PRECAST CONCRETE INDUSTRY: A SIMULATION OF ITS OPERATION AND POTENTIALS

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ABSTRACT

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Submitted to the Department of Civil Engineering on June 22, 1973, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Since about 1967, the precast concrete industry has experienced significant growth. In part, this can be attributed to the potential of the precast industry to solve a number of the problems faced by its competitor, the conventional construction industry. This recent growth makes it necessary that the industry engage in long-range planning in order to meet the increased demand for its products.

This work is the result of an attempt to lend objectivity, flexibility, comprehensiveness, and speed to the decision-making processes at the industry level which concern the performance of the precast concrete industry. In particular, a mathematical model which simulates the operation of the industry in the period 1960-1985 has been constructed on the basis of the qualitative and quantitative characteristics of the industry which are currently known or, in the absence of such data, on the basis of estimates and judgement which are explicitly stated. The model functions as a laboratory wherein systematic testing of all assumptions made about the industry can be (and has been) carried out to assess their internal consistency, as well as the agreement of results, obtained by incorporating these assumptions into the model, with independently known facts. In addition, the model has been used to trace the future effect that specific industrial, governmental, and labor policies, as well as market conditions, will have on the performance of the industry.

A study of the response, by use of this model, of industry performance to specific policy changes indicates that such performance depends strongly on factory utilization. The model predicts that, once a high and stable utilization factor is achieved, the industry will thereafter maintain a rapid growth. In fact, it is found that, under these conditions, specific unfavorable factors,

such as enactment of restrictive labor policies, non-optimal allocation of R & D funds, or the prefabrication of a non-optimal percentage of construction will decelerate, but will not arrest, the growth of the industry.

The effect that various policies and market conditions have on the precast concrete industry is found, by use of the model, to depend significantly on the state of the industry at the time of policy enactment. For example, as the industry advances to higher growth levels in the late 70's and economies of scale are achieved in certain sectors of its operation, such eventualities as oscillation in demand in some of the markets for precast concrete, a governmental policy of granting low-interest loans to the industry, or restrictive labor policies will have a much smaller impact on the industry at that time (late 70's) than in the 60's.

The optimal allocation of funds for R & D has also been found to depend on the state of the industry.

Precast concrete building systems will, in the middle or late 70's, become the major output of the industry and will acquire low-cost housing as major client.

Operation of the model indicates that the industry will be well advised to move in the 70's to prefabrication of a higher percentage of construction than is currently (1973) the case. Even if this direction is not followed, precast concrete will become a significant threat to conventional construction in the middle to late 70's; the resulting competition will subsequently lower construction costs.

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CHAPTER 1

INTRODUCTION

1.1 The Construction Industry and the Problems It Faces

Construction is one of the most important industries in the economy of the United States: In terms of value put in place, new construction constitutes over 10 per cent of the total gross national product. In terms of employment, it is the largest single industry in the U. S. economy, employing some 6 per cent of the national labor force.

The industry is affected by a set of forces. Predominant among them are government and labor policies, the state of the economy, and climatic conditions. In response to these forces, the industry has acquired a particular structure and mode of operation which determine its efficiency and effectiveness. Since the efficiency and effectiveness of the construction industry are of vital importance to the national economy, these, in turn, affect government policy and the nation's economy as well. Furthermore, as time advances and the consumer demand for quality increases, the industry has to reach new levels of competence in order to meet the new challenge.

Of the several characteristics of the construction industry, high fragmentation seems to be of significant importance. A major cause for the highly fragmented state of the industry is the instability in demand for its product. This arises from two reasons: (i) weather conditions, causing cyclical variations in demand for construction throughout the year; and (ii) a superposed fluctuation in national monetary policies, causing additional periodicity in demand.* In response to such unstable demand for their product, construction firms try to build into their operations the maximum flexibility possible. The result is a huge number of small construction firms.** We should add here that the acquired structure and practices of the industry, a result of unstable demand, themselves act catalytically, in many instances to perpetuate fragmentation. An example can be found in the bidding practices of the industry which prevent, on one hand, overhead expenditures for R & D and, on the other, yearlong employment for other than the few people that can be kept busy even in the valleys of demand.

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*Residential construction suffers the main impact of unstable governmental monetary policies through the following mechanism: First, increases in interest rates raise the carrying charges on mortgage loans. Second, increasing interest rates raise the cost of construction loans to builders and thereby increase the construction costs of new housing. Third, savers react to changes in the structure of interest rates by shifting deposits among thrift institutions, with the usual result of lessened credit for housing mortgages. Therefore, prices and availability of credit move simultaneously to reduce or expand new home construction. Finally, monetary changes impact new housing rather rapidly. Maisel (reference 45) noted that "on the average, a change in monetary conditions affects the rate of starts (of new housing) six months later."

It is interesting to note that other sectors of the construction industry suffer less from periodicity in governmental monetary policy. Fixed investment in non-residential construction primarily depends upon the expected rate of return that the investment will bring as well as upon expected increases in cost of construction.

**There are over 870,000 firms performing construction work (20). The firms are generally small: In 1967, the average firm employed between nine and ten men (average number employed throughout the year) (50).

In the long run, costs in terms of efficiency and economy are paid for the sake of short-term expediency gained by high fragmentation. Specifically:

a. Great inefficiency results from the lack of continuous working relationships among the various sectors that participate in the construction process as well as among the actors within each sector:

   Construction firms are too small to specialize in more than a small fraction of the construction process. Not being under the shelter of a single concern, each construction sector acts independently to satisfy its own objectives with little concern for overall optimization. For example, within the hardware segments of the building industry, little cross-fertilization of products and needs occurs--seldom does the manufacturer of one product consort with the manufacturer of another product in an attempt to solve problems in building which are of mutual concern. Tradition has taught the manufacturer of an individual construction product to rely upon the designer to assemble all the components of a building. Once the manufacturer has developed his individual product line, the responsibility of interfacing the products of various manufacturers in finished buildings is left to the designer.

   Within each sector, the lack of continuous working relationships between actors, while deserving credit for short-term economies, is nevertheless, accountable for long-term inefficiencies. A typical example is that of builders: General contractors prefer to hire workers as needed rather than to maintain permanent working relationships. The results of such transient relations are that, on one hand, the management need not maintain idle workers on the payroll when demand declines; on the other, as soon as demand rises, there is a rush to hire new employees, unfamiliar with the way the contractors operate. The result is perpetual learning costs.

b. Great inefficiency also results from the absence of managerial talent of high quality. This is the inevitable result of a proliferation of small underfinanced firms with few permanent employees.

c. Diseconomies also result indirectly from the existing large differences in the level of power among groups in construction. These differences undermine the fairness of the results of collective bargaining. Specifically, the small size of the firms is accountable for the fact that weak contractors have to face the much stronger labor unions. The results are:

- The industry is unable to cope with labor jurisdictional disputes; and featherbedding accounts anywhere from 15 to 40 per cent of the blue-collar construction payroll (2).
- In a favorable economic environment, and as a result of the collective bargaining structure in construction, labor wages can rise sky high (50). A good example are the wage increases achieved by the construction unions in the late 1960's. These increases reached a peak of 15 to 18 per cent annually in 1970 (while, at the same time, manufacturing

increases were no more than half that rate) and, no doubt, they would have continued into 1971 were it not for Federal intervention on March 29, 1971.

- The industry is faced by a lack of capacity due to a shortage of skilled labor:

  Not having a large number of permanent employees, the construction firms have left the task of hiring skilled labor to the unions which hire labor just enough to cover the valleys in annual demand (40). The remainder of the labor which is required to fill the peak annual requirements arrives as an inflow from other industries.* Given that construction can guarantee to these men yearlong employment much less than the other industries can, it follows that, in a period of full employment, construction is the first industry to feel the shortage of labor.

  We have to add here that, next to the unions, partly responsible for the shortage of skilled labor is the present trend towards white-collar employment which diminishes the pool of blue-collar workers (30).

  The net result of such shortages of skilled labor is a serious lag in industrial capacity.

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*Seasonality in demand for construction causes a large annual flow in manpower between the construction and other industries; for example, in 1970, construction contractors provided for 3.4 million yearlong jobs. However, due to turnover, more than 6 million persons at one time or another during this year were employed by the industry (50).

Figure 1, from reference 12 exemplifies the labor shortage. The figure illustrates the shortage of plumbers relative to the numbers required to meet the housing goals established by the Housing Act of 1968.* Plumbers are taken as being representative of the situation in the other related construction trades.

d. Also, inefficiency and ineffectiveness result from the relative absence of research and development (R & D). This absence is attributed to two reasons: one, inexistence of large firms, and two, the bidding practices of the industry which leave little room for overhead expenditures with respect to R & D.**

Unlike the chemical industry or the food industry, where new technologies are continuously introduced with a resulting improvement in product quality as well as the productivity, the fact that only scattered attempts at R & D are occasionally made by the construction industry prevents sustained improvements either in product quality or in productivity.***

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*The Housing Act of 1968 defines the need for 26 million housing units to be built from 1968 to 1978, with 6 million of those units needed for low and moderate income families. According to Assistant Secretary of Housing and Urban Development, H. Finger, this is an understatement of the national needs (27).

**The level of R & D activity amounts approximately to 0.1 per cent of total revenue, or about $121 million per year, while basic engineering research amounts to about 0.02 per cent of total revenue, or about $24 million per year.

***Productivity in construction rises about 1 per cent per year compared with 8 per cent per year for the agricultural industry which is heavily oriented towards R & D.

To summarize: In response to public policies, to economic and climatic conditions, and in an attempt to maximize flexibility, the construction industry has become highly fragmented. The long-term results of short-term expediency acquired in this manner are high construction cost, lack of capacity, and inability to meet specifications as construction projects become more complex and as standards for the quality of life increase.

