafter and truss systems in this area has yet to be proven

Physical properties:
- thermal insulation (R-value)
- maximum unsupported span
- load bearing capacity for a given span
- life of entire system except finishes
- life of finishes (interior and exterior)
- fire safety
- moisture resistance (chance of leaking)
- reliability of system (warranty, reputation)
- architectural flexibility

Aesthetic:
- interior and exterior visual appearance
- contribution to the overall appearance
- flexibility/range of finishes

Installation:
- speed of installation (may include intermediate milestones, such as house close up)
- number of trades required and their interaction
- skill level required
- total labor hours required
- maximum number of workers required at one time
- number and type of special tools required
- number and type of equipment required
- safety aspects

Sales:
- total ordering/installation time
- time required by purchaser during sales process
- ability to ensure timely delivery

Figure 15: PANEL VERSUS RAFTER AND TRUSS PERFORMANCE

to a rafter or truss system with R-30 batt insulation. Thermal bridging, thermal defects (the convection of heat through small
gaps between the framing members and the insulation), and convective loops (the convection of heat through hollow spaces adjacent to insulation) can reduce the effective R-value of a conventional wall or roof by 30% or more of the R-value of its insulation.\textsuperscript{22} Properly installed foam panel systems do not have thermal bridging or convective loops and the thermal defect-type phenomenon at the joints is minimal.

The effective R-value of panels is controversial because the high insulative gas found in urethane cores tends to leak out over time. Since the air that replaces the original gas is not nearly as insulative, the actual thermal performance of panels tend to deteriorate over time. How fast and how much have not yet been determined with certainty.

A second controversial aspect of panels involves the shingles. Few manufacturers of asphalt shingles will provide a fifteen year or longer guarantee on panel roofs due to their concern about the shingles overheating. Still another problem area is the issue of fire safety for polystyrene panels. Panels tested several years ago apparently passed the Underwriters Laboratory smoke and flame spread tests because the tests measure smoke and flame spread at the ceiling. Since the polystyrene core melts and drops to the floor, it no longer contributes to the measurements at the ceiling.

Timing: The typical time from the date of ordering to delivery of the panels to the jobsite is three weeks. The typical time for installing the panels and completing the roof is five to ten workdays, depending on the experience of the installer and the roof size and complexity.

COSTS:
As mentioned in Chapter One, the proper cost criteria to evaluate foam panel systems is life cycle costs, which are composed of initial purchase and installation costs, annual energy costs, maintenance costs, and replacement costs.

The initial purchase and installation costs of foam panel systems were gathered and compared to rafter and truss systems as part of the author's involvement with the MIT housing consortium. As shown in Figure 16, the foam panel system cost significantly more than the conventional rafter and truss systems. The details of the study and analysis of the results are provided in the Appendix.

<table>
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<th>SIMPLE</th>
<th>INTERM.</th>
<th>COMPLEX</th>
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<td>FOAM PANEL</td>
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<td>$7.06</td>
<td>$6.90</td>
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</table>

Figure 16: SUMMARY OF RESULTS FROM A COST STUDY

The savings in energy costs due to foam panels' superior thermal performance is significant, perhaps as much as 25% or more when compared to a rafter or truss system with batt insulation rated at the same R-value as the panel core and the typical thermal deficiencies described earlier. It is not known whether maintenance or replacement costs are higher for panel systems than for truss or rafter systems.
CHAPTER THREE: TECHNOLOGICAL ANALYSIS OF FOAM ROOF PANELS

It was stated in the introduction that the factors influencing the costs, performance, and market share of a residential component include the technological characteristics of its design, production and installation processes. These factors are examined in this chapter using a framework introduced here after first discussing some strategic issues of technology.

THE STRATEGIC ASPECTS OF TECHNOLOGY

The relationships between technology and performance, cost behavior, and market share are essential to effective business strategy, yet are often misunderstood in the component industry. There are three essential aspects of these relationships: First, technology pervades every activity that a firm performs and plays a significant role in influencing the performance, costs and value characteristics of the majority of activities. Second, technology, more than any other force, can cause quantum leaps in a product's characteristics and massive structural changes in the industry. Third, technology can serve as a significant competitive force to command a price premium. Proprietary technology is often an unbeatable means of differentiation.

It is acknowledged that increasing the level of technology in the design, production and marketing of panels should not be pursued just for the sake of increasing technology. The market for components and other residential construction products is not like the market for home entertainment equipment in which many consumers will purchase a product simply because it represents state of the art technology. In fact, the majority of buyers in residential construction seem to avoid state of the art products because they are unproven. It has been said,
only half in jest, that the amount of buyer resistance to a product in residential construction is exponentially related to the product's degree of innovation.

As Porter points out\(^{23}\) in *Competitive Advantage*, adoption of a specific technology, or of increased technology in general, must pass at least one of the following tests:

1. it lowers the firm's production costs
2. it shifts the cost behavior drivers (discussed in Chapter Five) to areas that will eventually allow the firm to lower its production costs relative to competitors
3. it allows the firm to effectively differentiate the product from competitors
4. pioneering the technological improvement brings first-mover advantages
5. it improves the structure and/or position of the industry as a whole.

There are two other tests that must be passed in addition to one of the five above:

A) the capitalization costs of pursuing and implementing the technology cannot be so high that the required scale (annual production volume) would be impossible for the firm to achieve, and

B) the competitive advantage accorded the firm or the benefits to the industry must be sustainable.

TECHNOLOGICAL ANALYSIS OF COMPONENT DESIGN AND PRODUCTION

The progress that has been made in the prefabrication of residential products over the past fifty years can be viewed in terms of improvement in six dimensions:

1. THE LOCATION OF THE WORK

---

\(^{23}\) Porter, *Competitive Advantage*, pp. 171, 176.
2. THE AMOUNT OF MECHANIZATION AND AUTOMATION
3. THE RELATIONSHIP BETWEEN THE PARTS
4. THE MATERIALS USED
5. THE STANDARDIZATION OF INPUT NEEDED
6. THE STANDARDIZATION OF OUTPUTS

The six dimensions or elements will be discussed one at a time. First, each element will be discussed as to what is meant by the term and how this element is evident in conventional construction and present prefabricated systems in general. Next, it will be discussed how each element is evident in the four roof systems reviewed in Chapter Two. Finally, some ideas for increasing the technological level in each element of roof panels will be considered. (The suggested changes are not intended to be a complete list of potential improvements, only a partial list of general areas in which conceivable technological improvements might be beneficial. This is brainstorming by an admittedly poor brainstormer.) As will be evident, the six elements are often interrelated. A change that increases the technological level in one element may increase the level in other elements. Also, most of these elements were mentioned in Chapter One since various authors have written about one or more of them. It is believed, however, that no author has ever identified all six of the elements and systematically used them to compare a specific prefabricated system with conventional construction or other prefabricated systems.

The term "conventional construction" refers in this thesis to homebuilders who have adopted few of the innovations introduced in residential construction over the past twenty years. (The builders in Tracy Kidder's *House* fit this description fairly well.) The term "present prefabricated systems" refers to components in their present forms. The term "future
prefabricated systems" refers to component or perhaps complete prefabricated systems in ten to fifty years.

Element 1: THE LOCATION OF THE WORK
General: The element people most often associate with prefabrication is the location of the work, i.e., whether the work is performed on a jobsite or in a factory. As discussed in Chapter One, moving the work into a factory is advantageous because required skill levels and wages are generally lower than those in the field. Further, controlled conditions allow year round production, increased productivity and improved quality control.

Conventional "stickbuilt" construction is accomplished completely in the field. Present prefabricated systems have a portion of the work performed in the factory. Upon completion, the component is shipped to the jobsite where significant additional work is still required, such as applying conventional finishes. Future prefabrication systems may have nearly all of the work performed in the factory, including the majority of finishes.

Present Roof Systems: As discussed in the previous chapter, conventional rafter systems are accomplished completely in the field. The precut rafter system differs from conventional rafter construction only in that the sorting (to eliminate defective pieces) and cutting of the framing lumber occurs in the factory. Little of the total work has moved off-site. The truss system has moved slightly more of the work into the factory in that the framing members are both cut and assembled there. Both precut rafter and truss systems still require another structural piece--sheathing--to be fastened to the framing members on site to complete the framing system.
The stresskin foam panel system has a greater portion of the work in the factory inasmuch as the number of pieces and volume of framing required to be installed on site is reduced. Additional sheathing is not required. It should be noted that with panels installed on timberframe systems, it is not desired to reduce the volume of framing installed on site since the size and appearance of the framing members are desirable attributes of the system.

Potential Improvements to Panels: Improvements in panel design and in the structural properties of panel cores and faces should allow longer spans, further reducing the amount of on site framing required with a panel roof. Another significant improvement should be increasing the degree of finish. Conceivably, both exterior and interior faces could be finished in the factory with materials that are attractive enough to satisfy homeowners and sufficiently durable to prevent damage during shipment and installation. Materials commonly used in residential construction today do not appear to be feasible. The problem with installing asphalt shingles, for example, lies in sealing the joints on site to achieve a roof free of leaks. Prefinished non-structural panels are being marketed today for both commercial and residential use; however, they do not seem to have the appearance to satisfy homeowners.

One of the performance advantages of panels is that a three-person crew can achieve a closed up shell in one or two days after the wall erection. Rafter systems typically take at least three days, often considerably longer. While a short close up time is valuable to homebuilders, panel manufacturers have been limited in their ability to sell this advantage to homeowners by the fact that performing the interior and exterior finish work in the field generally takes so long (five to fifteen days, depending on many factors) that the savings
resulting from the panel is almost inconsequential.  Prefinishing the panel surfaces would allow the value of reduced installation time to be captured.

Element 2: THE AMOUNT OF MECHANIZATION AND AUTOMATION

General: This element refers to the amount of work performed by machines rather than by manual labor. As discussed in Chapter One, prefabricated systems accomplish work through automated, mechanized equipment in order to improve the quality or consistency of the product, decrease the production time and labor required, and decrease the cost by shifting from manual labor to high productivity machines.

Conventional construction is performed completely manually. Some hand tools have been enhanced through electricity, but the work still consists of one man performing one action on one piece of material at a time. Present prefabricated systems use simple, mechanized equipment to perform a few simple tasks, such as conveyance, positioning, cutting, and fastening. Most equipment is not automated through computer controls. The labor input per output is reduced through the use of the equipment, but two to six laborers are still required per production line to feed, control and monitor the equipment. Future systems will use sophisticated, computer-controlled machines that will perform nearly all the work in the factory, thus requiring fewer laborers than are needed by present systems.

Present Roof Systems: Conventional rafter systems are installed completely manually using only simple electric saws. The precut rafter system uses some mechanized machines in the factory, such as multiple-cut saws and hydraulic or chain-driven conveyance equipment. The truss system uses the same multiple-cut saws and conveyance equipment, as well as
Some foam panel manufacturers use slightly more advanced equipment. In some cases, computer-controlled equipment is used in the production of the polystyrene or urethane cores, in bonding the cores to the faces, and in custom cutting panels for the perimeter, ridge, or skylights.

Potential Improvements to Panels: The number of production activities that use automated equipment can be increased, such as mechanized conveyance of panel faces from pre-production storage to where they are fed into the panel assembly equipment. Conveyance from the panel production machine to pre-shipment storage or custom production machines could also be mechanized. Custom operations, such as putting the bow in bow panels, cutting and routing for skylight or dormer installation, and applying finishes, could be mechanized where they are not already.

The activities that are already mechanized in some firms—mainly the panel assembly process—could have their level of automation increased. The goals of using more sophisticated equipment would be to further reduce the labor input, increase the quality of the product, increase the electronic storage and flow of information associated with production, and enlarge the scope of activities that could be performed in the factory. Examples of the latter might be applying finishes or joining devices at the end of the panel assembly line.

Element 3: THE RELATIONSHIP BETWEEN THE PARTS

General: This element measures a system's degree of integration, that is, the number of individual pieces and their aggregate volume needed to provide the desired functions. In the design of a constructed system (particularly in the design
of wood structures), a high number of individual pieces may be desired to minimize the consequences of failure of any one piece; however, a low number of pieces is desired for cost and time savings in procurement, factory assembly and on-site installation.

Conventional construction involves hundreds of differing pieces, each serving one portion of one function. For example, the studs in a wall are one portion of the structural system; roof shingles are one portion of the weather-proofing system. In present prefabricated systems, some pieces serving the same function and pieces serving different functions are combined into integrated pieces, resulting in both a decreased number of pieces and a reduction in system volume. Integration in future systems will be more extensive than at present. (Some readers may have toured or read about the GE Plastics Living Environments model home in Pittsfield, MA. Many of the "Level 3" concepts in the model home illustrate the trend towards advanced integration.)

Present Roof Systems: Both conventional and precut rafter systems are good examples of systems composed of many pieces, each serving one part of one function. As shown in Figure 4, the structural system is composed of rafters, sheathing, ceiling and rafter ties, and a ridge board. Depending on the span and spacing of the trusses, truss systems generally have even more pieces than rafter systems (each pair of rafters and ceiling ties is replaced by an assembly composed of three to ten pieces of lumber); however, the volume of actual wood is usually lower due to their high ratio of modulus of elasticity to volume, triangular design and moment-resisting connections between members.

Panel systems are significantly more integrated than rafter or
truss systems. The structural function is provided almost completely by the faces, particularly if deployed in a folded plate configuration. The insulation function is provided almost completely by the core. While the contribution of the faces and finishes to insulation and the contribution of the cores and finishes to stiffness are not insignificant, the important point is that few additional pieces are necessary in these areas.

Potential Improvements to Panels: As discussed in the previous two elements, installing integrated interior and exterior finishes would clearly reduce the number of parts and probably reduce the system volume requirements as well. Further reduction in the number of parts requires an improvement in panel properties to eliminate the need for additional framing members in even the longest spans found in houses. The joining system also needs improvement. The current system of installing splines, nails, and sealant after routing the edges is not amenable to a fast and quality installation. Future panel designs should also allow integration of plumbing and electric lines in the panels, although not necessarily in the factory. The MIT housing consortium and several manufacturers are separately developing removable cove bases in which utilities can be run.

Element 4: THE MATERIALS USED
General: As mentioned in Chapter One, many proponents of industrialized housing twenty years ago thought that the use of innovative materials—particularly plastics—were going to quickly revolutionize the industry as quickly as moving the work into the factory was going to. Neither element has been revolutionary, but significant gradual changes have been occurring.
Conventional construction uses only traditional materials. Present prefabricated systems use few or no innovative materials. Future systems will include innovative materials to a greater extent than do present systems. Materials are analogous to the system as a whole; innovation is not pursued just for the sake of innovation. Traditional materials will be replaced only when innovative materials offer superior engineering properties, lower system costs, or are required by environmental or other external factors. Engineered wood products, which are growing in availability and popularity, are an example of innovative materials resulting from all three of the above factors.

Present Roof Systems: Conventional rafter systems use solid lumber rafters just as they did one hundred years ago, although changes have occurred in sheathing. Solid lumber decking has been replaced by plywood, which is slowly being replaced by waferboard and oriented strand board (OSB). The precut rafter system is no different from the conventional rafter system for this element. While trusses also use solid lumber and board sheathing, fastening within the truss member itself is improved through the use of metal or wood gusset plates instead of nails.

Foam panel systems are not innovative in their materials per se. The rigid expanded polystyrene cores are identical to thinner boards used to insulate walls. As mentioned above, waferboard and OSB are used in some rafter and truss systems. Their use is much more prevalent in panel systems since their superior stiffness is critical for span capability.

Potential Improvements to Panels: For producers of panels with urethane cores, pursuit of improvements in the core materials should probably be assigned the highest priority. Urethane
cores achieve their high R-value per inch through the use of ozone-damaging chlorofluorocarbons (CFCs), which are to be banned in 1992. Several foam companies reported in early 1990 that they have already developed alternative blowing agents that provide nearly the same insulation values. The MIT housing consortium has made some progress towards developing a lightweight cementitious foam panel. The use of portland cement as the primary ingredient and air as the blowing agent should allow cost savings over polymer foams.

Improvements should continue to be made in the structural face materials, particularly their strength, weight, and amenity to having an integrated finish applied in the factory. The MIT housing consortium is developing a wood fiber face material that will offer improvements in these areas.

Improvements to the joining system may be achieved through development or adoption of an innovative material.

Element 5: THE STANDARDIZATION OF INPUT NEEDED
General: This element refers to the range of sizes, grades and materials that a production system can process. The wider the range, the higher the value of the system.

This aspect of a system needs to be approached from two sides: physical flexibility and cost flexibility. For the present purpose, physical flexibility refers to whether it is physically possible to manufacture the product with alternative raw materials, sizes or grades. This type of flexibility is important when some sort of crisis or significant event causes standard materials to be unavailable. The alternative to possessing this type of flexibility is to own separate machines to handle different sets of raw materials or to shut down production until the needed materials are available again.
Cost flexibility refers to whether it is possible to manufacture the product with alternative raw materials, sizes or grades and still be competitive in the market. Obviously, a production system cannot possess high cost flexibility without high physical flexibility. Cost flexibility is needed to cope with the wide and frequent swings in construction material prices. The alternative is to shut down production or continue to produce but with decreased margin. In prefabricated construction, cost flexibility is more important than physical flexibility 99.99% of the time.

The key factor in cost flexibility is whether the savings in material costs are offset by higher purchase (fixed) or operating (variable) costs for the more flexible machine. Other factors that determine whether a production system that has high physical flexibility also has high cost flexibility include the following cost behavior drivers: economies of scale, learning, capacity utilization, linkages, interrelationships, integration, timing, discretionary policies, location, and institutional factors. These drivers will be defined and their influence in panel production will be examined in Chapter Five.

Conventional construction possesses very high physical flexibility. The nature of the work and the tools used are such that an experienced carpenter could start with nearly any commercially available species, size or grade of lumber. Conventional construction also possesses fairly high cost flexibility. There are only a few basic items, such as joists, studs, plywood and nails, needed to achieve maximum production efficiency.

Present prefabricated systems require substantial standard-
ization, that is, they possess fairly low physical and, therefore, cost flexibility. Although the species and grades of lumber do not seem to matter, the simple equipment described in element 2 (the amount of mechanization and automation) can handle only a limited range of sizes. As such, volume discounts can be substantial, but only on a small number of basic items. Automated equipment in future prefabricated systems will possess greater levels of physical and cost flexibility than present systems, but not to the extent of conventional systems.

Present Roof Systems: Relative to the rest of the house, roofs generally do not require a wide range of material sizes and grades, nor have the prices or availability of the relatively small sizes of lumber needed fluctuated widely in recent years. Neither precut rafter nor truss systems, therefore, have typically been hampered by their lack of flexible machinery.

The flexibility of foam panel systems depend on whether the cores are produced in-house or not. Producers who assemble panels cores purchased from outside suppliers have high flexibility. Manufacturers who produce their own cores, particularly the few large firms producing the cores and assembling the panels in an integrated process, have low physical flexibility. The equipment in urethane systems, for example, tends to be very sensitive to slight changes in the mix of the liquid urethane and even to the temperature and moisture content of the faces.