1.2 Systems (or Industrialized) Construction

Given the importance of the construction industry, an investigation is needed of the merit of every solution which promises to alleviate some of the problems that the industry currently faces besides promising to increase the future efficiency and effectiveness of the industry.

Certain authors in the field argue that systems construction is one of the most promising means for solving some of the problems of the construction industry.

Systems (or industrialized) construction is defined as the integration of planning, design, programming, manufacturing, site operations, scheduling, financing, and management into a disciplined method of mechanized production of constructed facilities (4).

The definition of systems construction implies that this type of construction would be run by huge, well-financed corporations. These corporations would be able to finance aggressive R & D programs, to experiment on a large scale, and to distribute their products on a nationwide scale. Use of advanced technologies, high automation and high standardization is to be expected. In addition, in the collective bargaining meetings, one would expect to find strong corporations pitted against strong unions with a resulting anticipation for fair agreements. In such a setting, industrial, rather than craft, unions would perhaps form, thereby ameliorating the problem of jurisdictional disputes.

Proponents of the systems solution argue that all the above conditions, taken together with the fact that the whole construction process would be run by a single concern (thereby making it possible to achieve an overall optimization), would lead to dramatic returns in terms of improved cost and quality performance as well as improved industrial capacity.

On the other hand, opponents of the systems solution argue that this approach, at least as of today, is unrealistic for a number of reasons, the major being that the bulk and weight of the constructed product precludes economic justification of nationwide distribution. Such a difficulty with distribution would inevitably lead to a rather large number of plants servicing a limited geographic area rather than to huge centralized factories producing for the whole nation, as the proposal assumes. In addition, it is argued that whenever free markets operate, the firms should strike a proper balance between flexibility and standardization. However, achievement of the latter would lead to the adoption of a solution that would fall short of the severe standardization required by the highly automated production mode which is implied by systems construction. Furthermore, if huge corporations in the nation's economy are going to aggressively pursue systems construction, they should have some assurance that construction will not continue to be used as a major means for absorbing the impact of the nation's monetary policies. Such an assurance (from the part of the government) has not yet been given.

1.3 Prefabrication in Construction

The feasibility of systems construction has not been proven as yet. On the other hand, prefabrication*--a necessary (but not sufficient) step in systems construction--seems to be a less ambitious but feasible solution, as evidenced by the continuous and rapid growth of this activity during the last decade. The major advantages of prefabrication in construction--qualitatively the same as those argued for systems construction but less far-reaching--are the following:

a. Alleviation of instability caused by weather conditions. This results from the fact that the structural members can be produced in a factory thereby making the process independent of

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*For the purposes of this thesis, prefabrication is taken to mean fabrication of construction members in a factory. The factory is built and equipped particularly for this purpose. After being fabricated, the members are shipped to the place where they are to be used. There, they are hoisted, set into their final places, and assembled to form the complete structure--be it a bridge or a building. In the case of building construction, prefabrication might, besides the factory production and assembly of structural systems, also include the factory assembly of mechanical and electrical components to form complete and fully equipped parts of a building.

weather conditions. The members can then be installed on site to form a closed space in which the workers can continue with the required on-site operations without interruptions from a change in weather conditions.

b. Increased capacity of the construction industry. As explained in Section 1.1, the lack of capacity in the construction industry is the result of a serious shortage of skilled labor. Prefabrication can solve this problem by replacing labor with machines as well as reducing the requirements for skill.

c. Cost savings, which can accrue as a result of:

- Continuity in employment. The latter would eliminate inefficiency arising from perpetually forming new working relationships.
- The ability of firms to make much more intensive use of managerial talent which is so rarely encountered in conventional* construction.
- The ability to increase substantially as well as maintain an R & D effort.
- The ability to make quantity purchases of materials with resulting savings arising from discounts and the elimination of middlemen.**

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*The term "conventional construction" in this thesis is used to mean non-prefabricated construction.

**According to Reference 24 these savings would be realized for plant production of more than one million square feet of construction per year.

- Savings in the cost of labor. These would result from increased efficiency in the factory, which would bring about a decrease in the amount of required manhours per square foot of construction, as well as from transfer of part of the labor from the construction site to the factory, where wages are much lower.
- Shortened construction time. This would lead to savings in administrative and financial costs during construction, as well as savings in real estate taxes.

d. Better quality of construction. Such quality features can be included at the factory (at least if it is operating at sufficient volume) that the builder in the field simply cannot afford.

1.4 Timeliness of Prefabrication in Construction

Several conditions in the U. S. economy of the early 1970's are quite favorable to prefabrication of construction. These conditions are:

a. The technological requirements for large-scale mass production in construction can easily be met in the U. S. today. To quote from Reference 36, "The technical knowledge needed to effectively industrialize housing and achieve large-scale mass production exists now or can be readily supplied when a market is clearly identified."

b. Rather than start from a bare beginning, prefabrication in construction has a history. Therefore, it possesses an experience base from which it could take off with a measure of confidence.*

c. The U. S. Government is interested in promoting advanced technologies in the housing industry--for the purpose mainly of increasing its capacity--as well as in augmenting--by price-cutting--the effective demand for low-cost housing.** The result of this interest is a concentration of money and manpower in the housing construction area. However, the entire construction industry would benefit even if such efforts were directed towards only one of its sectors.

Not every condition in the U. S. economy favors prefabrication in construction, however. Consumer acceptance of prefabricated buildings has yet to come. The basic mistrust derives from memories of the postwar prefabricated homes that were, with few exceptions, cheaply built and aesthetically displeasing. The "new" industry has to prove that its product is versatile and flexible, of superior quality, and that it can offer this product at a competitive price. Another problem is that prefabricated construction is a capital intensive industry; therefore, a possible failure would necessarily be connected with very substantial losses of invested capital.***

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*Several European countries have had experiences with prefabricated construction which can be utilized in the U. S. as well.

**Example: The Operation Breakthrough program.

***Just the opposite is true of conventional construction which is labor intensive requiring little in terms of capital investment, thereby making a possible entry in the industry relatively easy. (20)

This problem coupled with the facts that (a) the market is yet untested, (b) there is a fluctuating demand for construction, and (c) prefabricated construction can only be economically competitive under high volume continuous production of standardized products makes many investors unwilling to take the risk of investing in prefabricated construction.

In summary, the construction industry is of primary importance to the economy of the U. S., and every solution which promises to alleviate some of the problems the industry faces and to increase its efficiency and effectiveness merits a thorough investigation. Systems construction and prefabrication are among the proposed solutions. Of those, the feasibility of systems construction has not been proved as yet while prefabrication is known to be feasible, as evidenced by the continuous and rapid growth of this activity during the last decade. Even if industrialized construction ultimately proves to be feasible as well as being the optimal solution, prefabrication is the necessary first step towards this end.

The line of reasoning presented above provides a justification for a thorough study of the current status and future potential of prefabrication.

1.5 Justification for Study of Prefabrication Based on Concrete as a Material of Construction

The prefabrication technology employed as well as the appropriate market both vary greatly from use of one basic material of construction to another. To pursue our goal of an indepth study, we have, therefore, limited ourselves to a study of prefabrication based on a single material of construction.

Concrete was chosen in the light of its several advantages as well as after consideration of the characteristics of the market in which this material is most competitive. Specifically, concrete as a building material offers the following advantages:

- On a cost/unit volume basis, it is one of the cheapest materials available anywhere.
- It is highly fire resistant.
- It can be molded into any shape.
- It can provide adequate sound and thermal insulation.

Concrete dominates prefabricated construction of middle- and high-rise buildings (see Fig. 2). This market is of particular importance because:

- The share of the total building output that middle- and high-rise buildings occupy continuously expands. One reason for this is the high cost of land. In the particular case of housing, the rapid expansion of apartment buildings (see Fig. 3) is mainly attributable to the age structure of the population.*
- Middle- and high-rise buildings seem to be the natural market for prefabricated construction, since a single building often provides enough volume to justify economically the production of members in factories. (In the case of, say, a single-family dwelling,

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*The subject is discussed in detail in Chapter 4.

a number of orders demanding similar houses must be aggregated before prefabricated construction becomes economically justified.)

1.6 Purpose of the Thesis

The purpose of this work is to develop an understanding of the nature and the dynamics of the precast concrete industry. In order to accomplish this goal, the major variables determining the state of the industry have been studied individually and in detail. In addition, a model of the industry has been built the purpose of which is:

a. To study the dynamic structure of the precast concrete industry, that is, to study how the main variables interact as functions of time.

b. To serve as a vehicle for present and future testing of policy alternatives in the expectation that this will facilitate the formulation of these particular policies and decisions which will benefit the industry most. This vehicle will be subject to continuous refinement as additional data on the precast concrete industry become available.

1.7 Scope of the Thesis

This thesis limits itself to the study of prefabrication which is based on the use of concrete as a material of construction.

In addition, the thesis will be concerned only with off-site prefabrication, that is, prefabrication of construction elements and members in plants built and equipped specifically for this purpose.

The model of the industry presented in this work was designed to study the effect that several specific, well-defined governmental, labor, and industry policies as well as economic conditions will have on the future of the precast concrete industry.

1.8 Plan of the Thesis

In Chapter 2, the state of the art in each of the main sectors of the precast concrete industry is studied separately, and indentification is made of the major problems which bedevil the industry.

The principles and methodology of the approach used in this work are discussed in Chapter 3. It is argued that a mathematical model would prove to be a useful tool for assessing the impact of specific policies and conditions on the precast concrete industry. Then, following a discussion of the various categories of mathematical models, the reasons are developed for the choice of an industrial dynamics approach, a computer simulation modeling technique developed at M.I.T. by J. Forrester and co-workers, as the preferred method for attacking the problem. The nature of results to be expected by use of the industrial dynamics approach is also briefly discussed.