Potential Improvements to Panels: Manufacturers that produce their own cores strongly believe that in-house production is the future of the foam panel industry as it brings quality and cost advantages. If this is the case, technological improvements are clearly required in the design and management
of the core/panel production equipment. Improvements in production machinery will allow panel manufacturers to use wider ranges of sizes and grades and reduce the sensitivity to variations in the materials' temperature, moisture content, etc. It is the author's understanding that foam panel production equipment is a bigger business in Northern Europe than in the United States. If panels achieve a larger market share in the U.S., equipment manufacturers will be more interested in serving the U.S. market and panel producers might be able to afford improved machinery.

Element 6: THE STANDARDIZATION OF OUTPUT

General: This element refers to the range of sizes, shapes, styles, and quality that a manufacturing system can produce. The term "Flexible Manufacturing" is often used today to describe this element. It is similar to standardization of input in many respects. As is the case with input, the more flexible the output, the higher the value of the system.

Again, this element needs to be approached from two sides: physical flexibility and cost flexibility. Here, physical flexibility refers to the range of output that the system is physically capable of producing. This type of flexibility might be important when a sudden change in consumer tastes or needs occurs, such as happened shortly after the oil embargo in 1973. One alternative to possessing this type of flexibility is again to own separate machines to handle different output; another is simply to let pass by the strategic opportunity for a rapid gain in market share that often accompanies a sudden change in consumer needs.

Cost flexibility means it is possible to manufacture a range of similar products with the same equipment and still be competitive in the market. This type of flexibility is not as
important as it is in standardization of input since changes in consumer tastes in residential construction do not change as often as do material prices. The key economic factor is whether the savings from not purchasing a separate piece of equipment are offset by higher purchase or operating costs for the more flexible machine. It is noted that some manufacturers may choose to produce a wide range of related products, even if their margins on these products are unsatisfactory, for the purposes of offering a range of products or other "loss leader" strategies.

The forms evident in conventional construction, present prefabricated systems, and future prefabricated systems for this element parallel those of the previous element, standardization of input. Conventional construction again has a very high level of physical flexibility and a high level of cost flexibility. Present prefabricated systems have fairly low physical flexibility and low cost flexibility. A driving force between physical flexibility and cost flexibility in present systems is the machines' inherent set up time (the time to reposition saws, jigs, etc. to produce a different set of angles and lengths). Future systems will be more flexible than present systems through their use of computer-controlled jigs and saws, but will probably still be less flexible than conventional construction.

The effectiveness of the engineering/sales/production interfaces (that is, how well sales and technical requirements are communicated to the production line) is another driving force in the cost behavior of present systems, particularly in custom production. This fact illustrates the important point that improvement in component production must include more than just advances in hardware.
Present Roof Systems: Roof systems follow the general pattern for residential construction stated above. Conventional rafter systems have the highest levels of both physical and cost flexibility. As mentioned previously, the recent trend in roof designs in the U.S. has been towards simpler designs. The complex roof designs found in some luxury and custom homes these days are typically built with rafters.

Although precut rafter systems do not differ from conventional rafter systems in their ability to provide habitable space in the "attic" and as many dormers as desired, they do suffer a slight disadvantage when it comes to handling complex designs. Cutting the rafters in the factory (or on site before the walls and ridge board is installed) makes it much more difficult to make up for small errors that may have accumulated during the installation of the first and second story walls.

The truss system is by far the least flexible of the four systems. Four factors seem to be involved. Two of the factors are related to the fact that trusses are engineered structures that achieve cost reductions through efficient use of small members. First, the engineering principles of truss design is such that deviations from the basic triangular shape (such as required to achieve habitable space) require exponential increases in materials. Second, truss design involves more extensive engineering for all custom designs. Rafter and panel design for a given loading condition basically involves checking a simple table for allowable spans and increasing rafter depth or panel face thickness if needed. Even with the crude truss design software available on the market, there is still a significant design cost involved in custom designs.

The third factor why trusses are the least flexible is that trusses do not handle dormers or other large penetrations in
the roof well. Custom trusses are required if the opening is placed where a truss is located. Master trusses, which are specially designed for heavier loads, are often required on both sides of the opening if the opening is placed between trusses. Dormers, even if they do not require master trusses, must be conventionally framed on top of the truss. The fourth factor is that truss production is more complicated than either rafter or panel production. Truss production involves cutting each solid lumber member to the needed length and angle and positioning them with jigs, positioning the proper size toothed metal connector and embedding the connectors using a hydraulic roller or hydraulic clamps. There are simply more steps that can go wrong, particularly if the truss design elements have not been effectively communicated to the workers on the floor.

The stressskin panel system is again more flexible than the truss system but not as flexible as either rafter system. Physical flexibility is quite high; panels can be deployed with conventional framing, post and beam purlins and/or rafters, ridge beams, or--for small spans--in a folded plate configuration without additional framing at all. Also, panels provide habitable space with cathedral ceilings and can themselves form dormers.

The cost flexibility of panels, however, is fairly low. At least two factors are involved. First, except for panels produced from polystyrene cores purchased from outside sources, all custom panels must be cut and routed from standard sized panels. This is a labor intensive process even for the few large firms that have invested in automated custom cutting equipment and significant wastage occurs. The second reason is that the large framing members that panels are often installed on (more for aesthetic than structural reasons) tend to be fairly expensive.
Potential Improvements to Panels: Improvements in the physical flexibility of panels are predicated on the use of more advanced production machinery. Improvements in cost flexibility are predicated on the costs of more advanced machinery, improvement in managing the interfaces between engineering, sales, and production, and advances in the design of the panels themselves. Examples of the latter include the use of alternative core and face materials that are easier to produce and assemble and improved physical properties to allow longer spans and improved joints.
CHAPTER FOUR: STRUCTURAL ANALYSIS

It was stated in the introduction that the factors influencing the performance, cost and market share of a component include the underlying characteristics and economic structure of the industry. These factors are examined in this chapter using the framework for performing a structural analysis of an industry developed by Michael E. Porter, a professor at the Harvard Business School.

A structural analysis is a systematic method for mapping out the underlying characteristics and economic structure of an industry and identifying how they influence the margins, production costs, and market share of firms within the industry. The procedure used in this thesis involves analyzing the strengths of five competitive forces within the industry and examining where the industry falls along three key dimensions: its degree of concentration, its state of maturity, and its exposure to competition from abroad.

The first part of this chapter introduces the theory, procedure and applications of a structural analysis. The second part provides a general description of each of the five competitive forces and evaluates the strength of each force in the components industry in general. The foam panel industry is analyzed in the same way. Strategic actions are suggested that individual producers and the foam panel industry as a whole could take to improve performance, lower costs, and increase market share of foam panels. The degree of concentration and state of maturity of an industry are discussed following the same steps.

THEORY AND PROCEDURE

Level of Analysis: Before introducing the benefits and methods for performing a structural analysis, it is important to note that a structural analysis can be applied on several levels. Porter suggests defining an industry as "a group of firms producing products that are close substitutes for each other."25 Taking the broadest view possible, the term "industry" can be the entire residential construction industry; the products could be completed houses. Instead of viewing competition on this level as firm competing against firm, it would be more appropriate to view competition as one group of firms that all produce (or contribute to) one system of completed houses (e.g. conventional stickbuilt) competing against other groups of firms that produce different systems of completed houses (e.g. houses assembled on site from components).

Another level that can be analyzed is to consider the products as roof systems. In this case, competition should be viewed as one group of firms that all produce one roof system (e.g. foam panels) competing against other groups of firms that produce different roof systems (e.g. trusses or precut rafter). A final possible level for analysis is to consider the products as one of the four common roof systems--for example, foam panels. In this case, competition should be viewed as one panel producing firm competing against another. All three levels of analysis will be referred to in this thesis; however, most comments will be directed towards the second level, that is, competition is between the panel producing firms and producers of alternative roof systems.

Influence on Margin: It is well known that a firm's profit

margin is influenced by its competition. It is not well known that the nature of the firm's competition extends well beyond its obvious rivals.

Competition in an organization is rooted in its underlying economic structure and goes well beyond the behavior of current competitors. The state of competition in an industry depends on five basic competitive forces.... The collective strength of these forces determines the ultimate profit potential in the industry....

Some oversimplified microeconomic theory might be useful here to explain the relationship between industry forces and margin. Porter's framework for structural analysis is a rational, organized survival kit for thriving in the world of the imperfect market. In a perfect market, competitive forces are everywhere and all powerful. There is no escape from them. It is impossible to achieve any profit above the free market rate of return. In reality, however, the vast majority of markets are imperfect to a substantial degree and therefore have weaker competitive forces. A structural analysis maps out the array of competitive forces facing a firm at the time and hints at how these forces may change over time, that is, how the industry may evolve. Using this map, the firm can maneuver around the forces better than its competitors and earn profits that are higher than the risk-adjusted rate.

Influence on Production Costs: Production costs consist of two cost groups: the costs of incoming resources and the costs of transforming these resources into a product. Incoming resources include raw materials, equipment, capital and labor. Both resource and production (transforming) costs are heavily influenced by the underlying characteristics and economic structures of the industries furnishing the resources and the industry doing the transforming. The collective influence of

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26 Ibid, p. 3.
these factors is referred to as supplier power and is discussed in detail below.

Distribution costs, including transportation by an outside shipping company and distribution by various channels, are often influenced by industry structures in much the same way as are resource costs.

Cost drivers are characteristics of the structure and nature of the industry that determine the costs within the industry. The interaction of cost drivers over various economic conditions is termed cost behavior. Cost drivers can be identified in every aspect of a firm's operations--procurement, marketing, or, as applicable here, production. On the firm level, the costs of transforming resources into a product is a result of how well the firm's actual production characteristics match up to the cost drivers found in foam panel production.

The most critical cost drivers in the manufacturing of components seem to be economies of scale and capacity utilization. The degree to which producers are able to achieve economies of scale or a high level of capacity utilization is influenced primarily by the intensity of rivalry within the industry, discussed below.

Influence on Market Share: A structural analysis examines how, on a broad level, characteristics of buyers, competitors, and the sales process influence a firm's or sub-industry's market share. Buyers are examined to determine the structure of their industry(s), the products they perceive as substitutes, and the motivations, strategies and bargaining power with which they approach the purchase process. Competitors are examined to determine their position within the industry structure and the generic strategies, motivations and assets with which they
attempt to compete. Buyers, competitors, and substitutes are each discussed individually below.

THE FIVE COMPETITIVE FORCES
As shown in Figure 17, the five competitive forces are intensity of rivalry, threat of new entrants, buyer power, threat of substitutes, and supplier power. A structural analysis of an industry includes an evaluation of the strengths and nature of each of these forces. The most significant of

![Diagram of the Five Competitive Forces]

Figure 17: THE FIVE COMPETITIVE FORCES
the five, called the "drivers", are then identified. Porter discusses two ways that a structural analysis can be applied to develop business strategy: It can determine the ultimate profit potential of the industry and it can allow the firm to better position itself against the competitive forces facing the firm in order to maximize its profit.

On a more operational level, a structural analysis allows a firm to identify the types of suppliers that can exert the least bargaining power, the customer groups that are most desirable, and the best generic strategy, product line and product scope with which they should be approached.

Each of the five competitive forces will first be briefly introduced and noted as to its general characteristics in the components industry and its specific characteristics in the foam panel industry. Possible actions representing significant competitive moves or just effective operating strategies are also discussed for the forces that are most significant.

INTENSITY OF RIVALRY: Rivalry among competitors is probably the most obvious factor influencing profit potential. Intense rivalry reduces margins by forcing firms to reduce prices or incur higher costs (in order to improve quality, features, or services). Porter discusses a number of interacting factors that collectively influence the margins that are possible in an industry:
- the number, relative strengths, and diversity of the competitors
- the growth of the industry as a whole
- the level of fixed, storage or switching costs
- whether differentiation is apparent
- the increments in which capacity can be added
- whether strategic stakes are involved
the strength of exit barriers

Components: The intensity of rivalry within the components industry is generally mixed. Factors contributing to a high intensity include a large number of competitors, substantial fixed costs (relative to small homebuilding operations), a general lack of differentiation, and sizable capacity increments. Factors contributing to a low intensity include fairly diverse competitors, reasonable industry and product growth, and the lack of strong strategic stakes or exit barriers.

Roof Panels: Most of the factors that Porter identified imply that rivalry within the foam panel industry should be fairly mixed. Competitors are numerous but not equally balanced. Industry growth has been quite slow but, as discussed later, it still appears that the panels are in the early stages of the product life cycle. Production, particularly for cores produced in-house, requires substantial fixed costs relative to conventional systems but not relative to typical manufacturing industries. Competitors are somewhat diverse: some producers were foam manufacturers who expanded into residential panels; others were builders who moved into manufacturing. Further, it is apparent that panel producers consider conventional systems as their main competition, not other panel producers.

THREAT OF ENTRY: New entrants into an industry reduce profits primarily by supplying additional capacity and reducing prices in order to gain market share. The threat of new entrants often accomplishes the same thing as firms act to deter new entrants. The threat of entry is a result of the barriers to entry coupled with the possible reactions of present competitors. Possible barriers to entry include:
- economies of scale
Components: The level of competitive pressure due to the threat of entry depends on the type of component. For some systems, high capital costs and moderate economies of scale result in a moderate threat of entry. Components for other systems can be produced literally in a garage and require little capital. The threat of entry for these systems are quite high due to a lack of product differentiation, fairly easy access to distribution channels, low switching costs, and little expected retaliation from the existing fragmented competition. Several truss manufacturers cited the main problem plaguing their industry was irresponsible competitors who, due to low entry barriers, enter in boom times and price their products low to gain market share. These firms are later driven out of the market when economic conditions turn down because they have not accumulated sufficient working capital, but not without damaging the stable producers.

Roof Panels: The barriers to entry are not substantial in the foam panel business. Economies of scale are not particularly significant. Compared to most prefabrication plants, fixed costs are relatively low, particularly for firms using polystyrene cores produced outside the firm. Volume discounts for raw materials are only average. Product differentiation within the panel industry is low; Even each firm's variations on the basic product/service line are quite similar. Capital requirements are mostly limited to fixed production costs and
are therefore fairly low. Switching costs are moderate as they are generally restricted to a contractor's familiarity with the manufacturer's organization and credit terms. Access to distribution channels is low inasmuch as existing manufacturers have not succeeded in establishing a solid dealer or homebuilder infrastructure. There are few cost disadvantages independent of scale, little proprietary technology, and no evidence of an above-average learning curve.

The expected retaliation by existing competitors does not seem to be a credible deterrent to entry. Most firms apparently do not act to preempt new entrants except for a few vague "words of caution about unestablished firms" in sales literature.

The combination of fairly low barriers to entry and expected retaliation explain the tremendous increase in foam panel producers over the past ten years. The combination also indicates the potential for substantial competitive pressure. The extent to which this pressure actually reduces margins is uncertain since products in the Growth phase typically are not hurt by new entrants.

Possible Strategic Actions: Present panel manufacturers need not take action now to reduce the threat of entry of all firms. As Porter points out, certain new competitors can actually be desirable for the following reasons: 1) they serve unattractive segments, 2) being early on the learning curve, they can provide a cost umbrella, 3) they can increase industry demand by bringing credibility and helping establish the necessary infrastructure, 4) they can share in promotion, R&D, and market development costs.

There are many possible actions manufacturers could take to deter entry of undesirable competitors, most of which involve
raising the barriers to entry. Economies of scale through volume discounts in material purchases, shipping and other distribution activities, and promotion could be pursued more aggressively. Economies of scope through horizontal integration into timberframing or conventional construction supplies or forward integration into installation could be feasible. Switching costs could be raised by introducing a proprietary joining system, offering substantial discounts for annual and cumulative volume, offering more generous credit terms, and joint advertising with homebuilders or distributors. Finally, entry capital requirements could be raised by unofficially raising industry quality standards such that high quality (and expensive) automation is required for all producers to compete.

The tests of a desirable competitor and the possible means of keeping out undesirable competitors may contradict one another. Clearly, successfully raising the entry barriers as listed above would result in only large, well-capitalized firms being able to enter the foam panel industry. While these firms would be ideal competitors for bringing credibility and stability to the industry, it is likely that they would refuse to participate in marketing cost sharing programs and move fairly quickly down the learning curve. In the long run, large competitors might prove to be the bane of the medium sized panel producers who are most successful now.

BUYER POWER: As Porter points out, "Buyers compete with the industry by forcing down prices, bargaining for higher quality or more services, and playing competition against each other—all at the expense of industry profitability."27 He presents a number of interacting factors that collectively influence the

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degree to which buyers reduce an industry's margins:
- the profitability of the buyers
- the concentration of the buyers
- the concentration of the industry itself
- whether the products are differentiated
- how important the products are to the buyers' operations
- the portion of the industry's volume that goes to the buyers
- the level of switching costs
- the buyers' threat of backward integration
- the industry's threat of forward integration
- the level of information both industries have about the other
- the sophistication of the buyers
- whether buyers choose to exert their bargaining power

Components: The bargaining power of buyers of components is generally mixed. Factors that raise buyer power include relatively low buyer margins, lack of product differentiation, lack of switching costs, a credible threat of buyer backward integration (particularly for the larger merchant builders), a limited threat of forward integration by manufacturers, and buyers' propensity to exert bargaining power. Factors that limit buyer power include an non-concentrated buyer industry, moderate manufacturer concentration, and a high degree of knowledge of the buyers' industry by manufacturers.

Roof Panels: The bargaining power of all three groups of foam panel buyers--builders, owners, and dealers--is generally quite low. Other than a few firms that sell a significant annual volume to large timberframe homebuilders, none of the three have buyers that purchase large portions of a firm's total annual sales. Both dealers and builders have moderate switching costs (more to do with familiarity with the
manufacturer's organization and services than product differentiation, but credible nonetheless). Only a few large homebuilders possess a credible threat of backward integration. Finally, the majority of buyers do not have full information about the producers' operations.

Possible Strategic Actions: As is the case with the threat of entry, taking steps to limit buyer power is not the most pressing concern of most panel manufacturers. Not only is buyer power not that strong at this time, but it is not clear what buyer segments are most desirable. While homeowners and small-volume homebuilders possess the smallest bargaining power and least threat of backward integration, they often require the highest percentage of administrative costs and contribute most to cyclical demand.

SUBSTITUTES: The price of perceived substitutes generally establish the maximum price an industry (or firm) can charge, even if the production and sales costs are such that the resulting margins are unsatisfactory. Most industries expend a great deal of effort and money attempting to differentiate their products and/or services in some way to minimize the number of perceived substitutes. This is true even for industries that traditionally compete on a low cost basis.

As shown in the model given in Chapter One, there are several factors influencing buyers' decision to purchase a new product. Buyers must be made aware of a new product's performance attributes, perceive these attributes to be more desirable than those of substitutes, and be willing to pay a price premium of at least the price differences between the product and substitute systems plus any switching costs. The price premium they are willing to pay is discounted to reflect any uncertainty about actually achieving the performance advantages
or other aspects of switching to the product.

Buyers are least likely to perceive that a product offers superior value when any of the following aspects are true: 1) cost or performance advantages occur over time, not immediately upon purchase; 2) performance advantages indirectly rather than directly benefit the activity the product is purchased for; 3) the product requires significant changes in buyer behavior or patterns of use; 4) the buyer is not consciously aware of all aspects of the buyer's own activities, and thus cannot appreciate how a product represents a net benefit to the buyer.

Components: Substitutes generally exert tremendous competitive pressure on components. Roof trusses excepted, manufacturers have made slow progress in convincing homebuilders and homeowners of the relative advantage that prefabricated components provide, and in reducing the risk buyers associate with components. The existing purchase and installation processes does not always allow one of components' biggest advantage--quick field installation--to be captured to the full extent possible. Furthermore, manufacturers have not been able to differentiate their prefabricated products or the services associated with them to the point that builders cannot switch back to conventional construction if desired.

Roof Panels: The competitive pressure exerted on foam panels by rafter and truss systems is typical of the pressure conventional construction systems exert on components. For example, it is rare for a conventionally framed house to be both designed and constructed to achieve the tight, well-insulated shell with vaulted ceilings that panels easily provide. Since most homeowners know little about the performance advantages of panels, or are not willing to pay for
this performance, conventional rafter and truss framing are perceived as more desirable substitutes since they are "tried and true."

Similarly, homebuilders are often not aware of panels' performance advantages. Those that are often subconsciously establish an excessive discount rate to reflect their inability to understand how panels function better than an insulated stud wall or their uncertainty that switching to panels would provide them with a competitive advantage over rafter or truss systems. Furthermore, they hesitate to start installing panels due to perceived switching costs, such as new tools and equipment needed, training and learning curve costs, and the loss of any reputation they might have enjoyed for being quality stickbuilt constructors.

As discussed in Chapter two, typical costs in New England for a 30'x40' roof of simple architectural complexity run $3.50-$4.00/SF of roof for conventional systems. The same roof erected with foam panels (without Post and Beam framing) runs $5.30-$7.00/SF. Since the vast majority of consumers are highly cost conscious and conservative, the results are predictable: most consumers stick with less expensive and traditional conventional systems.

Possible Strategic Actions: Obviously, if the market share of foam panels is to increase, buyers must value the performance advantages and life cycle costs of panels more than they do now. Buyers must first be made aware of panel's performance attributes. Promotion by the panel industry as a whole would be a cost efficient way to increase buyer awareness of panels performance. Effective promotion should not just broadcast raw data but communicate the advantages panels represent over substitutes. Once the advantage is perceived by the buyer,
promotion and other means of signalling should ensure that the value buyers attribute to the panels' performance advantages is not reduced by uncertainty about other aspects of switching to them. Some of the present uncertainty about panels apparently can be attributed to rumors of past failures due to quality problems in production or installation. Joint industry R&D, testing, and quality standards would help to reduce this uncertainty.

Even after establishing value and reducing uncertainty, buyers may still perceive a net economic disadvantage to panels due to perceived switching costs. While panel manufacturers are reducing switching costs somewhat by providing free training on panel installation and renting the special saw and router required, additional subsidization may be necessary in this area.

Some buyers will respond to offensive actions against substitutes quicker than others, either because they have a higher propensity to change or their perception of value matches well with panels' advantages. It seems that the majority of panels are sold to homeowners who are extremely energy conscious, and are willing to pay slightly more initially for an innovative product that provides superior thermal performance. These and similar buyers should be targeted. Segments of the homebuilder population should also be targeted. Geographic regions of the country, e.g. the Northeast, is the most obvious way to segment the market since panels advantages is related to climate. Socioeconomic and city/rural location are two other possible methods for segmenting the market. Targeting should not just include marketing efforts. Promising market segments should be considered when contemplating minor or major changes in product or service characteristics.
SUPPLIER POWER: Strong bargaining power by suppliers reduce margins by raising costs when the industry cannot raise prices and still compete against substitutes. Again, Porter presents a number of factors that influence the extent to which suppliers reduce an industry's margins, most of which parallel the factors influencing buyer power:

- the profitability of the suppliers
- the concentration of the suppliers
- the concentration of the industry itself
- whether the supplies are differentiated
- how important the supplies are to the industry's operations
- the portion of the suppliers' volume that goes to the industry
- the level of switching costs
- the suppliers' threat of forward integration
- the industry's threat of backward integration
- the level of information both industries have about the other
- the sophistication of the suppliers
- whether suppliers choose to exert their bargaining power

Components: The bargaining power of suppliers of components is generally high. Factors that raise supplier power include the extreme importance of the raw materials to the manufacturers, a credible threat of forward integration by suppliers, no threat of backward integration by manufacturers, and suppliers' propensity to exert bargaining power. Factors that limit supplier power include relatively low manufacturer margins, lack of product differentiation, and generally low switching costs.

Roof Panels: Supplier power is quite high in the foam panel industry. Buyer power is increased by the facts that the two
main supplies--sheet wood products for faces and chemical for cores--are dominated by relatively few companies, the supplies are vital to the final product, and it is likely that panel producers purchase small portions of the suppliers’ total volumes. On the other hand, supplier power is somewhat limited by the fact that it would be possible for most manufacturers to switch to alternate materials, for example OSB to plywood.

Possible Strategic Actions: There are four key issues in a firm’s purchasing strategy: 1) the stability and competitiveness of the supplier pool, 2) the optimal degree of vertical integration, 3) the allocation of purchases among qualified suppliers, and 4) maximizing the firm’s leverage with each supplier. Panel producers’ ability to reduce supplier power through aggressive strategic moves appears to be limited in all four areas. Panel producers are not substantial buyers to influence the structure of the supplier pool. Backward integration is not an option for the vast majority of panel producers due to capital requirements. It is expensive to spread out purchases of supplies due to limited switching costs and loss of volume discounts. Maximizing leverage is difficult given that the sensitivity of typical production equipment does result in some switching costs and long term contracts with suppliers do not mesh well with cyclical demand for panels.

ANALYSIS OF KEY DIMENSIONS
Identifying where an industry falls along three dimensions provides additional strategic information not obvious from analysis of the five competitive forces and allows development of more specific and thorough competitive strategy. The three dimensions are the industry’s degree of concentration, state of maturity, and exposure to competition from abroad. The third dimension need not be examined since panels are not yet exposed to international competition. Examination of the first two
dimensions indicate that the foam roof panel industry is a fragmented and emerging industry.

PANELS AS A FRAGMENTED INDUSTRY: Porter defines a fragmented industry as, "An industry in which no firm has a significant market share and can strongly influence the industry outcome." It is not surprising that the foam panel industry is fragmented since its successively larger environments--the component manufacturing industry, the entire residential construction industry, and the entire construction industry--are all fragmented as well. There are two sets of factors contributing to its fragmentation. One set involves the industry structure; the other does not.

Factors relating to the industry structure include low entry barriers, relatively high transportation costs relative to the cost of the product before installation, erratic sales fluctuations, and the importance to some buyers of a local image and local contacts. While they have been changing over the past ten years, two additional factors are the absence of economies of scale and strong local regulation.

Factors not relating to the industry structure include manufacturers' lack of an effective overall strategy and their lack of capital, expertise or vision to expand capacity or improve the product or production process.

Possible Strategic Actions: Porter identifies two general methods of dealing with a fragmented industry: overcoming the fragmentation or just effectively coping with it. Possible methods of overcoming fragmentation include establishing

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29 Ibid, pp. 200-205.
economies of scale (discussed above in threat of entry) or steep learning curves, neutralizing the parts of business subject to fragmentation (for example, franchising would provide the local contacts required), and recognizing industry trends early, such shifting buyer needs, emerging technologies, and changing channel characteristics.

Assuming the sources of fragmentation cannot be overcome, possible ways of positioning to best cope with fragmentation include tightly managed decentralization with small, autonomous plants, increased value added through additional services, etc., and customer, product, and geographic specialization.

PANELS AS AN EMERGING INDUSTRY: The panel industry exhibits many structural characteristics identified by Porter as common of emerging industries:30

1. Technological uncertainty: Manufacturers, installers, and homeowners are uncertain which panel design is superior—polystyrene or urethane core? OSB or plywood faces? Spline or an other joining system?

2. Strategic uncertainty: Manufacturers are experimenting without clear success with different product/marketing positioning (crude attempts at market segmentation), marketing strategies, services, etc.

3. High initial costs but with significant cost reduction: Producers are progressing down the learning curve, achieving significant reductions in wasted labor and materials to achieve consistent quality.

4. Wary first time buyers: Homeowners and homebuilders alike must be educated: a) of panels basic nature and functions, b) that panels actually perform their functions without failing for a very long time, and c) that the risks of

trying an innovative framing/insulation system are outweighed by the benefits, that is, panels represent a rational purchase.

5. Short time horizon: Management in panel producing firms tends to be reactive, not proactive; policies are sometimes developed by chance or whim.

As a result of some of the above structural characteristics and other factors not relating to structure, rapid development of the panel industry is constrained by many significant problems. These include: absence of product or technological standardization, customer confusion about the product advantages and risks, erratic panel and installed system quality, less than desirable credibility with the financial community, occasional problems with regulatory approval, and an absence of infrastructure, such as distribution channels, service, trained installers, and complementary products. As a result of these problems, the costs of panel systems tend to be higher than substitute systems, further constraining industry development.

As a new product in an emerging industry, the criteria for consumer receptivity to panels is different than criteria for a new model in an established industry. The following aspects are pertinent since the benefits of a foam panel system are oriented towards performance, not cost:

1. Depending on which system they are compared against, the performance advantages offered by panels are generally large; however, they are generally not obvious to homebuilders or homeowners.

2. Homeowners' perceived need to achieve higher insulation values has decreased over the past ten years. As a result, the performance advantages offered by panels generally do not significantly improve homebuilders' competitive position.

3. Both homeowners and homebuilders are generally cost
sensitive while the difference between the costs of panels and the costs of substitutes is obvious and fairly large. Therefore, the cost differences can hurt the competitive position of a homebuilder despite the performance advantages.

4. The risk of a failure in panels is unknown since most manufacturers have been producing residential systems for ten years or less. If a panel did fail, the homebuilder could sustain a major loss since the panel is part of an integrated system.

5. Switching costs, such as for tools and training, are minimal but Consumers general propensity to change is extremely low in the residential construction industry.

6. Basic support services are generally available, but need improvement.

Possible Strategic Actions: As participants in an emerging industry, each panel producer has consciously or not made two strategic choices. First, most firms have not attempted to shape the structure of the industry through their overall strategy, product configuration, marketing, pricing strategy, etc. Instead, most firms have followed the behavior of the producer across the state. Second, nearly all producers have elected to act in its own self-interest rather than as a team player to develop the industry as a whole.

For the panel industry to transition to industry maturity and gain a larger market share, firms must jointly and separately start shaping the evolution of the industry. An industry trade association might be ideal for these purposes. First and foremost, a trade association could increase consumer awareness of the performance advantages of foam panels. Second, it could conduct extensive market research to identify subtle shifts in consumer preferences and behavior. This process, a key step in
the "House of Quality" concept,\textsuperscript{31} would encourage improved and diversified products lines and services.

While both the market research and mass marketing functions could be (and to some extent, is now) provided by individual firms, it makes strategic sense for the industry to perform them collectively. Not only could the costs be distributed over more firms (as is the case with the Associated Foam Manufacturers), the resulting cooperation between firms would help stop the finger-pointing that goes on between expanded polystyrene and urethane panel producers.\textsuperscript{32} Increased consumer awareness, together with an industry united on the quality of its products, will undoubtedly help satisfy one critical consumer need that has not yet been fully satisfied by the industry: mass acceptance and confidence in the product by both homeowners and homebuilders alike.


\textsuperscript{32} Andrews, p. 56.
CHAPTER FIVE: VALUE CHAIN ANALYSIS

It was stated in the introduction that the factors influencing the performance, cost and market share of a residential component include the technological, economic and organizational characteristics of its production, marketing and installation processes. These factors are examined in this chapter using the framework for performing a value chain analysis also developed by Michael E. Porter.33

The term "value chain" has been embraced by many people in a wide range of industries. For some, analyzing the value chain means simply identifying the different firms involved in a product or service from cradle to grave. (Since each firm along the sequence often represents a separate industry using the definition given in Chapter Four, the value chain is sometimes viewed as a chain of industries as well as a chain of firms.) Others take the concept further by considering the costs and margins associated with each firm along the chain. Neither of these applications approaches the level of detail or value of a value chain analysis as presented in Porters book.

A value chain analysis is a rational process for analyzing a firm or industry that is more detailed than a structural analysis. A structural analysis is primarily intended to provide insight into the costs, margin and market share of an industry as a whole. This insight can then be used by individual firms to improve its competitive position. The opposite is true for a value chain analysis. It is primarily intended to provide specific insight into the costs, margin and market share of an individual firm by examining how the firm's

activities match with key cost drivers and the needs and desires of upstream or downstream organizations. It should be noted, however, that performing an analysis of a firm can provide insight into the underlying characteristics and economic structure of the industry that may not have been apparent after a structural analysis.

The first part of this chapter introduces the theory, procedure and applications of a value chain analysis. The second part is a value chain analysis of a hypothetical foam panel manufacturer performed on a broad level. This example has the dual purpose of providing further insight into the foam panel industry and of illustrating how a value chain analysis can be used to identify potential improvement in a component producer’s operations.

THEORY, PROCEDURE, AND BENEFITS OF A VALUE CHAIN ANALYSIS

The Value System: A firm’s value chain does not exist alone in the competitive environment. It is part of a total value system, which is composed of an upstream value chain (the creation and delivery of purchased input), a channel value chain (additional value added, if any, and delivery to the buyer), and a buyer value chain. How a firm’s value chain relates to a supplier’s value chain has definite cost implications. How a firm’s value chain relates to a distributor’s or a buyer’s value chain has cost and value, and, therefore, profit margin implications.

Like the industry structure in which the firm operates, a firm’s present value chain is determined somewhat by factors beyond the present control of the firm:

"A firm’s value chain and the way it performs individual activities are a reflection of its history, its strategy, its approach to implementing its strategy, and the underlying
Microeconomic Theory: A simplification in terms of microeconomic theory is useful. For any individual activity, a firm starts with some sort of input (raw or partially processed materials) and adds value through the expenditure of resources (labor, equipment, etc.) to achieve a product that is worth more than the total costs expended to achieve the product. In a perfect market, the difference between the value of the output and the total costs of the input is continually forced down by competitive forces to the free market rate of return, adjusted upward to reflect the risks associated with the industry.

In an imperfect market, competitive forces may not be strong enough to keep the value added at the level providing only the free market rate of return. Conversely, a firm may earn less than the free market rate of return if the underlying characteristics and economic structure of the industry result in particularly strong competitive forces, if there are organizational or technical deficiencies within the firm, or if the firm's operating characteristics match up poorly to the industry's cost drivers.

The Nine Generic Categories: Porter suggests that an important first step in the analysis is to view a firm's value chain in terms of nine generic categories of activities: inbound logistics, operations, outbound logistics, marketing and sales, service, firm infrastructure, human resource management, technology development, and procurement. As indicated in Figure 18, the first five categories are considered Primary Activities while the last four are Support Activities. Support Activities can be associated with one or all of the Primary

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34 Ibid, p. 36.
Activities. After segregating the value chain into generic categories, individual activities that comprise each category should then be identified.

Isolating Value Activities: The identification of value activities is a critical step in the analysis. Each activity should be physically, technologically, and strategically distinct. Using Porter’s words, "...Activities should be isolated and separated that (1) have different economics, (2) have a high potential impact on differentiation, and (3) represent a growing proportion of cost." While it is possible to break down the value chain into activities so

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**Figure 18: THE GENERIC VALUE CHAIN**


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small that no strategic insight can be gained by examining them, firms generally err on the side of lumping distinct activities together, thereby losing the ability to identify opportunities for small, cumulative improvements.

Buyer Value Chain: Before proceeding with the detailed analysis of the manufacturing value chain, it is necessary to spend some time thinking about each buyer's value chain. Ultimately, the costs of servicing the buyer and the profit margin on a product that the buyer will allow is a function of how well the manufacturer's value chain relates to the buyer's value chain. The relationships in value chains include two components. First, how well does the product serve the particular function for which the buyer intends it? Second, how well does the manufacturer's process of selling and delivering the product meet the needs and desires of the buyer?

Answering these questions requires both the "big picture" of the buyer's business as well as a somewhat detailed knowledge of the buyer's operations. A manufacturer can then better understand what dimensions of differentiation or costs the buyer may value in the products he purchases (even if the buyer is not consciously aware of the dimensions himself) and consider appropriate product improvements. Also, a manufacturer can then consider how the processes in which the two firms presently interact can be improved, and identify activities or processes in which the two firms do not presently interact but which could provide the manufacturer competitive advantage by doing so. The sample value chain analysis later in this chapter illustrates how a buyer's value chain is considered in the value chain analysis process.

Detailed Analysis of Each Activity: Once the buyers' value chain(s) are understood, each activity in the manufacturer's
value chain should be analyzed for the aspects listed below:

a. description of the actions
b. internal and external participants involved
c. human resource, equipment, physical plant, and financial assets needed
d. technology involved
e. cost behavior drivers
f. ways to achieve low cost advantage
g. ways to differentiate

Much of this step, particularly a. through f., may seem tedious and unproductive since the information may be considered obvious to all concerned. In most organizations associated with prefabricated construction, however, the information is not obvious. Management and labor alike often do not think about fundamental operating information, and when asked they give different answers. Identifying and recording the information in a. through f. thus ensures that the personnel performing and reviewing the value chain analysis have thought about the question and agree on the answers. A description and brief discussion of why each set of information is needed follows.

Brief but accurate descriptions of the actions associated with each activity are important to insure management has the same understanding of the operations that the activity title refers to. For example, one person may consider periodic inventory of stock raw materials as part of Basic Panel Production, instead of considering it a part of Receiving and Pre-Production Storage, as is the case in this sample analysis.

The internal and external participants involved in the activity are identified to remind management of two things: 1) what employees are responsible for each activity, 2) how and which
employees are interacting with one another and with individuals outside the organization, such as suppliers or buyers. This information is used when considering linkages, which are discussed shortly.

The human resource, equipment, physical plant, and financial assets needed are identified to ensure that these needs are present and effectively applied within the existing organization. Frequently, the needs are not met, due either to inadvertent inaction or a conscious decision by management to get by without the needed resources. Operating without the sufficient number and type of resources leads to inefficiencies in production, low morale, frequent breakdowns in equipment or the production process, increased accidents, cash flow problems, etc. These negative consequences are often subtle or hidden, so they are allowed to continue.

Identifying the technology involved in each activity that the firm performs is another area in which some of the value of the analysis is achieved simply by having management think about the firm's present situation. Many firms believe that they are "technologically progressive" because their main production system may be relatively new, yet they have material handling equipment that has not changed since the 1940s and information processing procedures that could have been established fifty years ago. Thinking about the technological aspects of each and every activity can be an eye opener.

As stated in Chapter Four, cost drivers are characteristics of the structure of the industry that determine the costs of a firm's activities. The costs of each activity depends on the match up between the firm's present operating characteristics and the cost drivers for that activity. For example, if learning is a key cost driver of an activity, a firm with a low
cumulative production volume will probably incur higher costs performing the activity than a firm with a high cumulative production volume. Porter identifies a number of cost drivers that are common in most industries. As shown in the sample value chain analysis, only a few drivers tend to be important for each activity.

Economies of Scale: Economies of scale imply that the costs per unit for an activity while operating at full capacity are lower for a high volume of units than for a low volume of units. Economies of scale may result from increasing returns to scale in production (i.e. output per input in terms of volume, not cost, rises with increasing volume) or in increases in overhead activities that are proportionally less at higher volumes. Economies of scale should not be confused with capacity utilization, discussed below.

Learning: A firm is often able to decrease the cost of performing an activity over time through improvements in the processes. Increased efficiency can result from many changes, including changing the personnel involved, how and what assets are used, scheduling, etc.