In Chapter 4, a computer simulation model of the precast concrete industry is developed. The model aims to attack the problems identified in Chapter 2.

Finally, the results of the model are interpreted in Chapter 5, and the conclusions are stated in Chapter 6.

CHAPTER 2

THE STATE OF THE ART IN THE PRECAST CONCRETE INDUSTRY. THE U. S.

2.1 The Industry - The Market

Members of the precast concrete industry are all plants that fabricate components either prestressed or not. The most common types of products are listed in Table 1. These are the products that manufacturers are equipped to produce on a day-to-day basis. In addition, most precasters are equipped to make any product if a given situation warrants.*

The precast concrete products can either be sold as separate components (for example, as bridge beams or floor slabs), or they can be combined to form a building system (see section 2.2). Building systems fabricated in the precast concrete plants range from merely providing the structure and skin of a building--as is today usually the case--to providing in addition the finishings; and the concept can even include "total systems" that incorporate compatible mechanical and electrical equipment.

As of February, 1971, there were 557 plants producing precast concrete components in the U. S. (57). Most of these plants were new in the field (see Fig. 4) and probably have not yet reached volume production. In addition, the plants were (and still are) moderate in size servicing an area of at most 200 miles radially around them (44).

The rather recent interest in prefabrication (from 1967 on, as shown in Fig. 4) is nationwide, and generally follows the distribution

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*In fact, a major problem troubling the industry is the sacrifice of benefits derived from standardization to a flexibility granted by the will to accept orders for custom-made components (56,34). The absence of standardization is more severe in the case of building components and less so in the case of bridge components (42).

of population (see (Fig. 5). Precast concrete producers, however, have not developed factories throughout the country to supply a national market, as some mobile home manufacturers have done.*

About 20 per cent of the 557 plants in existence in 1971 were owned by large corporations (58). The trend seems to be that more and more of the industry will be so owned. According to reference 58 by 1982, 30 to 50 per cent of the precast concrete plants will be owned by large corporations.

Another observed tendency in precast concrete firms is the tendency towards vertical integration (58). Precast concrete firms are being forced into it as a natural evolution. The dynamics of the marketplace involve producers in real estate and property development, and involve materials suppliers in construction and project financing. The prognosis is (58) that this tendency will continue and intensify in the next ten years as companies will find that vertical integration has advantages

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*The closest companies have gone towards a nationwide distribution was the formation of a consortium of forty-one precast concrete producers having sixty-seven plants throughout the country. This consortium was formed to provide a program capable of delivering nationwide standardized building components (a complete package of floors, roofs, exterior and interior walls, and structural systems) for multi-unit housing and commercial and institutional facilities (3).

in evening out production cycles, as a mechanism for introducing new products and developments and as an opportunity for broader capital utilization in the same market area.

The main actors of the precast concrete building construction, as well as their mutual interactions are illustrated in Fig. 6. The architect has the major role in the construction of the building because he designs the facility and then acts as an agent for the owner during construction. It is the architect who, basing himself on quality and cost considerations, generally chooses the structural material and the structural system to be used in any given building.

The role of the precast concrete producer varies from case to case, ranging from that of a simple component supplier to that of a general contractor or developer.

The most common distribution systems for producers of modular boxes are shown in Table 2. The same types of distribution systems can be traced not only in the particular case of modular boxes but in any type of precast concrete production except that the emphasis is placed somewhat differently in each case: Modular boxes are generally total systems (having entered into their design as much architectural expertise as ever is likely to enter), incorporating compatible mechanical and electrical systems and comprising close to 90 per cent of cost of the total building. On the other hand, precast concrete components, or merely structural systems form a small part of the total building and need to be compatible with the rest of the building as perceived by the architect. It follows that, in the case of modular boxes, the precaster most often sells to a builder-developer, while in the case of precast concrete components or structural systems, the precaster usually sells to the architect.* Discussions with Mr. T. McKeever (48) of the San-Vel Concrete Corporation, Littleton, Massachusetts, indicate that the precast producer must have extensive contacts with architects and must attempt to keep them informed of his capabilities and of the attributes of his products.

Table 3 shows the number of precast concrete plants which produce each major product category. The findings reported in the table are the results of a PCI survey in 1969 (56). The following points are of interest:

- Less than one-third of the plants are involved in marketing all products.
- A relatively small number of plants specialize in only one product.
- The industry proves to be less diversified than it is generally assumed to be: The majority of producers are not involved in the production and marketing of allied products such as concrete blocks, concrete pipes, or ready-mix concrete.
- As of 1969, only 40 per cent of manufacturers produced bridge elements. This finding is particularly interesting in view of the fact that the industry first made its start in the bridge market. Clearly, the main market currently is the building market.

Table 4 breaks down the market for precast concrete building systems according to building height. Figure 2 as well as references 44, 72, 64, and 4 seem to agree that concrete building systems are most

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*The precaster often undertakes the erection of his products on-site.

competitive in buildings that are in the middle and high-rise categories. More specifically, reference 72 states that, in England, concrete building systems are most competitive in buildings that are more than four stories high. San-Vel Corporation, a New England producer of precast concrete products, states the volume requirements in terms of units: According to reference 23, San-Vel can be competitive in orders for more than eighty-eight dwelling units; orders of that magnitude are almost always placed for middle- and high-rise buildings. In terms of type of building, the same reference reveals that two-thirds of the output of San-Vel goes to housing.

The discussion above leads to two conclusions: One, since precast concrete building systems are most competitive in high- and middle-rise construction, their main competitor is conventional concrete (3). This is so because the market of middle- and high-rise building is where conventional concrete is most competitive (wood dominates the single-family housing market and steel dominates the single-storey industrial buildings market (35)). Two, since housing is one of the markets of the industry, the latter has to face the problem of oscillating housing demand (see Fig. 7). Oscillation in demand is a serious problem for a capital intensive industry. To quote from the statement of Mr. Rosen (President of Urban Systems, Inc., Boston, Massachusetts) (64):

"I think that the cyclical variability which affects construction in general, and housing in particular, causes such a high level of instability in the industry that it makes it almost impossible for any kind of managerial overhead to be developed sensibly."

"The prime lack of willingness on the part of companies or firms to adopt new technology (in construction)* is that there is a high level of uncertainty associated with it (due to oscillation in demand),* and managers of large-scale institutions are risk averse."

We should add here that another factor (besides oscillation in demand) that also contributes to increasing the risk of precast concrete industry is the fragmentation of the construction market. This is mainly the result of:

- The bulkiness and high weight of its products that put high premium, in terms of transportation cost, to nationwide distribution.
- Consumer tastes: People resist buildings that look alike even though they accept identical looking automobiles. The result is a limited demand per given type of structural component.
- Building codes that may vary from one locality to another (the subject is discussed in more detail in section 2.6).

The need for market aggregation has been realized by the initiators of operation breakthrough one of the expressed purposes of which was to act as a center for collection and dissemination of information on the existing demand for various types of buildings in an attempt to pool demand and create substantial local, regional, and perhaps national markets (77).

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*Explanations in parentheses are the author's.

Since investing in the precast concrete industry is considered risky, investors (be it individual lenders, lending institutions, or equity holders*) require a high return.** This high return causes the cost of capital for the industry to be high (84) and leads it towards more labor-intensive operations.

Several proposals have been made to assist in alleviating the results of high risk. One of them (64) is to have the government guarantee to the industry low interest loans. This policy would cause a decrease in the cost of capital used by the industry which would lead the latter to more capital intensive operations; such activity would, in turn, hopefully increase the industry's competitiveness. A careful study is required at this point to assess the effects of such a policy on the precast concrete industry.

In spite of the adverse effects of an oscillating housing market, the record of the precast concrete industry in terms of sales volume still shows an uninterrupted rapid increase from a mere $150 million in 1960 to one billion in 1972 (see Fig. 8). The sales volume of precast concrete does not follow the oscillations of the housing market mainly because: (a) the multi-unit housing market by virtue of being based on income-producing

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*There is no data available on the capital structure of firms in the construction industry (i.e., on the leverage ratio = $\frac{\text{debt}}{\text{debt + equity}}$). As regards the kind of equity, Table 5 shows the types or organizations that participated in Operation Breakthrough (Type A proposals). It can be seen that 40 per cent were publicly owned corporations and 16 per cent were private companies.

**Data on required rates of return on capital and amortization times is provided in Chapter 4, section 4.5.

property, oscillates less severely in response to monetary policies than does the market for single-family dwellings; (b) The different markets* in which the industry sells its products reach their peaks and valleys of demand at different points in time (that is, the delay time for response to monetary policy differs in each case); and (c) The precast concrete industry has become more competitive and thus has increased its share of the market in the 1960-1972 period. The increased share of the market gained by the industry has possibly attracted revenue greater than could be deprived of the industry by the valley in demand.

The significant increase in the sales volume of the precast concrete industry, while partly attributed to increased competitiveness from the part of the industry as first mentioned, can also be attributed to the fact that one of the main market for precast concrete--namely, multi-unit housing--has significantly expanded. As Fig. 3 shows, the multi-unit housing market has shown a significant increase in its share of the total housing market, reaching a level of 40 per cent in 1970.

Given the importance of the multi-unit housing market to the precast concrete industry, an important question that merits investigation is what would be the effect on the industry if multi-unit housing stops expanding and instead starts oscillating around the level of output it has reached in 1970.

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*These markets are: multi-unit housing, non-housing buildings in the middle and high-rise categories, and bridge construction.

2.2 The Product

A large fraction of the literature on precast concrete is devoted to a description of the product of the industry (56, 57, 4, 37, 25, 41) In summary, as mentioned in section 2.1, the most common components produced by the industry are listed in Table 1. In addition, the industry is equipped to produce almost any custom order. Combinations of components form the various building systems. These generally fall into the following three categories in ascending degree of sophistication.