Capacity utilization: This driver is related to a firm's fixed costs. The higher the percentage of capacity a firm operates at, the broader the base that fixed costs can be spread over.

Linkages: The value activities within a value chain are often interdependent. The way one activity is performed may impact the cost of another activity, or the way it can be performed, indicating linkage. For example, the costs of custom panel production depends on many aspects of the initial production of basic panels. Similar linkages exist outside the value chain, between some of a firm's value activities and those of
suppliers, channels or buyers. It is not always the case that a change that benefits one activity is necessarily at the expense of the linked activity.

Interrelationships: Economies of scope are present when a firm can perform two activities for a cost that is less than the combined costs of performing each activity without the other. Economies of scope result from sharing the costs of fixed costs, such as management and administration, physical plant, distribution and sales. If the activities are horizontal (i.e., one activity does not occur sequentially before the other in a chain of activities), economies of scope benefits are termed interrelationships.

Integration: Economies of scope may also occur due to a firm sharing fixed or variable costs between vertical activities or businesses, termed integration. The benefits of integration are not restricted to economies of scope. In addition, a vertical business may increase the volume of the adjacent business, thereby increasing capacity utilization and increasing the ability to capture economies of scale.

Timing: Timing may serve as a cost driver on two levels. First, the timing at which a firm enters a business may influence its initial costs due to first mover advantages. Second, the pattern in which firms procures materials or performs activities over the course of the year may influence costs due to annual cyclical demand.

Discretionary Policies: Discretionary policies take two forms, both of which may influence the costs of performing an activity. One form is the ways a firm attempts to differentiate the product or service to buyers. The second form is the various policies and tactics of management that
affect internal operations, such as human resource management policies. Policies are often implicit and traditional, and may cost the firm more than is realized. As a result, the process of identifying the firm's discretionary policies in each activity as part of a value chain analysis is extremely beneficial for its own sake.

Location: The location where an activity is performed influences its costs in several ways. One obvious way is that the distances between the firm and suppliers and buyers influence the costs of shipping, telephone rates, etc. In addition, the local prevailing labor, material, and energy rates and access to financial assets and skilled or professional labor are also important. Finally, the local culture may influence the overall way a firm conducts its business.

Institutional Factors: The costs of performing an activity may be influenced by factors inherent in the industry. Common examples are costs associated with government regulations, unionization, and traditional modes of interaction with outside organizations.

Identifying ways to achieve low cost advantage in an activity involves listing all possible actions that might result in lowering the cost of performing the activity. There is no need at this point to consider whether the possibilities listed are feasible given the existing organization, technology, overall strategy of the firm, etc. All potentially cost saving actions should be listed and evaluated later. Lowering the cost in one activity alone rarely provides competitive advantage, but incremental improvements in many activities may do so.

Identifying ways to differentiate is similar to identifying
ways to achieve low cost advantage. Instead of cost savings, however, one lists all actions that might make the product or process more valuable to buyers. Again, this step is for brainstorming; evaluation comes later. Even if most of the ideas are completely infeasible for the firm, just identifying them as possible actions helps to anticipate what actions competitors might take.

Applying the Results of a Value Chain Analysis: The information and insight gained from a value chain analysis can be used on two levels: to formulate strategy for the firm (or industry as a whole) and to make improvements in the firm's individual activities.

On the broad or macro level, the information from a value chain analysis can be used to answer the following strategic questions:

1) How well does each operating strategy support the overall competitive strategy?
2) What are the most desirable market segments to match the overall strategy, the assets and skills, and the cost driver characteristics of the firm?
3) What changes to the firm's product line and product scope should be considered?
4) What strategic moves should the firm contemplate to reconfigure their value chain? Similarly, what benefits might accrue from re-configuring the entire value system?

The purpose of each of the possible changes mentioned above, of course, is to lower the firm's costs and/or increase the firm's differentiation in order to increase margin and/or gain market share.

On the detailed level, each activity in the firm's present
value chain should be examined to answer the following strategic questions:

1) How do assets in the areas of human resources, equipment, physical plant, and finance that were identified in the analysis as being necessary, compare to assets presently involved in each activity?

2) How effectively is the activity actually performed?

3) How does the present characteristics of the activity match up to the activity's cost drivers? What could be done to improve the match up, thereby lowering the costs?

4) How could the technologies used to perform the activity be increased?

5) Would there be overall benefits to contracting out the activity rather than performing it in-house?

6) As one potentially critical cost driver, what linkages could be pursued to decrease costs or improve performance?

7) How could the activity be differentiated? Would the added costs outweigh any price premium or increased market share that might result?

THE VALUE CHAIN OF A HYPOTHETICAL LARGE FOAM PANEL PRODUCER

The remainder of this chapter is a sample value chain analysis of a hypothetical large foam panel producer. In the interests of space and to maximize the insight into the industry as a whole, the analysis will be on a broader level than would be performed in industry.

Sequence of Events For Buyers: The sample analysis starts with a crude examination of the sequential processes that two of the sample firm's buyer groups undergo when purchasing stresskin foam panels. This document represents the sequence of events rather than their value chain. While it might be beneficial to perform a value chain analysis for a homebuilder buyer, the level of detail and space required is beyond the intent of this
example. It would not prove beneficial to perform a value chain analysis for a homeowner buyer since the value chains of consumers do not lend themselves to the generic categories of Figure 18, nor does it make sense to talk about a homeowner's cost drivers.

The purpose of describing the buyer's sequences of events is to indicate the decisions facing the buyer and the ways in which the buyer interacts with the panel producer and other participants in the process. The reader may then better understand the different ways a panel producer may differentiate or reduce costs to better appeal to buyers. For example, the description of events indicates the possible ways in which the homeowner links up with the homebuilder. A panel producer who facilitates this link up may successfully differentiate himself from a panel producer who does not.

The motivations and desires of the buyers at each step in the sequence are not discussed here, but it is essential that they be considered in an actual value chain analysis. For example, the first event in the buyer's sequence of events is his decision to build with panels rather than use conventional construction techniques. The analysis should consider what factors favored the use of panels, what factors opposed their use, and what factors were not considered in the decision.

Two Homebuilder Buyers:
Buyers that are homebuilders often fall into one of two groups. The first group is composed of medium sized homebuilders who have ten to thirty employees and build ten to fifty houses per year. They also offer custom house design. The number of firms in this group are few but they account for a significant portion of the panel manufacturer's total panel sales. The firms rarely build on speculation. They use post and beam
framing, not conventional framing. The second group are small homebuilders who have less than ten employees and build two to eight houses each year. They may switch back and forth between stickbuilt or panel construction, building on speculation or for a specific homebuyer desiring a custom house.

These two buyer groups approach the panel producer with significantly different needs and desires. Also, the sequence of events involving the homebuilder, the future homeowner and the panel producer may differ substantially. A panel producer seeking to improve the ways in which he differentiates himself from other panel producers should consider the needs of each buyer individually. For the sake of time and space, this sample analysis will only consider the small homebuilder.

The homebuilding process begins for a small homebuilder with the decision to build a panel house instead of a stickbuilt house. He may have made this decision twenty panel houses ago or the week before approaching the panel producer for the first time. If building a "spec" house, his decision is usually based more on his perception of the market, i.e. what type of house will sell fastest and allow him a reasonable profit, rather than a strong desire to build with panels.

If already linked with a homeowner, the decision to build with panels may be by the homeowner, not by the contractor. The link up may occur in one of several ways: 1) the homebuilder approaches the homeowner after hearing through word of mouth that the homeowner is planning to build, 2) the homeowner approaches the homebuilder through an informal referral, or 3) The homeowner approaches the homebuilder as a result of some sort of promotion by the homebuilder.

The next step is usually establishing the house design. Again,
several alternative situations are common: 1) The homebuilder offers several standard designs, from which the homeowner selects or modifies one design, 2) the homeowner obtains the design from outside design source, such as the many house plan books available or an architect, 3) the homeowner selects a standard design from the panel producer, or 4) the homeowner works with the homebuilder and/or panel producer on his own design.

The costs and completion date are generally established as the design is finalized or just after. If the link up between the homeowner and homebuilder has not yet occurred, the latter may be requested to furnish a bid on the homeowner’s concept or final design. If the link up has occurred, the homebuilder generally furnishes a guaranteed maximum price, sometimes after extensive negotiations on the costs and final design. The panel producer may or may not be requested to furnish quotes during this period.

The homebuilder then orders the panels and lines up subcontractors. Homebuilders differ in the portion of the work they perform themselves, particularly with panels. General Contractor homebuilders traditionally were carpenters and either performed all the work but the utilities or at least did the framing. This is not the case with panels. The panel shell is often installed by a subcontractor recommended by the panel producer. The homebuilder oversees the construction and performs one or more of the sitework, foundation or finish activities. The panel producer is often on site the first day that panels are installed if the installer is inexperienced.

When construction is completed, the homebuilder turns over the new house to the homeowner. Punchlist and warranty work are initiated by the homeowner calling the homebuilder.
A Homeowner Buyer:
The homebuilding process for the homeowner also begins with the decision to build with panels instead of stickbuilt construction. This decision may be the result of one or more events: 1) the homeowner sees a display by a panel producer at a home show, 2) the homeowner reads about panels in a homebuilding magazine, 3) the homeowner hears about panels through some other type of promotion, or 4) the homeowner hears about panels through a word of mouth recommendation.

A fair number of homeowners elect to play the role of General Contractor rather than hiring a homebuilder to do so. If the homeowner elects not to play General Contractor and hires a homebuilder to coordinate the construction, the link up between the two may be before or after the homeowner approaches the panel producer. If after, the panel producer may furnish the homeowner with a list of names of area homebuilders who have installed panels.

The house design process is similar to the process with a homebuilder buyer. The homeowner may select as is or modify a standard design obtained from either 1) the panel producer, 2) the homebuilder, 3) a book of house designs, or 4) an outside architect. Alternatively, the homeowner may come up with his own design.

The scope of the panel producer’s involvement in furnishing materials and the installation is usually established during the design stage. Some panel producers furnish the frame material only and will only spend a day on the jobsite to oversee an inexperienced installer. Other producers seek to both furnish the shell materials and be responsible for their installation. Still others furnish and install the materials.
for the entire building shell, including the foundation, windows and doors. The costs and completion date for the amount of materials and installation assumed by the panel producer are established at this time.

The panel producer, homeowner, or homebuilder then lines up the subcontractors, depending on the panel producer's agreed upon scope of work. If the panel producer or homeowner is responsible for the entire house, a homebuilder may be hired to coordinate the construction.

Turnover, punchlist and warranty work is the same as for a homebuilder buyer except that the homeowner may call the panel producer to initiate corrective work if the panel producer was responsible for the entire house.

Identification of the Manufacturer's Value Chain: Having reviewed the process that buyers of panels undergo, the next step in the sample analysis is to identify the manufacturer's value chain. As stated earlier, this analysis is on a broader level that would be desired if it was not for academic purposes. To save time and space the equivalent of Porter's generic categories (see Figure 18) will serve as the value activities rather than analyzing each specific activity separately. For example, rather than analyzing the three or four activities that make up the manufacturer's Inbound Logistics, all four activities will be considered together. The only exception is that the generic category Operations is split into two activities, Basic Panel Production and Custom Panel Production. The generic categories suggested by Porter will be referred to in some cases by titles that are more descriptive than his titles. For example, rather than referring to "Inbound Logistics", the title "Receiving and Pre-Production Storage" will be used. The list below indicates the
activity titles that will be used in this example.

<table>
<thead>
<tr>
<th>Generic Category</th>
<th>Activity Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbound Logistics</td>
<td>RECEIVING AND PRE-PRODUCTION STORAGE</td>
</tr>
<tr>
<td>Operations</td>
<td>BASIC PANEL PRODUCTION</td>
</tr>
<tr>
<td></td>
<td>CUSTOM PRODUCTION</td>
</tr>
<tr>
<td>Outbound Logistics</td>
<td>TRANSPORTATION TO THE JOB SITE</td>
</tr>
<tr>
<td>Service</td>
<td>TRAINING AND INSTALLATION MONITORING</td>
</tr>
<tr>
<td>Marketing and Sales</td>
<td>MARKETING AND SALES</td>
</tr>
<tr>
<td>Procurement</td>
<td>ORDER RAW MATERIALS AND SUPPLIES</td>
</tr>
<tr>
<td>Firm Infrastructure</td>
<td>GENERAL AND ADMINISTRATIVE OVERHEAD</td>
</tr>
<tr>
<td>Human Resources Mgt.</td>
<td>HUMAN RESOURCES MANAGEMENT</td>
</tr>
<tr>
<td>Technology Develop.</td>
<td>TECHNOLOGY DEVELOPMENT</td>
</tr>
</tbody>
</table>

Figure 19 shows these titles in the generic value chain.

Figure 19: THE GENERIC VALUE CHAIN FOR THE SAMPLE PANEL PRODUCER
RECEIVING AND PRE-PRODUCTION STORAGE

DESCRIPTION:
This activity includes the processes associated with raw materials coming into the plant.

(GENERIC CATEGORY: Inbound Logistics)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. shipping by supplier
2. off-load faces, lumber, chemicals
3. confirm quantities and quality
4. move to storage location
5. position
6. record
7. periodic inventory

EXTERNAL PARTICIPANTS: truck drivers

INTERNAL PARTICIPANTS:
warehousemen (same as production workers)
someone to record information
someone to file the shipping documents

HUMAN RESOURCES NEEDED:
material handling equipment (MHE) operator
data processor
clerical
inventory

EQUIPMENT NEEDED:
MHE: forklift

PHYSICAL PLANT NEEDED
unloading facility
storage space (covered, heated, humidity controlled)

FINANCIAL ASSETS NEEDED:
working capital for materials, labor
long term capital for MHE and physical plant

TECHNOLOGY USED:
MHE
information processing for recording inventory
COST BEHAVIOR DRIVERS:
capacity utilization: direct + overhead cost/unit for labor and 
amortization costs/unit for MHE, data processing personal and 
personal computer and physical plant depend on uniformity of 
volume

learning: labor cost to position and record materials decrease 
over time

location: shipping costs relative to suppliers, labor rates

linkages: 1. with Procurement (if supplier selection process 
considers shipping packaging, flexibility of schedule) 
2. with Operations (location and storage method affects cost 
to move into production area)

interrelationships: with packaging (capacity utilization, 
learning)

integration: with design and installation (capacity 
utilization, 
learning) if broadened scope increases volume

WAYS TO ACHIEVE LOW COST COMPETITIVE ADVANTAGE:
1. gain volume in primary or related products to increase 
capacity utilization during off-peak periods

2. use temporary resources (labor, equipment) to reduce fixed 
costs

3. learn from competitors and related industries

4. source from local suppliers

5. use information technology to increase the efficiency and 
accuracy of receiving and periodic inventory, improve the 
interface with production scheduling, and improve linkages with 
Procurement and transportation firms.

6. use automated conveyance and storage systems.

WAYS TO DIFFERENTIATE:
1. handling of incoming materials to prevent damage

2. close control of environmental storage conditions

3. use technology to acquire reputation as progressive, 
quality-oriented producer
BASIC PANEL PRODUCTION

DESCRIPTION:
This activity includes the processes associated with producing the basic 4x8 or larger panels.

(GENERIC CATEGORY: Operations)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. position raw materials
2. produce basic panels
3. cut to length
4. inspection
5. testing
6. inter-production and pre-shipping storage
7. maintenance of equipment

EXTERNAL PARTICIPANTS:
testing lab technicians
equipment maintenance personnel

INTERNAL PARTICIPANTS:
sales coordinator
production line workers
production line foreman
QC personnel
equipment maintenance (colla:eral duty)

HUMAN RESOURCES NEEDED:
planning to set production schedule
production labor
production supervision
production quality control
MHE operators
equipment maintenance

EQUIPMENT NEEDED:
pre-production positioning equipment
basic production equipment
inspection and testing equipment
equipment for maintenance of production equipment

PHYSICAL PLANT NEEDED:
large heated and covered area for production
smaller areas for temporary storage
FINANCIAL ASSETS NEEDED:
long term capital for basic production equipment, testing and inspection equipment, MHE
working capital on production labor, materials and utilities

TECHNOLOGY USED:
pre-production positioning equipment
basic production equipment
inspection and testing

FACTORS IN COST BEHAVIOR:
economies of scale: basic production equipment
learning: throughout process, maintenance of equipment
capacity utilization: basic production equipment, MHE, production space

linkages: 1. with inbound logistics (characteristics of storage), 2. with custom production (characteristics and location of panels after basic production), 3. with outbound logistics (location of panels after basic production)

interrelationships: with design and packaging (capacity utilization, learning) if broadened scope increases volume

integration: with installation (capacity utilization, learning) if broadened scope increases volume

policies: towards curing, quality, speed of production, inspection

location: labor rates

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. encourage buyers to purchase off-peak through pricing, marketing
2. increase volume by broadening product and service scope
3. manage learning
4. establish good interfaces with custom production, inbound logistics
WAYS TO DIFFERENTIATE:
1. pursue fast delivery time through higher speed of production or high stock on hand
2. offer greater range of sizes, thickness, materials of basic panels
3. offer convenience of accessory supplies
4. intensity of inspection and/or tightness of specifications
5. curing requirements
6. structural and appearance quality of faces
7. R-value of cores
8. ease, structural or thermal aspects of joints
CUSTOM PRODUCTION

DESCRIPTION:
This activity includes the processes associated with customizing basic panels to the specific sizes and layouts needed on individual jobs.

(GENERIC CATEGORY: Operations)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. position raw materials and/or basic panels
2. produce custom panels
   a. bend basic panels into bow roofs
   b. cut solid panels for specific locations on custom orders
   c. cut and route for windows, doors, etc.
   d. apply custom faces
3. inspection
4. inter-production and pre-shipping storage
5. maintenance of equipment

EXTERNAL PARTICIPANTS:
testing lab technician

INTERNAL PARTICIPANTS:
sales coordinator
production line workers
production line foreman
QC personnel
equipment maintenance (collateral duty)

HUMAN RESOURCES NEEDED:
planning to set production schedule
production labor
production supervision
production quality control
MHE operators
equipment maintenance

EQUIPMENT NEEDED:
MHE
custom production equipment (routers, glue application, saws, clamps)
equipment for maintenance of production equipment

PHYSICAL PLANT NEEDED:
large heated and covered area for production
smaller areas for temporary storage
FINANCIAL ASSETS NEEDED:
long term capital for custom production equipment, MHE
working capital for labor, materials and utilities

TECHNOLOGY USED:
custom production equipment
MHE
inspection
maintenance of equipment

FACTORS IN COST BEHAVIOR:
learning: throughout process
capacity utilization: custom production equipment, MHE, production space
interrelationships: with design and packaging (capacity utilization, learning) if broadened scope increases volume
integration: with installation (capacity utilization, learning) if broadened scope increases volume
linkages: 1. with basic production (characteristics and location of panels), 2. with outbound logistics (characteristics and location of panels)
location: labor rates

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. gain volume in primary or related products to increase capacity utilization during off-peak periods
2. manage learning
3. use information technology to improve interfaces with sales and production scheduling inbound logistics, basic production, outbound logistics
4. use automated conveyance and storage systems.

WAYS TO DIFFERENTIATE:
1. scope of customizing
2. quality of customizing
3. speed of customizing
4. aesthetic customizing
5. pricing of customizing
TRANSPORTATION TO THE JOB SITE

DESCRIPTION:
This activity includes the processes associated with moving panels from the plant to the jobsite.