1. Post and Beam (frame) Systems (see Fig. 9)

   Most frame systems consist of prefabricated columns and beams with panels, including windows and doors, that may or may not have a structural function. Such systems can be easily installed by unskilled workers. Systems of this kind are not more "industrialized" than is building with steel beams that come from the factory. So, the next step in this category of systems was the invention of portal frames: Column heights were extended beyond single-storey height, and whole frames were manufactured in the factory (Fig. 10). However, portal frames present serious problems in transportation, handling, and erection and, therefore, are not widely used.

2. Panel and Slab Systems (Fig. 11)

   This system consists of reinforced concrete elements that can be assembled in various arrangements. In terms of size, they are distinguished into small panel systems, permitting a high degree of architectural flexibility and into large panel systems allowing for cost savings due to the smaller number of joints.

In terms of configuration the panel and slab systems are divided into three categories:

a) Longitudinal systems (Fig. 12).

In this configuration, bearing walls are only the exterior walls which lie parallel to the long face of the building. In cases where building width exceeds certain limits, a new line of bearing walls or maybe a line of portal frames is used in the interior.

b) Both-ways systems (Fig. 13).

In this configuration, panels in either direction play the same role in the structure. This results in a building which has equal rigidity in both directions and in the advantage of having two-way slabs. On the other hand, these systems offer a limited flexibility.

c) Transverse systems (Fig. 14).

In this category the bearing walls lie transverse to the long face of the building so that longitudinal exterior walls are non-bearing. Transverse systems are preferred in this country because they excel over both-ways systems in that they are more flexible: Between two transverse walls, say 30 feet apart, one can form whole apartments.* In addition, transverse systems excel over longitudinal ones in that they offer rigidity in the transverse direction as well. (Rigidity in the longitudinal direction is sufficient in any case.)

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*The example is taken from the Techrete system used by San-Vel Corporation.

3. Modular Cell (Box) Systems (Fig. 15)

These eliminate the need for framing because the prefabricated box-like units are self-supporting. A unit consists of three walls, a roof, and a floor; or two walls, a roof, and a floor; or any other self-supporting combination.

One can further distinguish building systems into closed systems where only the components of a given system can fit together and open systems where different manufacturers can combine their products into one system.

Among the special problems raised by the precast concrete building systems is the problem of an overall structural stability (42); and the problem of joints which is well documented in hundreds of papers (42, 37, 68).

In the area of materials and techniques, precast concrete plants face the necessity of: (a) obtaining high initial strengths in order to reduce plant immobilization time; and (b) achieving the greatest possible reduction in the weight of components. On the other hand, the precast concrete industry benefits from the possibilities which are offered by production carried under factory conditions. High-grade materials or advanced techniques are consequently used some of which are, indeed, of an industrial character and could not be employed except in a factory.

Reference 42 provides a comprehensive study of the materials and techniques used in the precast concrete industry. In summary, the industry uses:

i) Lightweight concretes: These are (a) concretes made with lightweight mineral aggregates of natural or artificial origin and (b) cellular concretes. The latter are cement concretes made without any aggregate and having a fine cellular internal structure comprising a large number of small discrete cavities.

ii) High-strength concretes, allowing for reductions in the cross section of elements. However, part of this advantage is offset by increased deflections and greater risk of buckling. The usual methods of making high-strength concretes include:

- water extraction
- compaction
- autoclave treatment

iii) Expansive concretes: These are known as (a) shrinkage-compensating concretes when expansion of the material is just enough to offset shrinkage during curing, or (b) self-stressing prestressed concretes, when the material expands sufficiently to effect prestressing by constraining free expansion.

Critisism of Precast Concrete Building Systems

Post and beam systems generally provide only the structure and skin of a building. As of today, this statement is also true of most panel systems. Figure 16 shows the operations that have to be performed on-site after the erection of structure and skin. Table 6 gives an estimate of the percentage of construction cost formed by structure and skin. It can be seen that, through prefabrication of structure and skin, savings in only 37 per cent of the total construction cost can be realized in the case of low-cost housing.

Box systems are generally total systems. Up to 90 per cent by cost of the total construction is fabricated in the plant. These systems arrive on-site with all finishings ready and incorporate compatible mechanical and electrical equipment. Sometimes, they even include furniture. Unfortunately, precast concrete box systems are the exception rather than the rule in the industry today.

Given the right market conditions, there are obvious advantages to be derived by moving more and more of the construction into the plant: For one, in this way, the precast concrete industry would expand to supply a much higher per cent of a building. In addition, it would become more competitive as it would replace labor intensive on-site finishings (see Table 7) with mechanized production in the plant. Also, from the point of view of the government, the desire to expand the effective demand for low-income housing (feasible only through substantial price decreases in housing) stands a much better chance to be fulfilled if more of the building construction moves in the plant.

The vital question is: What are the "right" market conditions under which it would be wise for the industry to move to prefabrication of finishings and, finally, to the production of total systems?

As of today, investment in the precast concrete industry is regarded as risky--as evidenced by the high required rates of return (14). These high rates of return raise the cost of capital of the industry and leads it towards labor-intensive operations. In addition, also as a response to the estimated high risk, the industry adopted the "watch and see" approach, as evidenced--among other things--by the size of the plants: As of 1973, there are not many very large plants of the Lustron size. There is no nationwide copying of the technologies of Habitat and of the San Antonio Hilton.

Is the industry being too conservative, losing potential profits which might accrue by increasing the percentage of the construction which is fabricated in the plant? This is one of the vital questions which the industry as a whole should face.

2.3 Production and Assembly Technology

The production technology employed by the precast concrete industry is described in detail in the literature (for example, see References 37, 43, 51). Briefly, the employed technology ranges from labor to capital intensive, depending upon:

a) The size of the market.

In general, the more highly capital intensive the technology, the higher the level of output required to reach the break-even point (84). Therefore, since an adequate* market has not yet been secured in the U. S., the precast concrete industry tends to be labor intensive.

b) The achieved degree of standardization.

The optimum degree of standardization is a vital problem to be faced by the industry: Reducing the variety can help to

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*"adequate" from the point of view of justifying a capital intensive operation.

increase the demand for a standard component, but it may conflict with the user's needs. The greater the reduction in the variety of components available, the less it is likely that a particular user's requirements can be completely satisfied. Thus, the industry has to try to find the optimum solution between flexibility and reduction in cost.

Severe standardization was adopted in Eastern Europe, with an attendant reduction in the number of different components and in the number of pieces of production equipment; this led to the introudction of an automated process giving high productivity and low cost per item.

On the other hand, in free markets, much greater flexibility in design was deemed necessary. In an extreme case, the Balency system in Europe advertizes: "You design a building and then our engineers come and fit it with the system"; that is, they propose to panelize a given building rather than build it with standardized panels.

c) The cost of capital relative to the cost of labor.

As mentioned above, today, the precast concrete industry is considered a risky investment and, as a result, the cost of capital is high. This leads the industry towards the direction of being labor intensive.

Generally, and in terms of configuration, we can distinguish between two types of production (86). The first--known as assembly-point configuration--is an arrangement where the precast components remain stationary while the resources and materials move to the component assembly sites. The second--known as assembly-tree configuration--is an arrangement where the resources remain stationary while the items move through a network of stations in a predetermined sequence; the items meet at specified assemblies where they are formed into a single item.

In many cases a hybrid configuration is employed composed of the above two. For example, a configuration could employ the assembly-point approach for processing some of the items that compose the precast component and the assembly-tree approach for the remaining items.

The main production systems that fall under the first category (assembly-point configuration) are tilting tables, batteries, and hollow-core slab extrusion systems.

In the case of tilting tables all operations are performed at the site of the table by different beams of workers in a predetermined sequential order. After the casting and curing is completed, the table can be tilted up by about 85 degrees to facilitate the handling of the component. Tilting may, for instance, be effected by means of suitable hydraulic jacking equipment. Alternatively, the table can be equipped with suspension devices which are engaged by the lifting gear of the overhead travelling crane; by such means, the table can be swung to the nearly vertical position. The tilting table method is labor intensive and requires skilled manpower if high quality and speed are to be achieved. It is mainly used for small-scale production or for casting of special types of elements (like facade elements with special architectural requirements). It is also used for the production of sandwich elements containing plumbing and heating fixtures or materials for insulation.

In the battery method (Fig. 17, 18) the mold consists of a series of vertical steel plates; these plates form usually six to ten cells into which concrete is being poured from their open top. It is possible to adjust these cells within wide limits with respect to the thickness, width, and height of the slabs to be made. Often molds are installed below the factory floor level so that concrete can be placed in them with the least possible expense. Among the advantages of the method is that lifting the individual components can be done quite easily by equipping each panel with lifting eyes; furthermore, the surface finish of the panels produced is perfectly smooth and does not require any further grinding or polishing; finally, in the case of walls, since the latter are poured in a vertical position, an economy of 10 - 20 per cent on steel reinforcement is realized.

Relative to tilting tables, batteries require a higher initial investment. On the other hand, productivity is higher and the cost per panel is, for this reason, lower.

An operation with even higher productivity, which also is more capital intensive than the above, is the extrusion of hollow-core slabs (37). Here, the casting operation is performed by sophisticated extruders in a continuous sequence. The extruder advances on a long casting bed, leaving behind hollow-core slabs made of concrete which have been vibrated and compacted and which have sufficient strength that a worker can step on it (without causing any damage) immediately after casting.*

In the area of assembly-tree configurations, important categories are the pallet-line method and the continuous-moving conveyor method.

In the pallet-line method, concrete panels are cast on individual pallets which move from station to station for each set of operations; that is, the teams of workers are assigned fixed positions while the pallets are moved along the assembly line by an overhead crane or, rarely, by roller-mounted carts. After casting the concrete, the pallets are removed from the assembly line and stacked in a curing chamber. The latter phase often proves to be the bottleneck of the line, as curing time is at least three hours (37).

The continuous moving-conveyor method today is considered to be the ultimate in automation of precast concrete production. One of the best examples is the vibro-rolling mill of Kozlov (U.S.S.R.) still considered to be in the experimental stage. This is the most capital intensive as well as the most efficient and highly productive method today.

Of special importance to the precast concrete industry are the available curing techniques which enable the industry to shorten curing time thereby reducing plant immobilization time. To reduce curing time, wide use is made in the industry of the rule that increased temperature speeds up chemical reactions (such as the hydration of concrete). According to

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*Tilting tables, batteries, and slab extrusions are the main methods used by the industry for panel and slab production. Precast concrete components such as columns, beams, puzlins, etc. are preferably manufactured in wooden, steel or plastic individual, stationary molds. If prestressing is employed, the components may either be made by the "long-line" process, in which a number of components are cast one behind the other on a prestressing bed, or by the individual mold method.

the levels of temperature and pressure used in curing concrete, we can distinguish:

1. Atmospheric Curing

   After casting, the concrete elements are allowed to set for fifteen - twenty minutes. Then, the temperature is gradually raised to a constant level and kept there until the strength of the elements reaches the desired level. The elements are then gradually cooled to ambient temperature. High temperatures are achieved through the use of hot steam, hot water, hot oil, or by electric resistance heating.

2. Autoclave Curing

   Here concrete elements are placed in a special hermetically closed chamber, in which the steam pressure rises to 150 psig. As of today, this method is mainly restricted to small size elements like concrete blocks. However, the trend is to use the method for larger and larger elements.

3. Vacuum Curing

   In this method, concrete is mixed with sufficient water to fill completely the form after being vibrated. Vacuum is then applied, which squeezes out all excess water not required for the hydration of cement.

Although not yet widely used, the method has yielded very good results and is considered to be very promising.

After production, the precast elements have to be transported and erected on site. Many workers in the field believe (79) that the most promising opportunities for cost reduction in precast concrete construction are through reduction of the time and amount of operations done on site. To this end, designers of precast concrete systems have currently developed plans for work programming and organization that complement the efficiency of factory production.

The first major innovation has been the development of the "flow-line" method. In this method, construction is divided into a series of operations, each of which is undertaken by a separate team at a specific work station. Insofar as possible, the required time at each work station is made as nearly as possible the same for all teams. In the simplest case, therefore, after the first team has completed its job at the first work station, the second team begins at the first work station, and the first team moves on to begin work at the second work station.

A second major change has resulted from the greatly increased use of mechanical power on the work site. A good index for this is the utilization of cranes. The tendency here is not only to make more use of cranes but also to make use of cranes able to carry greater and greater loads. In this way, larger elements can be used requiring fewer joints on site.

2.4 Manpower

2.4.1 Managerial Talent

As discussed in Chapter 1, good quality managerial talent is a scarcity in conventional construction. In the precast concrete industry, the quality of managerial talent employed is, in general, proportional to the size of the plant. Large plants are able to derive economies of scale from two sources: one, advanced production technology and two, managerial efficiency. Some authors in the field argue that the economies derived in large plants, as a result of the availability of good management, are even more significant than those derived from the technologically more efficient operations (64).

2.4.2 Labor Unions (66)

Reference 50 identifies four aspects of technological changes which are involved in prefabrication of construction. These are:

1. increasing mechanization of the construction processes;
2. increasing standardization of components;
3. transferring of work traditionally done on-site to an off-site location; and
4. recombining of job tasks at the job site

The unions' perceptions of the impact of such change on their future job security, jurisdictional control, and health and safety determine their reaction to the change; namely whether they will try to encourage, compete with, control, or obstruct its introduction and use.

Job security is of utmost importance to the unions, especially in an industry which is as insecure as the construction industry. Reference 11 cites three goals which, if achieved, could provide job security:

1. obtaining full employment for the union's members;
2. securing a satisfactory wage for its members; and
3. preserving skills traditionally performed by its members.

- Increasing mechanization of the construction processes might be seen by some unions as a threat to the first and third of these goals.
- Increasing standardization of components might seem to threaten the third goal.

- Transferring of work off-site might seem threatening to all three goals, and finally,
- Recombining of job tasks might threaten the first and third goals.

On the other hand, technological change might be perceived by other unions as improving their job security by creating new jobs, providing more employment during winter, and so on. The diversity of effects on various unions is well demonstrated by the results of an analysis of impact on various unions given in reference 11. According to these results, prefabrication offers to the operating engineers and electrical workers the greatest opportunity for growth; and to the painters and bricklayers the least (a decrease is, in fact, predicted). Furthermore, operating engineers will have the greatest need for new skills, and the plumbers, carpenters, and electrical workers will be affected most by relocation from the job site to the factory.

Jurisdictional control is another item of considerable importance to unions. The recombination of job tasks on-site, as often occurs when a prefabricated product, manufactured by combining the skills of several trades, is brought onto the site to be installed, is seen by the unions to be a serious threat to their jurisdictional control. The result is a series of disputes.

In the controlled environment of a precast concrete plant, workers enjoy, on the average, better health and safety than in conventional construction.

The main policies adopted by these unions which decided to resist prefabrication in construction are (19): (1) a policy of obstruction; for example, the carpenters have refused to install prehung doors on the basis of a work preservation clause in their contract; and (2) a policy of control; for example, the tri-grade agreement, made by the electricians, plumbers, and carpenters with Prestige Structures, Inc., of Charlotte, Michigan, gave the three unions some control over work in the plant and on the job site (50).

Both of the above policies force the industry to use labor over and above its needs: This is the practice of featherbedding. Specifically:

Obstructing the use of prefabricated products may be done by:

1. requiring certain types of work to be done on the job site and refusing to handle or install such items which do not require the performance of traditional craft duties on the job site.
   To achieve the above, the unions seek to incorporate work preservation clauses in their contracts and to include contractual clauses which limit the subcontracting of work to be performed at the job site (9).
2. requiring excessive manpower or pay or performance of unnecessary tasks for the installation of the prefabricated items, or
3. refusing to use certain tools required for the installation of precast components. A policy of control of prefabrication by unions leads to similar results in terms of featherbedding (70).

Seriousness of the Unions' Constraint

There have not really been any comprehensive studies done on the impact of unions' resistance to the use of precast concrete systems. There are a number of reasons for this, among which are that the various unions react differently, that the industry and its unions are so fragmented that it is hard to make generalizations, and that apparent restrictive practices are sometimes the results not only of the efforts and interests of unions but also of contractors and suppliers. About the only conclusion that can be reached is that unions to date have not used all their potential (which is considerable) to resist prefabrication. For example, in studies done by Haber and Levinson (31),and by Maisel (46), it has been concluded that restrictive practices of unions might increase the total costs to a house buyer by 3 to 8 per cent.

But what if the unions in the future exert the full magnitude of their potential to create more jobs for their members and to increase the wages in the plant? For example, in England, workers get equal pay whether for on-site construction or off-site precasting. A study of the influence of such a labor policy on the future of the industry is greatly needed.

2.5 Costs of Precast Concrete Construction

The viability of the precast concrete industry highly depends upon the competitiveness of its products in terms of cost. An assessment of the economic performance of precast concrete products should include an estimate of the life of the products and of the necessary maintenance and repairs throughout their lifetime. On the other hand, in the short run, economic performance includes only the initial cost.

Precasters sometimes claim that their products are relatively free of maintenance. The fact remains that the precast industry is a relatively new industry, and there is little data available on the long-run performance of its products. References 14, 13, 37, 24, 33 provide useful data as well as methods of breaking down the initial costs of building systems. In addition, extensive data are provided in Chapter 4 of this work where also the initial cost performance of precast concrete is analysed in detail. Therefore, it would suffice to state here that the cost of precast systems (a) is determined by a wealth of variables, the most important of which are:

- the size of the market

  The larger the size of the market, the larger the size of plants; the more the economies to be realized through employment of advanced technology, managerial efficiency, and discounts on materials.
- factory utilization
- perceived riskiness of the industry.

  This affects the cost of capital through the chosen depreciation times (the less confident management is on the market, the sooner and on fewer projects it tries to depreciate fixed assets) and through the required interest rates.
- the level of technology

  The higher the level of technology, the more is output per units of input.
- labor productivity.

(b) The cost of precast systems highly depends upon the interactions of the above variables. Many of these interactions form closed cause-and-effect relationships. For example, the size of the market has an effect on the product cost; the latter, in turn, effects the size of the market. (c) It depends upon dynamic variables; that is, time must be taken into account. For example, the level of technology and labor productivity are functions of time.

Given the complexity of the interrelationships that determine the cost of precast components, it is difficult to estimate how various policies would affect it. Among the problems that merit investigation is how would guaranteed loans with low interest affect the cost; how would increases in labor wages affect the cost; and how would an expansion of the market (by prefabricating a higher percentage of the building in the factory) affect the industry's cost competitiveness.

2.6 Federal and Local Government Rules and Regulations in Construction (Building Codes)

Building codes are barriers to building systems in three ways:

1. There are too many of them. There are over five thousand codes in use in the U. S. and as many as one hundred in a single metropolitan area. This multiplicity of different codes in a small area is an obstacle to the high-volume production of standard parts which industrial methods demand.
2. Building codes are obsolete, one of the reasons being the cost of updating them.
3. They tend to discriminate against new methods and materials by specifying not the desired performance of the building but some specific, well-established means of attaining this end. To

alleviate this last shortcoming, a movement is lately underway to promote performance specifications as a means of promoting innovation. Another advantage of performance specifications would be that by specifying the requirement in functional terms, the social purpose of the standard would be clear. Among the disadvantages of performance specifications are serious problems of implementation. What are the objective tests by which the builder can prove that he has met the requirement? To answer this and other similar questions, the creation of an Institute of Building Sciences has been proposed. The proponents of this solution argue that this institute could be part of a National Council for the Development of Standards. With initial government funding, this organization could become self-supporting through collection of fees and subscriptions. Its activities would include the development and updating of building codes, evaluation and certification of building products, equipment, and techniques, the promotion and coordination of research, and the dissemination of information (87). Such an institute while advocated by both the Kaiser Committee and the Douglas Commission is not as yet a reality.