GENERIC CATEGORY: Outbound Logistics

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. Bundle
2. load onto transportation vehicle
3. drive to job site
4. unload at site

EXTERNAL PARTICIPANTS:
shipper
homeowner or installation subcontractor

INTERNAL PARTICIPANTS:
shipping personnel
sales personnel

HUMAN RESOURCES NEEDED:
bundler
MHE operator
shipping document processor
truck driver
interface on jobsite

EQUIPMENT NEEDED:
bundling equipment
MHE
flat bed truck (with or without crane attachment)

PHYSICAL PLANT NEEDED:
small heated and covered area for bundling
loading dock

FINANCIAL ASSETS NEEDED:
long term capital for bundling equipment, MHE, truck, physical plant, working capital for labor and shipping
TRANSPORTATION TO THE JOB SITE, continued

TECHNOLOGY USED:
bundling
MHE
shipping
un-loading

FACTORS IN COST BEHAVIOR:
economies of scale: shipping rates
learning: bundling

capacity utilization: truck, MHE

linkages: bundling linked to production

interrelationships: with packaging (capacity utilization, economies of scale, and increased demand)

integration: with installation (capacity utilization, economies of scale, and increased demand)

timing: shipping rates vary with time of year

discretionary policies: off-loading process

location: shipping rates, shipping costs relative to jobsites

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. use information technology to study shipping process and pricing scheme and ensure shipping cost passed onto customer

WAYS TO DIFFERENTIATE:
1. Bundling, identification, protection during shipping
2. speed of bundling and shipping
3. how off-load
4. ability to furnish real-time status on shipping to customer
MARKETING AND SALES

DESCRIPTION: This activity includes the processes associated with selling and distributing the panels.

(GENERIC CATEGORY: Marketing and Sales)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. advertising and promotion
2. sales force
3. quotations and pricing
4. interfacing with buyers and channels

EXTERNAL PARTICIPANTS:
homeowners
homebuilders
subcontractors
distributors
architects
advertising organizations

INTERNAL PARTICIPANTS:
salespeople
sales manager
company officers
estimators
clerical

HUMAN RESOURCES NEEDED:
sales
sales management
estimating
clerical

EQUIPMENT NEEDED:
PC for estimating

PHYSICAL PLANT NEEDED:
office space

FINANCIAL ASSETS NEEDED:
long term capital for PC, physical plant
working capital for overhead labor, advertising,
  promotional material, miscellaneous operating expenses
MARKETING AND SALES, continued

TECHNOLOGY USED:
sales process
advertising process
interface/process with channels
estimating

FACTORS IN COST BEHAVIOR:
economies of scale: promotional literature, travel time for sales force
learning: advertising, promotional literature
capacity utilization: sales force, sales aids
linkages: sales linked with distribution channels, product mix, delivery process
interrelationships: with packaging (capacity utilization, economies of scale, and increased demand)
integration: direct sales vs. distribution channels; with installation (capacity utilization, economies of scale, and increased demand)
discretionary policies: compensation schemes for sales force, installation supervision requirements
location: travel time for sales force

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. increase scale
2. use information technology to evaluate effectiveness of promotion, optimize sales regions, optimize compensation scheme for sales force
3. encourage off-peak sales through pricing, marketing

WAYS TO DIFFERENTIATE:
1. customer training
2. background and training of sales force
3. general tactics of sales force
4. location of sales
5. channel payment policies
6. discounts on purchases policies
7. image established through promotion
8. sales literature
9. credit policy
TRAINING AND INSTALLATION MONITORING

DESCRIPTION:
This activity includes the processes associated with ensuring panels are installed properly on site.

(GENERIC CATEGORY: Service)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. oversee installation by installer
2. oversee repair by installer
3. training of homeowner, installer
4. parts supply
5. verbal follow up with homeowner

EXTERNAL PARTICIPANTS:
homeowner
installer
other tradespeople
building inspector

INTERNAL PARTICIPANTS:
sales people
construction supervisors/advisors
shipping personnel (for parts)

HUMAN RESOURCES NEEDED:
sales
training
construction monitoring
shipping

EQUIPMENT NEEDED:
shipping truck also used for installation if outfitted with a crane attachment

PHYSICAL PLANT NEEDED: None

FINANCIAL ASSETS NEEDED:
working capital for overhead labor, minor operating expenses

TECHNOLOGY USED:
installation equipment
training materials
TRAINING AND INSTALLATION MONITORING, continued

FACTORS IN COST BEHAVIOR:
economies of scale: training materials
learning: overseeing installation
capacity utilization: installation equipment, installation monitoring personnel
linkages: service linked with sales, initial bundling, shipping
interrelationships: with packaging (capacity utilization, economies of scale, and increased demand)
integration: in-house crew or subcontractor installation? (capacity utilization, economies of scale, and increased demand)
timing: season of the year for subcontractor prices; group training
discretionary policies: quality of installation; relationships with subcontractors, homeowners
location: subcontractor costs, relative to jobsites for travel time for overseeing

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. use information technology to facilitate monitoring of subcontractors; good subs minimize oversight necessary
2. ensure effective bundling, shipping
3. encourage off-peak purchasing and installation

WAYS TO DIFFERENTIATE:
1. process for overseeing installation
2. follow up action with homeowner
3. training of installers
4. selection of installers
ORDER RAW MATERIALS AND SUPPLIES

DESCRIPTION:
This activity includes the processes associated with purchasing materials needed to run the operations.

(GENERIC CATEGORY: Procurement)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. identify needs
2. research potential sources (costs and characteristics)
3. negotiate price and delivery date
4. place order
5. communicate status of orders
6. pay invoices

EXTERNAL PARTICIPANTS:
vendor salespeople

INTERNAL PARTICIPANTS:
production managers
procurement personnel
accounting personnel

HUMAN RESOURCES NEEDED:
planning (to identify needs)
research (to identify sources)
negotiating
monitoring (of status)

EQUIPMENT NEEDED: (general infrastructure equipment)

PHYSICAL PLANT NEEDED
office space for procurement personnel

FINANCIAL ASSETS NEEDED:
working capital for overhead labor and miscellaneous expenses

TECHNOLOGY USED:
process of identifying needs
process of identifying sources
process of placing orders
process of communicating status

FACTORS IN COST BEHAVIOR
economies of scale: more bargaining power with suppliers,
more professional procurement personnel

learning: throughout out process
capacity utilization: keep procurement personnel busy

linkages: 1. with Production (accuracy of estimating needs, accuracy of status),
2. with Inbound Logistics (accuracy of status, selection of vendor),
3. with Vendors (processes of identifying prices and characteristics of supplies, negotiating price and dates, placing order, gathering data on delivery status)

interrelationships: with packaging (capacity utilization, economies of scale, and increased demand)

integration: with installation (capacity utilization, economies of scale, and increased demand)

timing: length of supply contracts, day of month ordered affects invoice discount deadlines

discretionary policies: loyalty to specific vendors

location: telephone rates cheaper for local vendors

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. gain volume in primary or related products to increase capacity utilization during off-peak periods

2. use information technology to improve interface with production and receiving schedules, with vendors

3. establish long term supply contracts in early stages of product introduction

4. source from local suppliers

WAYS TO DIFFERENTIATE:
1. procurement high quality supplies

2. establish procurement relations that achieve quick delivery when necessary
GENERAL AND ADMINISTRATIVE OVERHEAD

DESCRIPTION:
This activity includes the processes associated with ensuring the business is run effectively.

(GENERIC CATEGORY: Firm Infrastructure)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. general management
2. planning
3. finance
4. accounting
5. legal

EXTERNAL PARTICIPANTS:
banks
lawyer
management consultant
accounting auditors

INTERNAL PARTICIPANTS:
corporate officers
accounting personnel

HUMAN RESOURCES NEEDED:
operational, financial, strategic management
accounting clerical

EQUIPMENT NEEDED:
PC and software

PHYSICAL PLANT NEEDED:
office space

FINANCIAL ASSETS NEEDED:
working capital for overhead functions

TECHNOLOGY USED:
information systems
telecommunications

FACTORS IN COST BEHAVIOR:
learning: accounting process
capacity utilization: management, accounting personnel

linkages: management linked to all activities, planning and finance linked to sales expansion

interrelationships: with packaging (capacity utilization and increased demand)

integration: with installation (capacity utilization and increased demand)

discretionary policies: towards outside professional services, financing, Accounts Receivable/Payable, credit, requirement for pre-production deposits

institutional factors: cyclical, fragmented industry affects management, planning, finance, accounts receivable

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
Use information technology and outside consultants (if necessary to study, plan, manage to optimize:
1. procurement
2. production
3. distribution
4. marketing
5. sales
6. accounting

WAYS TO DIFFERENTIATE:
1. establish strategy to better serve buyer value chain
2. focus on market segments
3. expand or decrease product scope
HUMAN RESOURCES MANAGEMENT

DESCRIPTION:
This activity includes the processes associated with managing the firm's employees.

(GENERIC CATEGORY: Human Resources Management)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. hiring
2. training
3. compensation

EXTERNAL PARTICIPANTS:
labor and management pools

INTERNAL PARTICIPANTS:
"personnel" department (usually a corporate officer)

HUMAN RESOURCES NEEDED:
recruiting, interviewing
training

EQUIPMENT NEEDED:
equipment for training

PHYSICAL PLANT NEEDED: None

FINANCIAL ASSETS NEEDED:
working capital for overhead

TECHNOLOGY USED:
training
compensation accounting

FACTORS IN COST BEHAVIOR:
capacity utilization: training equipment

linkages: training linked to production and sales

interrelationships: with packaging (capacity utilization and increased demand)

integration: with installation (capacity utilization and increased demand)
HUMAN RESOURCES MANAGEMENT, continued

timing: time of year impact hiring?

discretionary policies: compensation scheme, retainage, training

location: local labor pool

institutional factors: compensation scheme typical in industry

WAYS TO IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. compensation serves as incentive to production goals (speed and quality)
2. identify and provide necessary training to support production goals
3. hire in off-peak season

WAYS TO DIFFERENTIATE:
1. compensation oriented towards quality
2. good wages, benefits attract good people
3. establish various programs to "boost morale"
4. establish policies and other programs to minimize turnover
TECHNOLOGY DEVELOPMENT

DESCRIPTION: This activity refers to all devices and procedures that the producer uses throughout the operations.

(GENERIC CATEGORY: Technology Development)

LIST OF DETAILED ACTIONS THAT ARE NECESSARY IN THIS ACTIVITY:
1. Adopt information systems and communications technology in one or more activities or departments
2. Develop new technology in product
3. Adopt technology in production process

EXTERNAL PARTICIPANTS:
Buyers
Suppliers

INTERNAL PARTICIPANTS:
whoever deals with innovation, product development (corporate officers?)

HUMAN RESOURCES NEEDED:
able to analyze operations
monitor and evaluate technology in other industries
strategic planning
implementation of new technology

EQUIPMENT NEEDED:
PC and various software
telecommunications

PHYSICAL PLANT NEEDED:
Space for prototypes, testing

FINANCIAL ASSETS NEEDED:
working capital for technical development overhead
long term capital for expansion, changes in processes or products

TECHNOLOGY USED:
information systems
telecommunications
new materials

FACTORS IN COST BEHAVIOR:
economies of scale: important for all three activities
capacity utilization: ditto
linkages: production technology linked to supplier and buyer technology; information and communications technology linked to supplier and buyer information/communication technology.

interrelationships: with packaging (capacity utilization, economies of scale, and increased demand)

integration: in-house of contracted technology development? with installation (capacity utilization, economies of scale, and increased demand)

timing: may be significant first mover cost advantages

discretionary policies: general policies toward innovation and technology, environmental considerations, etc.

location: easier to adopt tech if near the source

institutional factors: environmental regulations, ban on CFC

IMPROVE LOW COST COMPETITIVE ADVANTAGE:
1. pursue tech in process that shifts cost drivers to those better suited for firm in long run

2. pursue tech in process that shifts cost drivers to those that the firm could exploit before other firms do

3. manage the learning curve associated with process technology

4. develop product or process to allow use of alternative suppliers

WAYS TO DIFFERENTIATE:
1. establish reputation as an innovative, forward-technology firm

2. establish reputation as firm that is environmentally sensitive through technology

3. develop products with innovative technology

4. raise quality, product line, or speed of delivery standards to establish entry barriers, prevent backward integration

5. pursue technological process or product to establish switching costs

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CHAPTER SIX: SUMMARY AND CONCLUSIONS

This chapter summarizes the discussions and methods of analysis used in each chapter and the possible actions that were identified. In addition, it is discussed how the overall method used in this thesis to examine foam panels could be applied to other components used in homebuilding.

CHAPTER ONE reviewed the history of prefabrication in residential construction. It showed how the attempts to revolutionize the housing industry through prefabrication of complete housing units in the factory have generally been one disappointment after another. HUD-Code (mobile) and modular homes have made some gains over the past fifteen years, but they clearly have not penetrated the market the way roof trusses have, nor do they seem to have the growth potential that other components have.

Two key factors contributing to components' economic and sales advantages over complete prefabricated systems are the technology used in prefabrication plants today and homebuyer preferences for flexibility in size, architectural styles and finishes. If technological advances in automated production equipment result in shifting the cost behavior drivers away from economies of scale and capacity utilization, factory production of complete or modular houses may become more cost effective, even in the face of continued cyclical demand.

Similarly, if homeowner demand for architectural flexibility should decrease and the last residue of bad taste that mainstream homeowners still have in their mouths towards the idea of manufactured houses, modular and mobile homes may indeed see a significant growth in sales. This is a distinct
possibility, it seems, in light of the growing portion of society that cannot afford to buy a first house.

Until (or unless) the changes just described occur, components will continue to dominate the prefabricated industry and play in increasingly important role in on site construction (called "production homebuilding" these days). It was mentioned in Chapter One that there has and will continue to be a substantial but not entire transfer of value from the jobsite to the production plant.

This partial transfer of value has several fundamental implications for participants and processes associated with the homebuilding industry. As discussed previously, quality, performance, and predictability are increased while costs and labor requirements are decreased, at least in theory. Accompanying the reduction in number and skill level of labor is a change in the traditional homebuilding trades. For example, not only will fewer and less skilled carpenters be required, they will not even be carpenters as we know them. Instead of carpenters that specialize in framing, one group of subcontractors will be floor, wall, and/or roof component installation technicians. This is already starting to occur with the installation of stresskin foam panels.

The transfer of value to the factory will have strategic consequences for other traditional organizations. Architects that specialize in residential design will need to be more aware of the performance and design considerations of components in general and for specific proprietary systems. The traditional lumberyard will become a less important part of the homebuilding chain unless they move into retailing or distributing components. The building inspection departments run by local governments will find it necessary to change their
inspection policies and procedures. The three national model building code agencies and state and local code departments will increasingly need to revise their codes to reflect the shift away from stickbuilt construction.

Significant changes will occur in a portion of homebuilders. The vast majority of innovative components and other homebuilding products still lack an effective infrastructure, i.e. insufficient or ineffective distribution channels, installation contractors, complementary products, etc. Many manufacturers offering an innovative product find it necessary to be involved in the installation process. Rather than formally vertically integrating into installation/contracting, manufacturers are forming closer, long term relationships with homebuilders than is common in construction.

The goals of these value-added partnerships are to reduce the homebuilder's risks while increasing his profits. Both goals are necessary step to facilitate the adoption of an innovation by homebuyers. Johnson and Lawrence used construction as an example of an industry that has always had value-adding partnerships. It is assumed they are referring to the slight decrease in the adversative behavior that results when a general and subcontractor develop a long term relationship. It is advocated here that changes must go must deeper than the relationships in conventional construction.

The fact that a greater portion of the homebuilding industry will involve manufacturing and be carrying high fixed costs has implications both for governmental housing policy and the nature of competition in homebuilding. Increased manufacturing

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combined with increased homebuyer demand for quality will result in increased brand name recognition and demand in components.

A model was introduced in Chapter One that described how a innovation is accepted in the component market. Specifically, it showed how the performance, costs, and present market share of a component is a result of factors that go well beyond the technological characteristics of the innovation.

This model explains why the costs, performance and market share of stresskin foam panels have yet to reach their potential levels. The theoretical superiority of the materials and design of panels have not resulted in costs lower than conventional roof and wall systems due to several factors: 1) the organizational and financial abilities of foam panel producers to apply technology to achieve an innovative product offering lower costs have been deficient, 2) the match between the cost behavior drivers of panel production and the actual characteristics of most producers has been poor due to cyclical demand, slow growth in the panel industry, insignificant economies of scale, inability to capture timing advantages, and little attempt to manage production to better match cost drivers, and 3) the differentiated nature of foam panels, specifically their high thermal performance and quick, relatively easy installation.

These same factors explain why the technical superiority of the materials and design of panels have not resulted in panel producers achieving the potential performance of panels.

The model also explains why the performance advantages that panels do offer have not resulted in significant market share. Factors in this area include: 1) a large but not obvious
relative advantage in performance, 2) an apparent disadvantage in costs unless life cycle costs are considered, 3) the fact that it is not easy for non-engineers to understand how stressskin panels function, 4) a significant cost to the homeowner and homebuilder if a panel failed, and 5) perceived switching costs by homebuilders.

Additional factors that have hampered the market share of panels relative to substitute wall and roof systems include: 1) buyers (both homebuilders and homeowners) that typically do not understand how an innovation can improve all aspects of their own value chains, 2) buyers that have a low propensity to change, 3) poor interfaces between manufacturers and distributors and installers, 4) the uncertainty about product quality and which core material is better, and 5) the concern over environmental consequences of urethane cores.

CHAPTER TWO introduced in detail the four roof systems commonly used in single family house construction: conventional rafter, precut rafter, truss, and foam panels. Besides being used to facilitate the analyses in Chapters Three, Four and Five, the background information presented on each system in Chapter Two can be used to create a two by two generic strategy matrix for the four roof systems. Two by two matrices are simplistic but useful tools that are commonly used by strategists to evaluate generic strategies.

As shown in Figure 20, conventional rafter systems are located in the upper left corner. They offer low cost and can be used to construct almost every conceivable roof. Precut rafter systems are almost opposite of conventional rafters, not due to their technological characteristics but to the way precut producers have brought them to market. Precut systems are
Figure 20: MARKET CHARACTERISTICS OF ROOF SYSTEMS

not low cost because the producers generally use high-quality lumber and package them as part of a high-end house. They are therefore not appropriate to a broad range of buyers since the majority of homebuyers are not interested in paying for the high quality. The market share of precut rafters is thus fairly low but their profit margin is often quite high.

Truss systems can be used in many roofs and usually cost even less than conventional rafter systems. Inasmuch as they also offer quick installation on site, they can be considered somewhat differentiated as well. Trusses' location on the matrix explains their large market share: They are acknowledged as a system offering a broad range of uses with both cost and
performance advantages.

Foam panels systems are even further from conventional rafter and truss systems than precut rafters. Like precut rafters, panels' position in the matrix is due not so much to their inherent characteristics as much as the way producers have marketed them, and--even more importantly--how they have been received by homebuyers. Panels are clearly differentiated from the other systems in their performance. Among their many advantages, they offer high thermal and sound insulation, quick installation, and vaulted ceilings. Yet due to a number of reasons discussed earlier, panels have yet to be embraced by a broad range of buyers. Instead, they have been considered a roof and wall system primarily for houses with post and beam framing. They are not considered low cost because the cost criteria is purchasing costs, not life cycle costs. The arrow in Figure 20 represents the direction that panels should move as the industry matures.