However, the seriousness of the constraint posed by the building codes has been alleviated by certain governmental steps as well as by the efforts of private citizens. For example, after testing of the Operation Breakthrough prototypes, a certificate is provided by H.U.D. to the system. It is hoped that this certificate will override local building codes and will be considered adequate evidence of the safety and soundness of the systems. In addition, during the past two years (1970-72), California, Ohio, Washington, and Virginia have passed legislation under which the state evaluates and certifies industrialized systems, which are then freed from having to meet local requirements (Ohio's law concerning industrialized systems will probably be challenged by a city and its constitutionality will be judged by the courts) (87).

Even though the constraint imposed by building codes still exists, the steps described above, as well as other steps which are being taken in the same direction, seem to lend support to a concensus (44,11) that codes of this kind are not any more determinant factors in the success of building systems.

2.7 Research and Development (R & D)

Funds for R & D come from three sources: the industry, the government, and the consumer. According to reference 58, the industry must make sure that at no time are funds allocated for R & D less than 1 per cent of total industry revenue.

The R & D effort can be channelled into two directions. In the first, R & D is used aiming to raise the level of production and assembly technology--thereby decreasing the product cost; and, secondly, R & D effort is expended aimed at raising the level of the technical performance and marketability (i.e., responsiveness to user's needs) of the product. There is criticism (73) that too large an amount of Federal funds is spent to promote design rather than production methods. However, by no means has a concensus been reached on what is the optimal way to allocate R & D funds. This is a serious question facing the industry today.

On the other hand, there seems to be a concensus that evolutionary rather than revolutionary changes are to be expected in both directions of R & D effort mentioned above (11). In the case of research on product performance and marketability, the Long-Range Planning Committee of PCI (58)suggests that specific emphasis should be directed towards:

a. Improvement in the strength-weight ratio of concrete. The design advantages of such an improvement are considered by the committee to be the most important single factor in promoting precast concrete construction.

b. Improvement in the design efficiency of structural concrete shapes.

c. Seismic designs and the development of product and connections to meet seismic requirements.

d. Reduction and eventual elimination of volumetric changes in concrete.

e. Achievement of optimum fire ratings for all precast concrete building products.

f. Development of adequate and timely statistics on markets, production, and business, in order to understand better the precast concrete industry and thus be able to improve its competitive position and to measure progress in achieving its goals.

g. Development of efficient information systems for the speedy distribution of R & D results.

In order to enhance product quality, the committee recommends, in addition, the creation of certification programs that will embrace the plants and products of all industry members.

In order to promote standardization of products, the committee recommends the development of a catalog of totally standardized products which would be available throughout the country.

2.8 Summary

Market characteristics, type of product, technology employed, the manpower required, resistance of unions, all interact to determine the competitiveness of the precast concrete industry in terms of cost and quality. R & D is directed to enhance the competitiveness of the industry, and the problems faced by R & D change as the needs of the industry change.

Our knowledge on aspects of the industry varies from being non-existent to being well documented. For example, there is no published data available on the capital structure of the industry. On the other hand, recent surveys list the major and minor concrete producers by plant location and type of product they manufacture. Although we know much about the product categories and production technology, we know considerably less about the costs associated with the production of the various products at different volumes of output.

Some of the constraints on the growth of the industry seem more binding than others. For example, labor resistance or market oscillation appear to be potentially more limiting than building codes.

As evidenced by its sales volume, the precast concrete industry has recently started to experience a significant growth. Decisions taken at this stage will crucially affect its future development. The goals of this work are to study the effect of various anticipated policy decisions and economic conditions on the industry. The peculiar characteristics of the industry have strongly influenced the choice of the approach used in this work. This choice is discussed in detail in Chapter 3.

CHAPTER 3

PRINCIPLES AND METHODOLOGY OF APPROACH

The rapid growth of the precast concrete industry, which has been documented in the previous chapter, has generated a need for a systematic evaluation of specific governmental, labor, and industrial policies, as well as market conditions on its future growth. In order to choose the appropriate methodology for such an evaluation, detailed consideration was given to the major characteristics of the precast concrete industry. These characteristics are summarized below:

1. Only recently has attention been focused on prefabrication. The result is that data on some aspects of the industry are scarce or unavailable.
2. The state of the industry is influenced by a very large number of variables. In Chapter 2, it has been shown that among the major variables are market characteristics, type of product, technology employed, manpower requirements, and the resistance of unions. These major variables can be decomposed into lower level variables. The market, for example, has been decomposed* into building and non-building construction market sectors. Furthermore, the building market has been decomposed into housing and non-housing buildings. The nature of the goals pursued in this work determined the level at which further decomposition of variables become unnecessary for the purpose of the desired analysis.

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*See Chapter 2

3. The interactions of variables which influence the precast concrete industry are of primary importance in determining the effect of various policies and economic conditions on the industry. For example, it has been shown (Chapter 2) that the market characteristics, i.e., size, type, and risk, determine the type of production technology that may be optimally employed.

   - Many of the interactions among variables form a closed chain of cause and effect: For example, market characteristics are among the factors that determine the competitiveness of the products of the industry. Such competitiveness in turn affects the precast market characteristics (size, risk, etc.)
   - Many of the interactions among variables are of a form which is more complicated than a simple linear one: For example, the capital required for fixed assets per plant is due to economies of scale, a non-linear function of the size of the plant.

Given that the performance of the industry is determined by a large number of variables interconnected in a complex way, we need a systematic means for tracing the effect that various policies and conditions will have on the industry. In addition, given the scarcity of data in the industry, we need a quantitative framework which places the fewest restrictions possible to problem representation. Such a quantitative framework or mathematical model which could be used to study the precast concrete industry can basically belong to one of the following three categories (38):

1. Econometric Models

Econometric techniques have been developed by statistical economists engaged in deriving and testing the principles and predictions of economic theory.

These workers employ such well-known techniques as regression, input-output, and Markov processes, all of which are particularly useful where large amounts of data are available. Furthermore, the latter are rather rigid mathematical formulations with no a priori judgement of the goals. It follows precisely from the above characteristics--mathematical rigidity and requirement of masses of data--that the use of econometric methods to construct a model of the precast concrete industry for policy testing ought not to be considered.

2. Linear, Quadratic or Dynamic Programming Models

Linear programming models are closed analytical systems with one objective function. A solution to the problem is one that optimizes the objective function subject to linear constraints. Such a method would be appropriate in cases where there is need to optimize the performance of a well-known system but would be unsuitable if the purpose of the study is (as precisely happens to be the case with this work) to enhance the understanding of a system.

Additional limitations of linear programming that preclude it from being our choice are that we cannot introduce the element of time and that constraints have to be linear.

Dynamic and quadratic programming both have the potential for handling discrete as well as non-linear objective functions; they also have the potential for introducing the dimension of time. However, these too, can be very valuable tools in optimizing the performance of well-known systems rather than being tools which aid in understanding systems. In addition, as of today, these methods can handle only quite limited number of variables (see Table 8).

3. Simulation Models

Of the three categories of mathematical models described in this chapter, simulation places the weakest restrictions on problem representation. Practically the only requirement is that variables should be quantified and their interrelationships defined. Then, if the state of the system is known at one point in time, the equations that describe the variable interrelationships can be used to compute the state of the system at the next point in time. By repeating this process in step-by-step fashion, it is possible to calculate the course of variables over any desired time interval and produce various patterns of industry adjustment corresponding to various assumptions about the nature of dynamic change.

A simulation model can be used to enhance our understanding of a system in the following way: Various well-defined assumptions (inputs) are introduced in the model, and the corresponding behavior of the model (output) is observed; this process is repeated as long as is necessary to observe model behavior which is self-consistent as well as conforming as best as possible to the few known characteristics of the actual system.

Once we have confidence on such a model, it can be used to trace the effect on the system of various policies.

To obtain quantitative results, one assigns specific values to all parameters. Then, if it is desired to try different parameter values, the whole set of calculations has to be repeated once more ("rerun" of the model). There are several significant advantages to simulation (32).

1. The model can contain many variables.
2. It is not restricted to linear formulations.
3. It has considerable tolerance for unverified assumptions and unexplained relationships.
4. It is dynamic, i.e., it contains time as a variable.
5. Minor changes (e.g., leading to investigations of alternative formulations or use of different parameter values) can be easily made.
6. It can be inexpensively used.

The above advantages of simulation, considered together with the shortcomings of the other modeling techniques with respect to our particular problem, have led to a choice of simulation modeling in this work.

There are basically two types of simulation:

A. <u>Discrete or Event Simulation</u>

Discrete simulation is concerned with the discrete events producing changes in the state of the system. For example, when simulating a company, individual orders are traced through each step of production. However, in the broader case of simulating the whole industry, such detail may obscure the momentum and continuity exhibited by the industrial systems with which we are concerned.

B. Continuous Simulation

The system is described on the basis of continuous flows and interactions of variables. We feel that this is the most appropriate approach for our problem since a continuous flow model would help to concentrate attention on the central framework of the system. Diversion of attention toward separate isolated events at this stage of our knowledge of the industry would tend to obscure the central structure of the system that we are trying to define.

Generally, a description of a continuous flow system is made by means of a set of simultaneous differential equations. If a digital computer is used, as is usually the case, the set of simultaneous differential equations is approximated by a set of non-simultaneous difference equations.

Of special interest is the industrial dynamics approach--a continuous simulation approach--developed at M.I.T. by J. Forrester and co-workers (28,29). The advantages of the industrial dynamics approach are:

- It is basically a philosophy of structure in systems. Its basic procedure is to follow cause and effect so that one will have representational rather than phenomenological hypotheses. In our case, where it is the structure of the industry itself (rather than, say, technology alone or labor alone) that determines the failure or success of the various policies, an approach emphasizing structure would be most appropriate.

- In addition, the industrial dynamics approach, for all practical purposes, poses no limits to the number of variables that can be used and poses no restrictions to the form of their interactions.
- The approach has been extensively used to model the structure of various industries with very good success (for example, see References 67, 61, 49, 85).
- Together with convenient conventions to represent the model, the Industrial Dynamics group at M.I.T. has developed a special-purpose compiler for digital computers which is called DYNAMO (60). The use of DYNAMO is optional; one can use a general-purpose program compiler like FORTRAN instead. However, DYNAMO has been preferred in this work because it offers the following advantages (28).
- More easily understood model statements--which is not a trivial advantage if the model is to be understood by policy makers who may not be familiar with computer programming languages.
- Easily specified outputs in both tabular and plot formats.
- Automatic ordering of equations for computation of results.
- Thorough error checking ("debugging") and easily understood error remarks.
- Faster compilation and faster simulation operations.

Having decided to use an industrial dynamics type model in our work, our specific methodology consists of three steps:

1. Problem Conceptualization

This is by far the most important step in model building. It includes problem definition, a clear statement of objectives, the time horizon of the study, variables to be included, level of aggregation of variables, and system structure.

2. Model Representation

In this step explicit assumptions are made about the interrelationships of variables, measurements of constants are made and initial values of variables are obtained, and finally, equations are written in DYNAMO notation.

3. Model Validation

This is an area of modeling in which much research needs to be done. At the present stage of development, we feel that "adequate" is a more appropriate word than "valid" for a model, since "valid" is a rather inflexible word implying that a model is either entirely sound or else is not valid. However, there is no such thing as an entirely sound model in the sense that it is a perfect representation of the real world. As an abstraction from reality, the model leaves some of the reality behind. Therefore, the question of the model validation is one of degree and subjective judgement, and we feel that the real issue now is: "Is the model adequate for the purposes for which it has been built?" Before one can answer this question, a clear statement of what the model builder expects from the model should be made:

- In building the model of the precast concrete industry, we expect to enhance our understanding and to clarify our thinking about the industry in its current state.
- In addition, we are interested in predicting the direction and approximate extent of the major changes in the performance of the industry occurring as the result of various alternative policies which may be implemented in the future.

At this stage of our understanding of the precast concrete industry we cannot expect the model to predict the exact state of the industry at specific future times (28). This is so because exact predictions require perfect knowledge. If, for example, the frequencies and growth rates of the model variables and their real world counterparts are not exactly the same, or if they are excited into changing phase owing to different noise in the model and the real industry, the variable of the real industry will not have the same value with the corresponding variable of the model. This does not imply that modeling is not worth our efforts. It still helps us to understand the industry and derive predictions of the directions and extent of the major changes in the industry as a result of the tested policies.

But how do we know that we have actually achieved these goals? An actual test is possible only after a specific desired change has been actually brought about and there is some measurement or observation of the performed change in the real system. In the absence of such an actual, definitive test, there are several alternative testing procedures that can be followed to study the validity or "adequacy" of the model.

1. Model Structure

Have the appropriate variables been included and are they properly interrelated? By the word "appropriate," we mean those variables that are necessary and sufficient to meet our goals. By "properly interrelated," we mean that the dependency of the variables on other variables is sensible, its form is reasonable, and its direction follows cause and effect.

2. Sensitivity Testing

Have we performed sensitivity tests to isolate the parameters to which the model is sensitive? Are we confident of the values of these parameters? Have the residuals been carefully studied for signs of missing variables?

3. Overall Model Behavior

Is the overall model behavior reasonable? If the model is run over a period of time for which there is historical data, does it reproduce history reasonably well? If not, the model is not "valid." If yes, the model might be "valid," but not necessarily so since there is an endless variety of invalid data and structure that can give the same apparent system behavior.

A completely tight-proof test of model validity is an unrealistic expectation. There are only certain tests to be performed, and the more tests the model passes the more our confidence of the "validity" or "adequacy" of the model is enhanced. Care should be exercised to properly select the tests. For example, the results of a standard statistical test of an industrial dynamics model would be misleading.

Consider an attempt to assess the predictive accuracy of the model by the least squares method. The test generates a coefficient of determination R^2, which is a measure of the number of locations where actual and predicted values agree. But it does not take into account patterns of growth or change and the ability of the model to predict patterns may be more important than its ability to predict exact magnitudes. Such a test would assign a very low validity to a model which can predict the actual pattern of changes although slightly shifted in time.

To summarize, after a consideration of problem characteristics and of available methodologies, the industrial dynamics approach has been chosen as best suiting our purposes. The specific steps to be taken for the development of an industrial dynamics model of the pre-cast concrete industry and the expectations from such a model have been discussed. The next chapter is a detailed description of the model developed in this thesis.

CHAPTER 4

A SIMULATION MODEL OF THE PRECAST CONCRETE INDUSTRY

4.1 An Overview of the Model

This chapter presents a mathematical model which simulates the performance of the precast concrete industry. For reasons discussed in Chapter 3, the model is based on the industrial dynamics approach, emphasizing the interrelationships between the variables which determine the state of the precast concrete industry.

Figure 19 provides an overview of the model. Arrows connect two variables when they interact. The arrow points from the variable that causes a change to the variable that is affected by the change. When a variable is only cause of changes and cannot be altered by the other variables, it is called an "external" variable to the model.* The alternative, an "internal" variable of the model can be changed by the other variables. It can be seen that causality (as indicated by the arrows) can be linear or circular. Circular causality, or a closed continuous path from one variable to another and then back, is called a feedback loop. For reasons of simplicity, Fig. 19 shows the main variables in the model in a highly aggregated form. Thus, although direct paths are shown to and from the interacting major variables in the figure, in the detailed model (discussed in section 4.5 and graphically shown in Fig. 20), paths pass through several intermediate variables.

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*Arrows in the figure would only start from (and not point to) such a variable.

The basic chains of cause and effect (feedback loops) in the model are:

- The cost of precast products partly determines the precast market which, through its size, influences the product cost.
- As precast concrete starts acquiring a significant share of the market, the conventional concrete industry responds through mechanization which increases its competitiveness and diminishes the share of the market acquired by precast concrete.
- Product quality (that is, product technical performance and marketability) helps to determine the size of the market which, in turn, determines the magnitude of funds to be spent for R & D with a resulting effect on product quality.

The known or hypothesized relationships between the model variables are presented in a precise form in Appendix A and are discussed in section 4.5.

4.2 Federal, Labor, and Industrial Policies and Economic Conditions Tested by the Model

The precast concrete industry model developed in this thesis was built specifically to investigate a number of policies and economic conditions.* These are presented below in the form of questions to which a satisfactory answer will be sought:

- Is it profitable and if so when is it most profitable for the precast concrete industry to move from prefabrication of structure

*The importance to the industry of these issues has been argued in Chapter 3.

and skin to prefabrication of structure, skin, and finishings and finally to total systems?

- What benefits would the industry derive from government guaranteed loans at low interest?
- What would be the effect on the precast concrete industry of different patterns of demand for middle-and high-rise buildings?
- What would be the effect on the industry of increased labor resistance?

What is the optimal allocation of funds for R & D?

4.3 The Basic Assumptions of the Model are the Following:

1. The main market of precast concrete industry includes (a) multi-unit housing in the low-cost range; (b) multi-unit housing in the high-cost range; and (c) high- and middle-rise non-housing buildings.
2. The main competitor in the above market is conventional concrete construction.
3. The data on effective demand within each of the three market categories mentioned above are a variable external to the model. In other words, the performance of the precast concrete industry would not affect the size of the market: The precast product would merely increase its share relative to that of conventional concrete. An exception is the case of the low-cost housing market which would expand as precast concrete achieves substantial gains.
4. The architect is the agent who decides what share of the market goes to precast concrete. This decision is reached following an

assessment of the precast product which is based on three grounds. These are:

i) The ability of the product to meet the needs of a client (for example, in the case of a building, this would consist of design flexibility, aesthetics, etc.). This quality is called marketability of the product.

ii) Technical performance--examples of this in the case of a building would be thermal insulation, sound insulation, fire resistance, and watertightness

iii) Economic performance - besides cost, criteria of economic performance over a long term normally include maintenance, services, and the lifetime of the product.

5. The precast concrete systems will mature in the following sequence.

   i) prefabrication of structure and skin,

   ii) prefabrication of structure, skin, and finishings,

   iii) total systems; that is, in addition to what is covered in Step (ii), included here are systems with integrated mechanical and electrical equipment.

   The model provides for the dynamics of the industry in all three degrees of prefabrication stated above.

6. Research and development (R & D) helps to raise the level of economic and technical performance of the product as well as its marketability.

   The funds for R & D come from three sources: the government, the industry, and the consumers.

7. Since the precast concrete industry is capital intensive, the instability of the construction industry makes an investment in it a high risk proposition.

8. The resistance of labor unions to precast construction is expressed by their forcing the industry to hire labor over and above its needs (example, the crew of ten men that escorts concrete boxes and panels).