Chapters Three, Four and Five analyzed aspects of stresskin foam panels and suggested possible actions to lower their costs and increase their performance, profit margin, and market share. CHAPTER THREE introduced a framework for analyzing the technological aspects of a component. It was shown how cost and performance improvement in components over the past thirty years has been achieved through advances in six elements of prefabrication:

1. THE LOCATION OF THE WORK
2. THE AMOUNT OF MECHANIZATION AND AUTOMATION
3. THE RELATIONSHIP BETWEEN THE PARTS
4. THE MATERIALS USED
5. THE STANDARDIZATION OF INPUT NEEDED
6. THE STANDARDIZATION OF OUTPUTS
This framework was applied in detail to common roof systems to show how stressskin foam panels represent a significant improvement over conventional and precut rafter systems and truss systems. Potential ways to improve the cost and performance of foam panels were suggested by identifying how further advances could be made in each of the six elements of prefabrication. They are recapped here.

1. The amount of work on site could be reduced further through several changes: a) by improving the structural performance of the panels, thereby reducing the amount of framing material needed, and b) by applying one or more finishes in the factory (e.g. shingles or some other roofing material). Buyers may be more apt to accept a narrower range of available exterior finishes than interior finishes. Reduced on site work should decrease costs and the overall completion time, which should increase panel's market share.

2. The level of automation used in the factory could be increased. This should increase quality and, if both economies of scale and production volume sufficient to exploit the economies of scale are present, lower costs. Both increased quality and decreased costs should result in increased market share.

3. The degree of system integration could be increased, such installing improved utility chases in the factory and reducing the number of parts required at joints. Again, this should decrease costs and completion time, thereby increasing market share.

4. New core materials could be developed that offer equal or higher thermal performance, a lower cost, and no damage to the environment or concerns about fire safety. Increase market share could result from the eliminating the uncertainty or
negative attitudes associated with the urethane and polystyrene foams.

5. Increasing the cost flexibility of the input materials, that is, expanding the range of material sizes and characteristics that are cost effective to use in production could reduce costs, thereby stimulating market share. One likely means of expanding input flexibility is through advancements in automation,

6. Increasing the cost flexibility of output could reduce costs, increase the structural performance and architectural flexibility, and expand the customer base.

CHAPTER FOUR summarized Porter’s framework for analyzing the structure of an industry. A structural analysis of the foam panel industry was conducted, which identified some of the reasons why foam panel’s technological superiority over alternative roof systems has not resulted in the maximum profit margins or market share. Specifically, it was discussed how the panel industry is subjected to significant competitive pressure from a high intensity of rivalry, a high threat of entry into the industry, tremendous pressure from substitute roof systems, and substantial supplier power. Further, the market share of panels has been hampered by the effects of being a fragmented and emerging industry.

Possible ways of lowering production and sales costs and increasing margins and market share were suggested. These suggestions were based on reducing the competitive pressures identified above and countering the negative effects of the industry’s fragmentation and lack of maturity.

7. The competitive pressure of a high intensity of rivalry and the negative effects of being an emerging industry could be
reduced through individual firms aggressively stimulating industry growth, rather than just their own market share. One of the most promising ways to accomplish this was an industry trade association, similar to the American Plywood Association. Industry-sponsored research could be a cost-effective way to reduce costs and improve performance. Joint efforts to increase buyer awareness of panels' advantages and reduce buyer uncertainty, thereby increasing market share against substitute systems.

8. The threat of entry could be reduced by raising the barriers to entry for undesirable entrants. Possible means of raising barriers include raising the level of fixed costs required to compete through development of improved joints or panels protected by proprietary technology, exploiting economies of scope and scale if they exist, and raising switching costs by offering discounts to long-term buyers. These actions all probably impossible for most firms since they are quite capital intensive. A possible action to raise entry barriers that would not require excessive expenditures by individual firms is to establish high industry quality standards. Again, an industry trade association might be the best vehicle to accomplish this.

9. The competitive pressure resulting from substitute roof systems could be reduced through some of the same actions to reduce the intensity of rivalry and threat of entry. Increased consumer knowledge and valuation of the performance advantages that panels offer is essential. Panel producers should therefore focus on consumer segments who are most likely to value panels' performance. Most producers already seem to be focusing on a narrow group of homebuyers, but have yet to successfully target homebuilders. It is still necessary to reduce builders' perceived switching costs and uncertainty
about whether installing panels instead of stickbuilt construction will provide them with a competitive advantage.

CHAPTER FIVE summarized Porter's framework for analyzing a firm's value chain in order to improve its competitive advantage. A broad value chain analysis was performed for a hypothetical panel manufacturer. The sequence of events and needs of the firm's two main buyer groups were considered, followed by a detailed analysis of each of the producer's activities.

Figure 21 represents a panel producer's generic value chain with the above activity titles instead of Porter's generic category titles. Also, the size of each activity reflects the importance of the activity for the producer's success.

The following information was identified for each activity:

a. description of the actions
and procedures were established under different operating conditions and no longer provide sufficient benefits to outweigh the added costs.

14. A producer should investigate all the actions that might result in sustainable cost reductions. The sample analysis identified some (but certainly not all) possible changes. These are listed on the bottom of each activity analysis sheet.

The four suggestions above should achieve lowered costs and, to some extent, improved performance. These improvements should then result in increased margins and market share. There are also several possible actions to achieve increased margins and market share that may not reduce costs.

15. A producer should investigate activities in which he could improve the value chain of other participants in the value system--such as suppliers, distributors and buyers--by identifying and managing linkages.

16. A producer should investigate all the actions that might result in cost-effective, sustainable differentiation. The sample analysis identified some possible actions. These are listed on the bottom of each activity analysis sheet.

The second group of suggestions were strategic moves that would encompass several or all activities that the panel producer performs. Again, several of these suggestions tend to be general management guidelines that are facilitated by a value chain analysis. All of the "macro level" changes except the first one should raise margins and market share, not only because they should reduce costs, but because they may be effective ways of differentiating the firm, thereby allowing a price premium to be charged.
firm's production characteristics in the activity. Most activities will require macro changes to improve the match up; some will not. For example, if it is identified that learning is important cost driver in an activity, is sufficient management attention being paid to monitor and control the learning? For activities with cost drivers that cannot be improved, management should consider contracting out the activity.

Figure 22: POSSIBLE USES OF INFORMATION TECHNOLOGY WITHIN AND BETWEEN ACTIVITIES

13. A producer should look hard at each discretionary policy that affects the cost behavior of an activity. Many policies
b. internal and external participants involved
c. human resource, equipment, physical plant, and financial assets needed
d. technology involved
e. cost behavior drivers
f. ways to achieve low cost advantage
g. ways to differentiate

This information was used to suggest various actions to reduce the costs and increase the performance, margin and market share of panels. Two groups of actions were suggested. One group considered improvements in individual activities. The other group included strategic "macro" moves associated with the panel manufacturer's value chain.

Most of the suggestions for individual activities were common sense management guidelines rather than revolutionary concepts. It should not be overlooked, however, that the value chain analysis is a crucial and effective step for gathering the information that makes it possible for management to apply the guidelines. Some of the suggestions are given below.

10. A producer should ensure that the appropriate number and type of resources are present within the organization and are being effectively applied.

11. A producer should explore ways that technology, particularly information technology and automation could improve the way an activity is performed, particularly if the activity is linked to another activity. Figure 22 indicates some of the activities that could be improved through the use of information technology.

12. A producer should consider ways to improve the match up between the cost drivers of an individual activity and the
17. A producer should consider whether any operating strategies conflict with other operating strategies or with the overall strategy. A value chain analysis facilitates this process by forcing management to identify discretionary policies and other aspects of operating strategies evident in individual activities.

18. A producer should evaluate which market segments cost less to serve, either because the buyers require less sales and overhead expenses or they allow the producer to improve their match with cost drivers. For example, large homebuilders may be more desirable because they require low design and sales time for the volumes they purchase and tend to be less seasonal in their purchases, thereby allowing a better match up with the capacity utilization cost driver. (On the other hand, large firms may be less desirable than small homebuilders due to the large firm’s higher buyer power.)

19. Similarly, a producer should evaluate which market segments better match up to the producer’s assets, strengths and overall strategy. For example, a producer with little ability or inclination to be a leader in technology development should not pursue buyers seeking to buy panels with state of the art design and materials. Such a poor match up would result in high sales costs with unsatisfactory results. Another example of a poor match up is a producer who emphasizes low cost, no frills panel sales pursuing homeowners who need extensive service throughout the sales and installation processes.

20. A producer should evaluate whether the firm’s product line and product scope could be expanded or shifted. Two benefits could result if effective changes are made in these areas. First, desirable market segments could be better targeted.
Second, the producer may be able to achieve a better match up with industry cost drivers.

For example, expanding the product line to include thermally broken headers (structural beams over doors or other openings in walls or roofs) would better appeal to homeowners or homebuilders looking for accessory products. Further, if headers could be produced using the same equipment as that which produces the basic panels (and take up relatively little storage space), the firm's match up to capacity utilization could be improved by producing headers during off-peak periods.

Offering formal construction supervision is an example of expanding the product scope. Many firms presently retain some capability to oversee at least the first day of installation by an inexperienced installer, such as homeowner doing the work himself. Economies of scope and an expanded customer base might result from offering full time supervision throughout the installation process.

21. Finally, a producer should consider ways to reconfigure his value chain that might result in substantial competitive advantage. As stated in Chapter Two, most panel producers started out as homebuilders. Many established the boundaries of their own value chain around panel production only because of the need and desire to concentrate on one type of operation. Forward or backward integration to exploit interrelationships, linkages, and integration cost benefits may be more viable than indicated by the numbers of panel producers that have already done so.

Significantly increasing and improving the ways panel producers interface with buyers could also result in reconfiguring the value chain. As has been the case with many other industries,
Manufacturer Value Chain

General and Administrative Overhead
Human Resource Management
Technology Development
Order Raw Materials and Supplies
Receiving and Pre-Production Storage
Basic Panel Production
Custom Panel Production
Marketing and Sales
Transportation to Jobsite
Service

Homebuilder Buyer Value Chain

General and Administrative Overhead
Human Resource Management
New Job Development
Order Materials and Supplies
Material Pick up and Receiving
Perform Construction
Oversee Sub-contractors
Sales
Warranty work

arrows represent possible linkages with homebuilder as a means of differentiation

Figure 23: POSSIBLE LINKS BETWEEN PANEL PRODUCERS AND INSTALLERS
information technology may be the vehicle to make these sort of changes. Figure 23 represents the generic value chain of a typical homebuilder buyer of foam panels and the activities that could be improved by linking with the panel producer via information technology.

**SUMMARY**

Stressskin foam panels are an innovative component that have potential for substantial market share in residential construction. A portion of their potential results simply from the fact that panels are components, which are expected to play an increasingly dominant role in residential construction. More importantly, foam panels offer a greater potential for reducing costs and increasing performance than other components, as evidenced by high levels in most of the six elements of prefabrication identified in this thesis. Finally, the two major aspects of performance in which panels are superior to other components--high thermal performance and fast installation time--should grow increasingly important to homeowners and homebuilders alike.

Achieving the potential growth and market share, however, will not be easy for panel producers. Residential construction is an industry characterized by risk-adverse buyers who often do not place a high value on an innovation offering superior performance. The fragmented nature and strong competitive forces present in the industry will also hamper panels' growth. Finally, many producers of foam panels lack experience and knowledge in activities that are essential if the commercial and technical characteristics of panels are to be improved.

For the cost, performance and market share potential of panels to be realized, five sets of actions must be taken. First,
producers must make improvements in the panels themselves, i.e. in the materials and design of the panels. Second, producers must make both cost reduction and differentiating improvements in the production, marketing and installation processes associated with panels. Examples of improvement in production include increased automation, improved cost accounting, and management of key cost drivers such as learning, linkages, and capacity utilization. In areas other than production, producers should explore ways to better serve the value chain of homeowners and homebuilders. Third, producers must target buyers and make extraordinary efforts to educate them on panels' performance and life cycle costs advantages. Fourth, producers must raise production and installation quality by establishing industry standards. Fifth, producers must aggregate the market to support the high fixed costs that will result from improvements in the product and processes.

These five sets of actions will be extremely difficult, if not impossible, for the vast majority of individual panel producers as they now operate. Three fundamental changes will be necessary in the industry. First, producers must start taking strategic actions as an industry, not as individual competitors. An industry trade association would be an important vehicle for bringing about this change. Second, producers must start to look outward for help in specific areas. Strategic partnering for technical expertise and capital will become critical. Potential partners may include present suppliers and large corporations not presently in the residential components industry. In addition, management, technical and even public relations consultants may be needed. Third, like many other American industries, panel producers must adopt an outlook that emphasizes long term development rather than just short term responses to the immediate environment.
INTRODUCTION
A cost study of four existing roof systems was conducted over the past year in conjunction with a joint industry/MIT development of an improved roof panel system. (The group developing the new system will hereafter be referred to as "the Consortium"). The primary purpose of the study was to determine 'benchmark" costs, that is, figures that would serve as target costs for a new system. It was assumed that buyers would not be willing to pay significant additional costs for improved performance; thus, the cost of a new panel system would have to be competitive with existing roof systems.

A secondary objective of the study was to gain insight into the relationship between cost and architectural complexity for each system. The degree of architectural complexity of a roof is determined by the number of surfaces, their pitches, and the number of hip ends, valleys, and dormers. It was acknowledged during the design stage of the study that complexity has a direct bearing on roof costs, although the exact relationship is not known.

METHODOLOGY
The need for benchmark data was established shortly after it was decided that the Consortium would pursue development of an improved panel system. Approximate costs of existing roof systems were soon identified; however, members of the Builders Advisory Committee felt that more accurate numbers were needed. A more rigorous cost study was devised by a graduate student and a Research Associate after brief consultations with members of the group.

It was thought necessary to ensure that all cost estimates in this more rigorous study were based on the exact same designs to allow meaningful comparison between the various systems. Three typical designs were drawn up, each representative of a different level of roof complexity [Exhibit 1 indicates the intermediate level of complexity]. While not typical of most existing homes, the designs included the requirement for the attic space to be "habitable." That is, the space under the roof had to have a finished ceiling at least 7’ high.

The three designs were part of a package sent out to a group of firms associated with MIT. The group consisted of a truss manufacturer, two homebuilders who manufacture their own trusses, a producer of precut homes that includes precut rafters, and a manufacturer of foam panels for walls and roofs. The two homebuilders generally produce large runs of fairly
standard trusses. The other three firms routinely produce roof systems for both custom and standard designs. Each firm was requested to develop a cost estimate for producing the three designs included in the package. In an attempt to facilitate the analysis and comparison of the data, the packages also included templates that specifically indicated how the data should be broken down. As shown in Exhibit 1, forty-two categories were identified. Each category was grouped under one of four chronological stages: Design, Manufacturing, Transportation, and Installation.

Manufacturers were requested to identify for each category manhours and costs, as well as the factors that influenced these costs, e.g. design parameters, grades of materials used, and the quality of the end product. It was requested that the data be compiled and returned to MIT for analysis within thirty days. Assistance in compiling the data was offered to the firms since it was recognized that not all the data would be readily available.

PROBLEMS
The graduate student who had initiated the study left the Consortium shortly after distributing the cost study packages. The author was assigned to complete the study. Problems with the cost study packages appeared immediately. The sketches had conflicting dimensions. The amount and type of habitable space in the attic were not clear. Once the amount and type were made clear, the truss manufacturers pointed out habitable space required attic trusses, which comprise less than two percent of their total production, are much more expensive than standard King Post or W trusses, and would require approximately twenty manhours just to design the trusses for the three roof designs. One of the truss homebuilders indicated they do not manufacture hip trusses since they do not build houses with hip roofs. Finally and most importantly, none of the five firms could provide the level of cost breakdown that was sought. They could provide accurate estimates of in-plant material costs and transportation costs, but did not have job costing accounting systems that kept track of labor and overhead costs to the degree of detail desired. Further, they were unwilling to expend the effort to breakdown costs manually.

Revised packages were sent out that included corrected sketches of the designs, simplified categories for breaking the costs down, and a detailed list of items that were to be considered a part of the roof system [see Exhibit 2]. Each plant was then visited at least once to gain insight into production operations and to encourage completion of the study.

Note: The lack of sophisticated cost control systems were
surprising given the author's assumptions about the housing component industry. For example, it was assumed that detailed knowledge of fixed and operational costs was required to survive in a cyclical industry with traditionally tight margins on standard products. It was also assumed this detailed knowledge was necessary to provide realistic quotes for the custom designs. Furthermore, it would seem necessary for both standard and custom designs to be able to provide realistic installation costs to the occasional homeowner who approached the manufacturer directly. Since all of the firms surveyed are well-established firms who seem to consistently earn satisfactory profits, it appears that one or all of these assumptions are invalid.

DATA
Completed packages were received from the precut rafter producer and the panel manufacturer. This data was adjusted by adding or subtracting cost items as necessary to ensure all cost estimates were based on exactly the same scope of work. The estimates were then returned to the firms for their review. The cost of a hip truss package was received from one of the truss homebuilders after the requirement for habitable space was dropped; however, the package did not include breakdown production costs, only total production costs and an approximate sales mark up rate.

Because the sample group did not include a homebuilder who installed conventional rafter systems, the estimate for this system was performed using 1989 Residential Cost Data from the R.S. Means Company. In addition, the Means data was used to estimate a truss system for the simple design only. It was not possible to use Means to estimate the intermediate and complex designs as their data does not include hip trusses. The city cost index for Worcester, Massachusetts (1.10) was used to adjust the cost of each item. Means data was also used to estimate the cost of items not included in the data from the three firms but necessary for equal comparisons.

Exhibits 3, 4, 5 and 6 detail the cost data collected for the conventional rafter, precut rafter, truss, and stresskin foam panel systems, respectively. The ranges of total costs per installed square foot identified for roofs of varying architectural complexity were as follows:

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>SIMPLE</th>
<th>INTERMEDIATE</th>
<th>COMPLEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional rafter</td>
<td>$4.78</td>
<td>$5.72</td>
<td>$6.08</td>
</tr>
<tr>
<td>Truss</td>
<td>$3.82</td>
<td>$4.84</td>
<td></td>
</tr>
<tr>
<td>Precut rafters</td>
<td>$7.75</td>
<td>$8.36</td>
<td>$8.76</td>
</tr>
<tr>
<td>Foam panel</td>
<td>$5.30</td>
<td>$7.06</td>
<td>$6.90</td>
</tr>
</tbody>
</table>

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As indicated, the truss costs are for roofs of simple and intermediate complexity only. Truss design and manufacturing is such that a trussed roof for the complex design would have been prohibitively expensive. In other words, truss systems are not used for roofs with varying pitches, numerous dormers, and other than the standard gable ends. As noted earlier, it was not possible to even obtain an estimate for the complex design as it would have required an excessive number of manhours spent on engineering time alone.

It should also be noted that these costs may not represent the costs of an entire roof system, depending on how the roof system is defined. The scope of work items included in the study [see the second page of Exhibit 2] was designed to capture all possible differences between the four systems, not to capture every conceivable cost above the walls. For example, the cost figures above do not include end wall framing or roof trim, which are often included in a systems estimate of roof costs.

DISCUSSION OF RESULTS
COMPARING COST CATEGORIES FOR AN INDIVIDUAL SYSTEM:
For all four systems, the total costs per square foot of roof for the intermediate design were significantly higher than for the simple design. This fact reflects the increased labor hours and waste materials required to produce a roof shape with significantly more surfaces.

Precut Rafter System: The total costs for the precut rafter complex design were higher than for the intermediate design, but not substantially so. The increased labor hours and waste materials required to produce a roof with even more surfaces were apparently somewhat offset by the significant increase in roof surface area.

The total labor costs for the precut rafter system increased faster than did the total material costs. This fact is probably a result of an inherent deficiency of precut systems. Increasing the complexity of a roof increases the number of differing parts. For example, the framing for a gable end roof consists mostly of identical common rafters. The framing of a hip end roof consists of many pairs of hip jack rafters, each pair with a different length. The time it takes on site to inventory and sort the entire kit at the beginning of construction, then find the proper piece during each stage of the installation, seems to increase exponentially with the number of differing parts.

Foam Panel System: The design/engineering costs for the foam panel system increased significantly between the simple and
intermediate designs, reflecting the engineering time necessary to determine if additional framing is necessary at dormers, hip ends, etc. The manufacturer's labor costs are also substantially higher for the intermediate roof than for the simple roof due to the extensive custom cutting required for the more complex shape. The installation costs per square foot of roof were actually lower for the complex roof than for the intermediate roof. This surprise resulted from the pricing policy of the specific panel producer studied. The producer pays their subcontractors a set rate per square foot of roof and per linear feet of framing materials, regardless of how complex the roof shape is.

COMPARING COST CATEGORIES BETWEEN SYSTEMS:
Exhibit (7) summarizes and reorganizes the data in Exhibits (3) through (6) to allow side by side comparison of the cost groups for each roof design. The results in some of the categories are worth noting.

The first three categories--manufacturer materials, labor and overhead/profit--represent the value that occurs in the factory. The truss system should have had numbers for these categories since a significant portion of the total value of a truss roof occurs in the truss plant. As mentioned previously, it was not possible to obtain a breakdown of the truss production costs.

Manufacturer Overhead and Profit: Although not indicated on Exhibit (3), the Contractor's overhead and profit in the Means conventional rafter estimate was approximately 23%. Not surprisingly, the precut rafter and panel producers have significantly higher combined overhead costs and profit--both around 50% of their production costs.

While it was not possible to determine whether either the precut or panel producers had higher profit margins than either conventional rafters or trusses, three areas that contribute to higher overhead rates could be identified. The first area is fixed costs associated with the production equipment. For example, the production equipment and physical plant of one of the foam panel producers initially cost over $1,000,000. The second area is the extensive marketing that the precut and panel producers undertake. For example, the precut rafter producer recently built a sales model for which the land alone cost over $200,000. Marketing and overhead costs such as these are rarely incurred even by the largest conventional homebuilders installing rafter or truss systems. The third area is personnel and other costs associated with providing customer services not offered by the typical conventional homebuilder, such as detailed custom design.
Transportation: The costs for transporting the materials for the truss and conventional rafter systems are included in the contractor materials category.

Contractor Labor: Since portions of the labor for the precut and panels systems are performed in the factory instead on the jobsite, one would expect that the contractor labor costs for these systems would be considerably lower than for the conventional rafter and truss systems. This was not the case. One possible explanation may be differences in performance and quality. The precut rafter producer studied provides 2x10 rafters in all of their houses while the Means estimate assumed 2x8s. Installing larger rafters contributes slightly to higher costs. Having all rafters precut at the design lengths and angles requires precise, quality installation of both the walls and rafters, i.e. installation is slower so labor costs are higher. This factor is similar but not the same as the inherent deficiency of precut systems discussed earlier. In addition, there may be costs resulting from other quality aspects that were not identified.

Total Materials: The total material costs for the precut rafter system was slightly lower than for the conventional rafter system. Apparently, the higher costs of the precut system's better quality lumber was offset by volume purchasing and reduced wastage. Despite the fact that foam panels provide superior thermal performance, the total material costs for the panel system were significantly lower than the other systems. This is probably a result of panels being an integrated system, i.e. there are fewer separate pieces composing the system.

Total Labor: The total labor costs for the truss system were substantially lower than the other systems. One explanation for truss labor costs being lower than precut rafter and panel labor costs is that trusses systems are more mature and common than either precut or panel systems. Truss producers are much farther down the learning curve than panel producers and there are many more contractors willing to install truss roofs than precut rafter or panel roofs. Truss systems have lower total labor costs than conventional rafter systems due to the fact that trusses are fabricated in a factory and are inherently more efficient in their use of materials.

Total labor costs for the precut rafter system was significantly higher than the conventional rafter and the panel systems as a result of the inherent deficiency discussed previously. One might expect the total labor costs of panels to be significantly lower than for conventional rafters since a portion of panel systems occur in the factory. This was not the case, probably due to panels' superior thermal performance.
DATA ACCURACY:
To determine whether the cost data collected is sufficiently
correct to serve as target costs for a new panel system, three
questions should be asked: 1) Is the data representative of
the firms' actual costs/prices for the precut rafter, panel,
and truss systems? 2) Are these costs/prices representative of
the costs/prices of each system across the country? 3) How
accurate need the data be?

The first question can be answered with guarded confidence. As
noted above, most data was based on educated estimates, not the
results of detailed job costing systems. (The data for con-
ventional rafters was detailed but is still an estimate.) It
is the author's perception that for all systems studied the
total costs are within ten percent of actual, while the cost
for any individual category (for example, manufacturer overhead
and profit) is within twenty percent of actual.

With respect to the second question--whether these costs are
typical of similar systems across the country--it is believed
that most of the costs are slightly high. Inasmuch as experi-
cenced estimators agree that Means cost data runs 5-15% higher
than typical bids, the conventional rafter costs are probably
around 10% high. Since the Means data was used to estimate
roughly one-half of the truss system, the truss system costs
may be as much as 8% higher than average market prices. The
panel prices were confirmed by surveying prices lists for basic
foam panels across the country. The precut rafter costs may be
as much as twenty percent higher than typical precut systems as
the producer providing the data for the study has a strong
reputation for producing quality precut home packages.
Obviously, it would be desirable to obtain additional data for
each system from more firms, particularly some firms located
outside the New England region. Construction costs in the
Northeast are generally among the highest in the nation.

The answer to the third question--how accurate the data should
be--depends on, among other things, the Consortium's ability to
predict the eventual costs of the panel system being developed.
Development of the system design and the innovative core and
face materials are still in the early stages. It is the
author's opinion that the perceived accuracy of the data
obtained in this study is sufficient for the Consortium's use
at this time.

USE OF THE DATA AS BENCHMARKS:
Using the data obtained in this study to establish target costs
for a new panel system is probably not as simple as originally
envisioned by the Consortium. Determining which total system
costs should serve as the benchmark depends on what assumptions
are made in key areas of market analysis. Three areas will be
discussed below: industry price structure, the scope of the product, and expected consumer behavior.

1) Industry Price Structure: One could assume the present pricing structure as investigated in this study. Alternatively, one could assume a pricing structure that might be established by producers of existing systems if an inexpensive, high performance cementitious foam panel was successfully introduced such that competitors were forced to lower their prices. Another possibility would be to assume a pricing structure that might result if improvement were made in existing systems in areas such as purchasing, design, production, installation, ability to aggregate volume, etc. The author does not have sufficient knowledge of the industry to discuss possible cost reductions resulting from improvements in each of these areas.

2) Scope of the Panel System: As discussed in Chapters Three and Four of the thesis, there are two general aspects of a product's scope: the scope of the physical product and the scope of services. Possible changes in both aspects were discussed in Chapters Three and Four. The reductions in costs for the producer and installer that would result from each of the possible changes would depend on how the change influenced the new system's match up to the cost behavior drivers introduced in Chapter Five.

3) Buyer Behavior: The main assumption in this area is how many buyers would perceive the performance advantages that an improved panel system would offer and be willing and able to pay more for them? (The issue of performance versus market share was briefly discussed in Chapter One.) While it is assumed that the goal of the Consortium is to develop a new panel system that can achieve a high annual sales volume, since dramatic increases in new housing starts are not expected in the near future, achieving a large sales volume will necessitate a high market share. In other words, the Consortium must produce a panel that homebuilders and homebuyers will choose over existing roof systems.

As discussed throughout this thesis, unless producers of a new panel system are successful at differentiating the new system, the vast majority of buyers will not accept the new panel system unless the cost is below or equal to the cost of its competitors. A new panel system must therefore not cost more than the total cost of the least expensive system identified in this study. The benchmark cost for a roof of intermediate complexity would be $4.84 per square foot for an installed roof.

Producing a new panel system with an installed price of $4.84/SF—even using panels with an inexpensive core such as a
cementitious foam—will be difficult unless significant reductions occur in other areas. Of the $7.06 total panel costs identified in this study, approximately $2.56 represents direct production costs of the panel to the consumer. The remaining costs of $4.50 ($7.06−$2.56) represent production overhead and profit ($0.66), transportation ($0.21), finish and accessory ($1.09), and installation costs ($2.55). Even if the direct and overhead production costs was reduced to by $2.22 per square foot and the panels were sold at $1.00 per square foot, the new system would still cost more than conventional rafter or truss systems unless reductions occurred in the transportation, accessory and installation costs.

It is unlikely that transportation or accessory and finish costs will decrease significantly. Growth in the total volume of panel sales might result in slight decreases in transportation costs, but would probably not affect the costs of purchasing finish materials (such as shingles and drywall) or accessory materials (such as foam sealant). Significant reductions in finish and accessory costs would require the improved panel system to be substantially different from existing foam panels, such as a vastly improved joints or changing the scope of the panels.

On the other hand, growth in the total volume of panel sales and expansion of the limited sales and installation network may result in significant reductions in installation costs. Expanding the number of subcontractors willing to install panel houses should eliminate the need for the crew travel expenses. Further, the prices that present installers charge should be reduced as more contractors bid for panel work and charge less of a premium to cover the uncertainty associated with installing an innovative system.

The discussion above would not hold true if manufacturers and/or distributors were able to successfully differentiate the new system such that even buyers in the Starter and Move-Up market segment chose the panels over less expensive roof systems. As discussed in Chapters Five and Six, differentiation could take the form of increasing consumer awareness and appreciation of panels performance advantages, changing the scope of the panels, improvements in the sales and distribution processes, etc.

COSTS VERSUS COMPLEXITY:
The data does provide some general insight into the relationship between roof costs and the degree of architectural complexity. As indicated on Exhibit 7, the costs per square foot increased at approximately the same rate going from simple to intermediate complexity for all systems except the foam panel system, which increased at a higher rate than the others.
Comparing the rate of increase of the three prefabricated systems going from the intermediate to the complex designs, the precut rafter system again increased at approximately the same rate, the truss system increased at a much higher rate, and the foam panel system actually decreased for the reasons discussed previously. It should be noted, however, that a line drawn directly from the costs for a simple design to the costs for a complex design for foam panels is still steeper than the line for conventional rafter system. Thus, while it is apparent that the each of the three prefabricated systems differed in how their costs increased going from the intermediate to the complex design relative to the conventional rafter system, none of the prefabricated systems overall are more cost-effective relative to conventional rafters at higher levels than at lower levels of roof complexity.

**SUMMARY AND CONCLUSIONS**

A study was conducted to determine the typical costs of four types of roof systems: conventional rafter, truss, precut rafter, and foam panel. Data was obtained from several New England firms associated with MIT. Although the data may not be as accurate as desired due to the fact that the firms did not have detailed job costing systems, the results provide useful estimates of existing roof systems. The costs obtained in the study ranged from $3.84 to $8.76 per square foot of installed roof, depending on the type of roof system and the degree of architectural complexity. Conventional rafter and truss roofs were found to be considerably less expensive than precut rafter or foam panel roofs; however, the latter two systems provide significant performance advantages. The costs per square foot of roof for each of the three prefabricated systems increased with increasing roof complexity at a rate equal to or exceeding the rate of conventional rafters.

It was concluded that using data obtained in the study to establish benchmark costs for a new panel system depended primarily on whether the targeted market segment would recognize the performance advantages provided by the panel system. It was further concluded that an innovative panel system, which offers equivalent or superior performance to existing stresskin foam panels but costs less due to the use of innovative materials, will still cost more than typical conventional rafter and truss systems unless significant reductions can be achieved in the accessory and installation costs.
LIST OF EXHIBITS

1) sketch of intermediate roof from original cost study package
2) revised cost study package
3) cost data for conventional rafter system
4) cost data for truss system
5) cost data for precut rafter system
6) cost data for stresskin foam panel system
7) summary spreadsheet and graph to allow comparison
8) lessons learned
CASE 2: INTERMEDIATE

- 8/12 Roof & Turn Gable Pitch
- 12/12 Dormer
- 1 foot Eave on 2 sides &
- 1 foot Rake for Turn Gable
CASE II INTERMEDIATE:

STAGE ONE (DESIGN):

<table>
<thead>
<tr>
<th>Cost (Type)</th>
<th>Item/ Remarks</th>
<th>Manpower</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td>Equipments, Rent, Management, Administration,...etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Costs</td>
<td>Schematic Design (architectural).</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Engineering Design.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shop and Field drawings.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Meetings.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Modifications and Developments.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Others Costs (Specify).</td>
<td></td>
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</tr>
</tbody>
</table>

STAGE TWO (MANUFACTURING):

<table>
<thead>
<tr>
<th>Cost (Type)</th>
<th>Item/ Remarks</th>
<th>Manpower</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td>General Administration.</td>
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</tr>
<tr>
<td></td>
<td>Management.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Equipment.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Costs</td>
<td>Labor;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1) Handling (raw materials)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cont'd.

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3 Fixed Costs is expressed as the cost of an item, e.g. rent or equipments divided by the Amortization (annual payments) to find the fixed annual costs. Dividing this cost by the number of jobs finished each year, the cost is expressed as follows: (Cost/ Amortization). # of Jobs annually
Contd.

<table>
<thead>
<tr>
<th>Cost (Type)</th>
<th>Item/ Remarks</th>
<th>Manpower</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2) Cutting.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Handling (processed materials).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Assembly.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Packaging.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Others (Specify).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Materials ;
  1) Lumber.
  2) Plates.
  3) Fasteners/ Hangers/ Flashing.
  4) Sheathing.
  5) Felt and Shingles.
  6) Insulation.
  7) Cull and Waste.
  8) Others (Specify).

- Special Storage Facilities ;
  1) Raw Materials.
  2) Finished Parts.
  3) Management.
  4) Others (Specify).

STAGE THREE (TRANSPORTATION) :

<table>
<thead>
<tr>
<th>Cost (Type)</th>
<th>Item/ Remarks</th>
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<tbody>
<tr>
<td>Fixed Costs</td>
<td>(Specify if Rented or owned)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
  - Loading and Packaging.
  - Banding materials.
  - Delivery.
  - Others (Specify).

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STAGE FOUR (CONSTRUCTION/ ASSEMBLY):

<table>
<thead>
<tr>
<th>Cost (Type)</th>
<th>Item/ Remarks</th>
<th>Manpower</th>
<th>Cost ($)</th>
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</thead>
<tbody>
<tr>
<td>Fixed Costs</td>
<td>• Equipments.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Working Capital.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Others (Specify).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Costs</td>
<td>• Labor;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1) On-site Preparation.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) Skilled/ Unskilled Labor Ratio.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3) Waste.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4) Others (Specify).</td>
<td></td>
<td></td>
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</tbody>
</table>

GENERAL REMARKS:
EXHIBIT 2
EXPLANATION OF ROOF SYSTEM COST/PRICE BREAKDOWN

ENG/DSGN = TYPICAL COST OF ENG. AND DESIGN EFFORT ON ROOF.

PRODUCTION:
MATERIALS = COST TO YOU OF ALL MATERIALS INVOLVED IN PRODUCTION.
LABOR = PLANT LABOR COSTS + FRINGE BENEFITS, WORKMAN’S COMP. AND OTHER BURDEN.
OH—PLANT = OVERHEAD FOR PHYSICAL PLANT AMORTIZATION.
OH—MGT/ADM = OVERHEAD FOR MANAGEMENT, ADMINISTRATION AND MARKETING.
PROD COST = MATERIALS + LABOR + OVERHEADS.
PROFIT = PROFIT ON PRODUCED GOODS.
PROD PRICE = PRICE OUT THE DOOR TO OWNER OR GENERAL CONTRACTOR.

TRANSPORTATION:
TRANS.CO. = AMOUNT PAID TO TRANSPORTATION CO. OR AMORTIZED COST OF TRUCK + FUEL, DRIVER, ETC. IF YOU DO YOUR OWN SHIPPING.
ASSUME 150 MILES.
OH—MFR = OVERHEAD TO YOU ASSOCIATED WITH SHIPPING, IF ANY.
TRANS COST = SUM OF ABOVE TWO ITEMS.
PROFIT—MFR = PROFIT TO YOU ON SHIPPING, IF ANY.
TRANS PRICE = TRANS COST + PROFIT—MFR.

ON SITE: (NOTE: M=YOUR FIRM, K=CONTRACTOR)
M MATLS = ADDITIONAL MATERIALS NOT INCLUDED ABOVE.
M LABOR = DIRECT LABOR COST + BURDEN FOR ON-SITE INSTALLATION.
M EQUIP = AMORTIZED OR RENTAL COST OF EQUIPMENT USED ON SITE BY YOUR CREW.
M OH = OVERHEAD ASSOCIATED WITH ON-SITE WORK.
M COST = M MATLS + M LABOR + M EQUIP + M OH.
M PROFIT = PROFIT ON ON-SITE WORK.
M PRICE = M COST + M PROFIT = AMOUNT CHARGED TO OWNER.

K MATLS = MATERIALS PROVIDED BY AND INSTALLED BY CONTRACTOR.
K LABOR = ALL LABOR ON SITE BY CONTRACTOR, REGARDLESS OF SOURCE OF MATERIALS.
K EQUIP = AMORTIZED OR RENTAL COSTS OF ALL EQUIPMENT USED BY CONTRACTOR.
K OH = FIELD AND HOME OFFICE OVERHEAD OF CONTRACTOR.
K COST = K MATLS + K LABOR + K EQUIP + K OH.
K PROFIT = PROFIT ON ABOVE ITEMS.
K PRICE = K COST + K PROFIT = BID TO OWNER.

CONTINUED
EXPLANATION OF ROOF SYSTEM COST/PRICE BREAKDOWN, CONTINUED

ON-SITE COST = M COST + K COST.
ON-SITE PRICE = M PRICE + K PRICE.

TOTAL COST = ENG/DSGN + PROD COST + TRANS COST + ON-SITE COST.
TOTAL PRICE = ENG/DSGN + PROD PRICE + TRANS PRICE + ON-SITE PRICE.

GENERAL NOTES:

A. ALL THE ABOVE COSTS/PRICES SHOULD APPLY TO THE ROOFING SYSTEM ONLY. FOR EXAMPLE, THE ENGINEERING/DESIGN COSTS SHOULD BE THAT PART OF THE TOTAL ENGINEERING/DESIGN COSTS THAT CAN BE ATTRIBUTED TO THE ROOF.

B. IT IS IMPORTANT THAT A SEPARATE NUMBER IS PROVIDED FOR EACH LINE. AN EDUCATED GUESS IS BETTER THAN NO NUMBER AT ALL, PROVIDED IT IS IDENTIFIED AS SUCH.

C. EACH LINE CAN BE GIVEN IN EITHER TOTAL $ OR $/SF OF ROOF.

D. THE FOLLOWING ITEMS SHOULD BE INCLUDED IN THE ABOVE DATA:
   FRAMING (TO SUPPORT ROOF)
   RAFTER END NAILERS, 2"X4"
   SHEATHING, 5/8"
   FELT, 15#
   SHINGLES, ASPHALT, IN ORGANIC CLASS A, 210-235LB/SF
   RIDGE AND EAVE VENTING
   INSULATION, R30 BATT
   DRYWALL, 1/2", TAPED

THE FOLLOWING ITEMS SHOULD NOT BE INCLUDED IN THE ABOVE DATA:
   GABLE END WALL FRAMING OR SIDING
   SIDING ON DORMERS
   FLOOR JOISTS
   FURRING ON JOISTS
   TRIM (SOFFIT, FASCIA OR RAKE)
CASE 1: SIMPLE  (2 GABLE ENDS)

ASSUME:

ROOF SLOPE = 8/12.
1' EAVE ON BOTH SIDES.
ASSUMED BEARING DETAIL BETWEEN RAFTERS AND WALLS SHOULD CONSIDER EAVE VENT AND 9" BATT INSULATION.
ALL SPACE WITH CEILING 6' OR HIGHER WILL BE CONSIDERED HABITABLE AND SHOULD HAVE NO OBSTRUCTIONS IN IT EXCEPT FOR ESSENTIAL POSTS. SEE BELOW.

SEE ISOMETRIC DRAWING IN ORIGINAL PACKAGE, IF NECESSARY.
CASE 2: INTERMEDIATE (1 GABLE END, 1 HIP END, 1 TURN GABLE, AND 1 GABLE DORMER)

NOTES:
ALL SLOPES = 8/12 EXCEPT FOR 12/12 DORMER.
1' EAVE ON BOTH SIDES.
1' RAKE ON TURN GABLE.
ASSUMED BEARING DETAIL BETWEEN RAFTERS AND WALLS SHOULD CONSIDER EAVE VENT AND 9" BATT INSULATION.
ALL SPACE WITH CEILING 6' AND HIGHER WILL BE CONSIDERED HABITABLE AND SHOULD HAVE NO OBSTRUCTIONS IN IT EXCEPT FOR ESSENTIAL POSTS. SEE BELOW.

SEE ISOMETRIC DRAWING IN ORIGINAL PACKAGE, IF NECESSARY.
CASE 3: COMPLEX
(1 GABLE END, 1 HIP END, VARYING PITCHES, 1 TURN GABLE, AND 4 GABLE DORMERS)

NOTES:
ALL SLOPES = 12/12 EXCEPT FOR ONE 8/12 SIDE.
1' EAVE ON THREE SIDES.
2' RAKE ON TURN GABLE SIDE.
ASSUMED BEARING DETAIL BETWEEN RAFTERS AND WALLS SHOULD CONSIDER EAVE VENT AND 9" BATT INSULATION.
ALL SPACE WITH CEILING 6' AND HIGHER WILL BE CONSIDERED HABITABLE AND SHOULD HAVE NO OBSTRUCTIONS IN IT EXCEPT FOR ESSENTIAL POSTS. SEE BELOW.

SEE ISOMETRIC DRAWING IN ORIGINAL PACKAGE, IF NECESSARY.
MEANS CONVENTIONAL RAFTER ESTIMATE

5/17/90

QUANTITIES AND UNIT COSTS:

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<th>ITEM</th>
<th>QUANTITY</th>
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<td>1616</td>
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<td>161</td>
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<td>RIDGE VENT</td>
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<td>FELT, 15#</td>
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<td>1615</td>
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<td>1615</td>
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<td>RIDGE SHINGLES</td>
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<td>1500</td>
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<td>DORMER SYSTEM</td>
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<td>1080</td>
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<tr>
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<tr>
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<td>RIDGE BOARD</td>
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<td>42</td>
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<tr>
<td>CEILING JOISTS</td>
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<tr>
<td>DRYWALL, 1/2&quot; TAPED</td>
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MATERIAL AND LABOR/EQUIPMENT SUBTOTALS FOR EACH ITEM:

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<tr>
<th>ITEM</th>
<th>MATERIAL COSTS</th>
<th>LABOR + EQUIP. COSTS</th>
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<td>RIDGE SHINGLES</td>
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<td>SUBTOTAL</td>
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Exhibit 3
MEANS CONVENTIONAL RAFTER ESTIMATE (ITEMS FOR RAFTER SYSTEM ONLY)

<table>
<thead>
<tr>
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<th>Material</th>
<th>Labor</th>
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<td>Hip Rafters</td>
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<td>Hip Jack Rafters</td>
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<tr>
<td>Valley Jack Rafters</td>
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<td>267</td>
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<td>Rafter Tie</td>
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<td>227</td>
<td>671</td>
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<td>761</td>
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MATERIAL + LABOR + EQUIPMENT TOTALS AND PERCENTAGES:

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(ITEMS COMMON TO BOTH RAFTER AND TRUSS SYSTEMS)

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**NOTES:**
1. UNIT COSTS ARE FROM MEANS 1989 RESIDENTIAL COST DATA. THEY INCLUDE A CITY COST INDEX OF 1.10 (FOR WORCESTER, MA)
2. PERCENTAGES SHOWN ARE WHAT PERCENT THE TOTAL COST FOR THAT ITEM IS OF THE TOTAL SYSTEM COSTS. PROFIT AND G&A OVERHEAD ARE NOT INCLUDED.
3. PROFIT + G&A OH = 10% ON MATERIALS AND 35% ON LABOR + EQUIPMENT, AS SUGGESTED BY MEANS.
4. SCOPE OF SYSTEM ESTIMATED IS SHOWN ON SKETCH BELOW:
RAFTER SYSTEM
(Gable End)
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<th>% OF TOTAL COSTS</th>
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<th>MANAGEMENT OVERHEAD</th>
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<td>32</td>
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</table>
GENERAL: INCLUDES PRECUT 2X10 RAFTERS.

1. INCLUDED IN MANAGEMENT OVERHEAD

2. INCLUDES THE FOLLOWING ADDITIONAL ITEMS FROM MEANS COST DATA:
   - Batt Insul: 825 825 985
   - Drywall: 761 761 908
   - Total/SF: 0.98 0.98 0.98

3. INCLUDES THE FOLLOWING ADDITIONAL ITEMS FROM MEANS COST DATA:
   - Batt Insul: 135 135 202
   - Drywall: 685 685 949
   - Subtotal: 820 820 1151
   - Labor*: 2.29 2.50 2.55
   - Total/SF: 2.79 3.01 3.15
   * FROM A CONTRACTOR WHO INSTalls PRECUT HOME PACKAGES

4. INCLUDED IN CONTRACTOR MATERIALS AND LABOR.

5. SCOPE OF SYSTEM ESTIMATED IS SAME AS SKETCH FOR CONVENTIONAL RAFTER EXCEPT RAFTERS ARE 2X10, NOT 2X8.
TRUSS ESTIMATES

QUANTITIES AND UNIT COSTS:

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<thead>
<tr>
<th>ITEM</th>
<th>QUANTITY</th>
<th>UNIT COST</th>
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<tr>
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<td>0</td>
</tr>
</tbody>
</table>

TRUSSES:

| MEANS SIMPLE | 23 | 83 | 21 |
| PROD. A SIMPLE | 23 | 75 | 21 |
| PROD. A INTER. | 1615 | 1.13 | 0.4 |

MATERIAL AND LABOR/EQUIPMENT SUBTOTALS FOR EACH ITEM:

<table>
<thead>
<tr>
<th>ITEM</th>
<th>MATERIAL COSTS</th>
<th>LABOR + EQUIP. COSTS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>MEANS</td>
<td>PRODUCER A</td>
</tr>
<tr>
<td></td>
<td>SIM</td>
<td>SIM</td>
</tr>
<tr>
<td>SHEATHING</td>
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<td>517</td>
</tr>
<tr>
<td>END NAILER</td>
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<tr>
<td>RIDGE VENT</td>
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<td>100</td>
</tr>
<tr>
<td>FELT, 15#</td>
<td>48</td>
<td>48</td>
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<tr>
<td>SHINGLES</td>
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<td>549</td>
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<tr>
<td>RIDGE SHINGLES</td>
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<td>30</td>
</tr>
<tr>
<td>INSULN, R30,BATT</td>
<td>825</td>
<td>825</td>
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<tr>
<td>VALLEY JACK RAFTERS</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RIDGE BOARD</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DORMER SYSTEM</td>
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<td>0</td>
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<td>2120</td>
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<td>1725</td>
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</table>
TRUSS ESTIMATES, PAGE TWO

MATERIAL + LABOR + EQUIPMENT TOTALS AND PERCENTAGES:

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<th>SIM</th>
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<th>INT</th>
<th>SIM</th>
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<td>2</td>
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<td>960</td>
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<td>14</td>
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<tr>
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<td>3077</td>
<td>4150</td>
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<td>2208</td>
<td>2471</td>
<td>44</td>
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<td>37</td>
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</tbody>
</table>

TOTALS:

MATERIALS + 10%        | 4432| 4230| 4942|
LABOR + EQUIP. + 35%   | 1944| 1944| 2874|
TOTAL COSTS            | 6376| 6173| 7816|

COSTS / SF:

MATERIALS / SF         | 2.74| 2.62| 3.06|
LABOR + EQUIP. / SF    | 1.20| 1.20| 1.78|
TOTAL COSTS / SF       | 3.95| 3.82| 4.84|
NOTES:
1. TRUSS INTERIOR SPACE IS NEITHER FINISHED NOR "HABITABLE."

2. ALL COSTS EXCEPT FOR PRODUCER A TRUSSES ARE FROM MEANS 1989 RESIDENTIAL COST DATA. THEY INCLUDE A CITY COST INDEX OF 1.10 (FOR WORCESTER, MA).

3. PRODUCER A TRUSS COSTS ARE BASED ON A TRUSS DESIGN PACKAGE FROM A TRUSS PRODUCER, AS FOLLOWS: ONE HALF OF A HIP PACKAGE = $796, PLUS 14 #06252 (STANDARD W TRUSSES) TO EXTEND LENGTH = $1033, PLUS LABOR COSTS OF $.30/SF AND $.40 /SF FOR SIMPLE AND INTERMEDIATE ROOF DESIGNS, RESPECTIVELY.

4. PERCENTAGES SHOWN ARE WHAT PERCENT THE TOTAL COST FOR THAT ITEM IS OF THE TOTAL SYSTEM COSTS. PROFIT AND G&A OVERHEAD ARE NOT INCLUDED.

5. PROFIT + G&A OH = 10% ON MATERIALS AND 35% ON LABOR + EQUIPMENT, AS SUGGESTED BY MEANS.

6. THE SCOPE OF THE SYSTEM ESTIMATED IS SHOWN ON THE SKETCH BELOW.
TRUSS SYSTEM

Ridge Vent and Shingles

1/2" Sheathing

#15 Felt

Asphalt Shingles

Top Chord

2"x4" Nailer

Gusset Plates

Bottom Chord

Webs

R30 Batt Insulation (between chords)
## Exhibit 6

**FOAM PANEL SYSTEM**

5/17/90

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SEE NOT</th>
<th>COSTS/SF ROOF</th>
<th>% OF TOTAL COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF INSTALLED</td>
<td>SIMPLE</td>
<td>1615</td>
<td>1665</td>
</tr>
<tr>
<td>SF UNCUT PANELS</td>
<td>NTERM</td>
<td>1680</td>
<td>1912</td>
</tr>
<tr>
<td><strong>MANUFACTURER</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ENGINEERING/DESIGN</td>
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<tr>
<td>PRODUCTION LABOR</td>
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<td>PRECUTTING</td>
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<td>0.66</td>
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<td>7.06</td>
</tr>
<tr>
<td>total materials</td>
<td></td>
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</tr>
<tr>
<td>total labor</td>
<td></td>
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FOAM PANEL SYSTEM NOTES:

GENERAL: DATA IS FOR A 4 1/2” URETHANE SYSTEM. EXTERIOR IS OSB. INTERIOR IS BLUEBOARD.

1. CALCULATED BY TMT. SEE “SQFEET.WK1” SPREADSHEET.

2. CALCULATED BY FIRM. SEE ORIGINAL PACKAGE. EXAMPLE: IT TAKES 1680 SF OF UNCUT PANELS TO PRODUCE 1615 SF OF INSTALLED (SIMPLE) ROOF.

3. THIS FIGURE ASSUMES THE PANELS ARE SOLD AS AN INDEPENDENT SYSTEM FOR A PRE-DESIGNED HOUSE. DESIGN COSTS WOULD BE HIGHER IF THE PANELS WERE GOING INTO A HOME DESIGNED BY PANEL MANUF. (TO COVER COMPLETE DRAWINGS.) COST INCLUDES $400 FOR A P.E. STAMP.

4. ALL IN-PLANT COSTS EXCEPT ENG/DESIGN INCLUDE WASTE FACTORS OF 4% (1680/1615), 13% (1912/1665), 16% (2512/2128) FOR SIMPLE, INTERMEDIATE COMPLEXITY, RESPECTIVELY.

5. FIRM CHARGES $0.65/SF OF ENTIRE ROOF FOR ROOFS THAT REQUIRE PRECUTTING. THEY ESTIMATE THEIR ACTUAL COSTS TO BE $.40/SF.

6. OBTAINED BY SUMMING ABOVE COSTS.

7. OBTAINED BY SUBTRACTING TOTAL PRODUCTION COSTS FROM SALES PRICE. IT INCLUDES MARKETING AND MANAGEMENT OH.

8. OBTAINED BY MULTIPLYING DIRECT PRODUCTION COSTS BY A MARK UP RATE. FIRM HAS FIVE MARK-UP RATES TO REFLECT THE SIZE OF ORDER AND WHETHER IT IS A ONE TIME OR A REGULAR CUSTOMER. THE COMPLEXITY OF THE ROOF IS NOT CONSIDERED. THIS RATE IS THE SECOND LOWEST--FOR A HOMEBUILDER/DISTRIBUTOR WHO PURCHASES 50,000-100,000 SF PER YEAR.

9. FIRM USES ITS OWN TRUCK UP TO 500 MILES. POLICY IS TO CHARGE ONLY ACTUAL COSTS. THIS FIGURE ASSUMES 150 MILES.
10. INCLUDES THE FOLLOWING ACCESSORY COSTS ESTIMATED BY THE FIRM:

SPLINES

<p>| | | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td>131</td>
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FOAM

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<td>135</td>
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NAILS

<p>| | | |</p>
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</thead>
<tbody>
<tr>
<td>34</td>
<td>44</td>
<td>54</td>
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</table>

AND THE FOLLOWING ACCESSORY COSTS FROM MEANS COST DATA:

PURLINS

<p>| | | |</p>
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<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>504</td>
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RIDGE BEAMS

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INTERIOR POSTS

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<tr>
<td>21</td>
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EAVE & DORMER NAILERS

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SHINGLES

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<tr>
<td>759</td>
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TOTAL/SF

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11. INCLUDES

PURLINS, BEAM

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SHINGLES

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TOTAL/SF

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PANEL INSTALLATION

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TOTAL

<p>| | | |</p>
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<tbody>
<tr>
<td>1.26</td>
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12. INCLUDES 8/16/20 HOURS CRANE RENTAL @ $85/HOUR.

13. INCLUDES TRAVEL, LODGING, MEALS.

14. OTHER OH AND PROFIT INCLUDED IN DIRECT COSTS.

15. MATERIAL COSTS/SF INCLUDE:

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<tr>
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</tr>
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</table>

Note: Vertical dimension is exaggerated
### Exhibit 7

**COMPARISON OF INDIVIDUAL COST GROUPS**

5/17/90

KEY: M = MANUFACTURER, K = CONTRACTOR

#### SIMPLE ROOF DESIGN
SF OF INSTALLED ROOF SURFACE = 1615

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CONV. RAFTER</th>
<th>TRUSS</th>
<th>PRECUT RAFTER</th>
<th>FOAM PANEL</th>
</tr>
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<tbody>
<tr>
<td>M MATERIALS</td>
<td>0.00</td>
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<td>1.60</td>
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<tr>
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<td>0.00</td>
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<td>0.35</td>
<td>0.15</td>
</tr>
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<td>M OH/PROFIT</td>
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<td>TRANSP.</td>
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<td>2.81</td>
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</tr>
<tr>
<td>K LABOR/EQUIP</td>
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<td>1.20</td>
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<td>2.58</td>
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<td>TOTAL LABOR</td>
<td>1.96</td>
<td>1.20</td>
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<td>4.77</td>
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<td>7.75</td>
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#### INTERMEDIATE ROOF DESIGN
SF OF INSTALLED ROOF SURFACE = 1615

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CONV. RAFTER</th>
<th>TRUSS</th>
<th>PRECUT RAFTER</th>
<th>FOAM PANEL</th>
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</thead>
<tbody>
<tr>
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<tr>
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<tr>
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<td>1.09</td>
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<tr>
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<td>1.78</td>
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<td>2.02</td>
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<td>1.78</td>
<td>3.50</td>
<td>3.17</td>
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<tr>
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<td>5.71</td>
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196
COMPARISON OF INDIVIDUAL COST GROUPS, CONTINUED

COMPLEX ROOF DESIGN

SF OF INSTALLED ROOF SURFACE = 1928

COSTS/SF ROOF

<table>
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<tr>
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<th>CONV. RAFTER</th>
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<tbody>
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<td>M MATERIALS</td>
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<td>0.96</td>
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<tr>
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<td>0.64</td>
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<td>3.15</td>
<td>2.42</td>
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<td>TOTAL MATERIALS</td>
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<td>2.79</td>
<td>1.96</td>
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<tr>
<td>TOTAL LABOR</td>
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<td>3.06</td>
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<tr>
<td>TOTAL</td>
<td>6.08</td>
<td>8.76</td>
<td>6.90</td>
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COSTS VERSUS ROOF COMPLEXITY

[Graph showing costs versus roof complexity]
LESSONS LEARNED

The study provided many opportunities to learn from one's mistakes. Researchers performing any type of economic or cost study of a segment in construction would do well to keep the following guidelines in mind:

1) Verify that the level of detail being sought is available before proceeding with the study.

2) Stick with typical designs. While it is important to "compare apples to apples," the extra effort by all parties required to obtain data for one specific design (instead of each firm's comparable standard design) is probably not worth it.

3) Ensure everyone involved in the study, including the researcher and his/her management, understands the level of effort required. Accurate, effective studies take months and more hours than one would expect. Get a solid, written commitment from firms who agree to participate.

4) Ensure all firms involved in the study have a clear understanding what items and costs are to be included in the study and what items are not.
BIBLIOGRAPHY


Sales and installation literature from the following panel producers:
Atlas Industries--Lenap system (Ayer, MA)
Cheney Building Systems-Chase Thermo-Panels (WI)
Concept 2000 Homes (St. Charles, MO)
Enercept, Inc. (Watertown, SD)
Foam Products Corp.--Insulspan panels (MO)
Poly-Foam, Inc.--AFM R-Control system (MN)
RADVA, Inc. (Radford, VA)
Winter Panel Corp. (Brattleboro, VT)