4.4 The Basic Features of the Model are the Following:

1. In the current form, the model describes in detail the short-term economic performance, namely, the initial cost of precast concrete construction. The components of cost are:

   a) For the precast concrete industry:

      cost of capital for the production of precast members

      cost of labor in the factory and on site

      cost of materials

      factory operating overhead, transportation and site overhead

      total cost of precast concrete

   b) For the conventional concrete industry (the competitor sector):

      cost of labor
      cost of materials
      overhead cost

      total cost of conventional concrete

2. The emphasis of the model is on precast concrete building systems. However, part of the output of the industry is in the form of

precast concrete components sold to the building and bridge market. The model estimates the output of components as well, in order to derive plant capacity requirements and economies of scale.

4.5 Model Description

What follows is a description of the sections appearing in the simulation model of the precast concrete industry in order of their appearance in the model. The whole model in graphical form, showing how the various sections are interconnected, appears in Fig. 19 and 20. The model itself, followed by a description of names of variables used in it, appears in Appendix A.

4.5.1 Total Market

The main market for the precast concrete industry is that of buildings which exceed a certain critical volume (i.e., primarily middle- and high-rise buildings) so that the use of prefabricated concrete is economically justified (Reference 4). The secondary market for the precast concrete industry is non-building, mainly bridge, construction (Reference 42).

Conventional concrete is also very competitive in the middle- and high-rise building market (wood dominates in the construction of single-family houses, while steel dominates in single-story industrial building construction). Therefore, conventional concrete is the main competitor of precast concrete (37).

In this sector of the model, the market for concrete plays the role of an external variable. Only one section of this market, namely, low-cost housing, expands if precast concrete becomes economically very attractive in it (variable EM in the model).

The high-volume concrete building market is broken into three segments in the model: the multi-unit low-cost housing, the multi-unit high-cost housing, and the high-volume, non-housing building market.* This subdivision was necessary in view of the fact that differences in cost and quality have different effects on the three markets named above.

What follows is a description of the model inputs in terms of effective demand for the three main building market categories as well as for the bridge market.

Multi-unit Housing

The model input for effective demand in the area of multi-unit housing is shown in Fig. 21. This figure shows in millions of square feet of housing starts the housing market for five or more family units.** From 1960 to 1972, the data are historical. Projections thereafter were derived from Reference 72a on the assumption that dwellings with five or more family units would comprise 40 per cent of the total residential construction. It is interesting to note

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*Throughout the model the following convention has been adopted: Variables referring to low-cost housing have the number 1 at their end; those referring to high-cost housing have the number 2 at their end; and variables referring to non-housing buildings end with the number 3.

**Construction Review (78) gives the number of units started per year. This number was multiplied by the number of square feet per unit, taken from Reference 22, to derive Fig. 21.

that while residential construction as a whole oscillates with a six-year period not showing any net average growth between 1950 and 1970 (Fig. 7), residential construction with five or more family units shows a considerable growth due to its increased share of the residential market (Fig. 3). For the following reasons, multi-unit housing is expected to keep its high share of the residential market:

1. Land has become very expensive, and there are no signs showing that the cost of land will decrease (Reference 1)
2. Population changes; (Reference 72a)

- The primary single-family homeowning groups, ages 30-54, will experience no growth from 1970 to 1985.
- Conversely members of the population aged between 20 and 30 will be increasing more rapidly than in the last thirty years. This group, if not living in school, tends to live in multi-unit dwellings.
- Furthermore, the group over 55 will grow by two million. This group too, would tend to live in multi-unit dwellings.

Multi-unit residential construction does not have to follow closely the ups and downs of single-family residential construction: In tight money times, while the rest of residential construction is experiencing a decline, the lenders are more prone to finance income-producing property such as apartments. In view of this, the projections of multi-unit housing demand presented in Fig. 21 do not oscillate.

The alternative hypothesis, namely, that future demand for multi-unit housing would oscillate, is shown in Fig. 22.

Both Figs. 21 and 22 give the total demand for multi-unit housing. The model assumes that 33 per cent of this demand forms the market where concrete is competitive and then it goes on to divide the latter into 18 per cent of high-cost multi-unit concrete housing and 82 per cent of low-cost multi-unit concrete housing. The distinction of multi-unit housing into a high- and low-cost range is based on the cost of finishings; that is, the basic structure and skin cost is the same in both categories. Finishings are much more expensive in high-cost housing than in low-cost housing.

The percentage of multi-unit housing where concrete is competitive was estimated as follows:

Twenty per cent of multi-unit housing involves high-rise buildings (80), in 100 per cent of which concrete is competitive. The remaining 80 per cent of multi-unit housing is in garden apartments, town houses, and clusters. Reference 44 gives the results of a survey on producers of factory-built homes. It reveals that concrete was the predominant material in 16.16 per cent of their systems for garden apartments, town houses, and clusters (Table 9). If we are to assumme that precast concrete has the same percentage of the market among building systems that conventional concrete enjoys in conventional construction, then the total market where concrete is competitive is 0.2 + 16.16 x (0.8) = 0.33 of the total market.

Both of the assumptions above, on the percentage that concrete occupies in the multi-unit housing market and on the ratio of low-cost versus high-cost housing, represent our best judgement based on data presently available. If in the future more data become available, these two coefficients might have to be changed in the model.

Non-housing Buildings

Besides multi-unit housing concrete is competitive in high-volume non-housing buildings (Market 3 in the model). For the purposes of the model, non-housing buildings are taken to be commercial, educational, non-housekeeping, residential buildings and hospitals, as shown in Table 10. The high-volume buildings among those are assumed to account for 20 per cent of the total square footage. Figure 23 gives in millions of square feet the sum of the four categories above (both high- and low-volume buildings are included). Historical data are taken from Reference 81 and 78 and projections are based on Reference 21.

Bridge Market

In addition to its use in buildings, precast concrete enjoys also demand in other areas as shown in Table 11. Outside the building market, the main area in which precast concrete sells its products is the bridge market. For this reason, the bridge market is also included in the model as shown in Fig. 24. Both historical data and projections in Fig. 24 are based on Reference 5.

4.5.2 Per Cent Industrialized Coefficient

The precast concrete systems will mature in the following sequence:

1. prefabrication of structure and skin
2. prefabrication of structure, skin, and finishings

3. total systems: In addition to what is covered in Step 2, systems will be developed with integrated mechanical and electrical equipment.

The per cent industrialized coefficient (PIC) can acquire the values of either 1, 2, or 3. When PIC = 1, the precast concrete industry prefabricates only structure and skin. Where PIC = 2, the precast concrete industry prefabricates structure, skin, and finishings; and for PIC = 3, the industry moves to production of total systems.

4.5.3 Funds for Research and Development

Funds for R & D accumulate from three sources: the industry, the government, and the consumer.

- The industry spends approximately 1 per cent of its total revenue on R & D (Reference 58).
- The government contributes about 15 million a year to R & D (Reference 76).
- As the industry grows, it attracts more of the interest of the consumer who invests more in the industry. The model assumes that funds for R & D coming from consumers are proportional to industrial funds while the latter are proportional to the total revenue of the industry.

4.5.4 Product Performance and Marketability

As indicated in Fig. 25 and defined above under "The Basic Assumptions of the Model," precast concrete is to be judged in terms of its ability to meet the user's requirements (a quality called marketability), its technical performance, and its cost. The model lumps the qualities of marketability and technical performance into one variable called Product Performance and Marketability (PPM). The level of PPM varies with time in a sigmoid manner (see Fig. 26). There is a slow initial growth, followed by a rapid growth which slows again as PPM appears to approach maturity. From then on, the level of PPM rises at a constant rate of 0.15 units of performance per year, the same rise that the conventional concrete industry experiences. The absolute value of the annual rise in PPM level after it reaches maturity is of no consequence to the results as long as it is identical to that of conventional concrete. The value of 0.15 was chosen here as a reasonable number since the model requires specific numerical assumptions.*

A rise in the level of PPM can come from two sources: (a) a planned rise that is proportional to money spent on R & D to raise the level of PPM and which depends on the present level of PPM; and (b) a revolutionary change in PPM. This is indicated as a pulse of magnitude MRCPPM (for Magnitude of Revolutionary Change in Product Performance and Marketability) at a time RCPPMT (for Revolutionary Change in Product Performance and Marketability Time).

The money spent on R & D to raise the level of product performance and marketability results in implementation of the research after

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*It is the difference in the levels of product performance and marketability between precast and conventional concrete that determines the product market. The absolute value of PPM has no effect whatsoever.

three years work. In the model, this money is multiplied by a deflator derived from Fig. 27 to account for differences in the purchasing power of the dollar during the 25 years that the model covers.*

There is also a decision variable F, the fraction of the total money for R & D that would be spent to raise the level of PPM. By giving various values to F, we can study the effect of various allocations of funds for R & D at various times basing ourselves on the assumption that the rise in PPM is proportional to money spent on R & D and is also a function of present level of PPM.

4.5.5 Product Performance and Marketability of Competitor

It has been assumed that the Product Performance and Marketability of Competitor (PPMC), i.e., of conventional concrete, has already reached maturity. In the model, PPMC advances at a constant rate of 0.15 performance units per year.**

4.5.6 Per Cent Difference in Quality Between Precast and Competitor

The previous sections give the mean values of PPM and PPMC. On the assumption that the distribution of these values is normal with a standard deviation of 1, the model derives the probability that Precast has Better Quality (PPBQ) and the expected Per cent Difference in Quality (PDQ) between precast and competitor.***

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*The model runs from 1960 to 1985.

**See remarks on this figure in the section on Product Performance and Marketability

***"Quality" here is taken to mean product performance and marketability.

The normal distribution is given by the formula

$$P(Q) = \frac{1}{\sqrt{2 \times \pi}} \times \frac{1}{SDQ} \times e^{-(Q-MV)^2/2 \times SDQ^2} \qquad (1)$$

where SDQ is the standard deviation, and MV is the mean value.

For SDQ = 1 and Q = MV + 4 x SDQ = MV + 4, the probability P(Q) is approximately zero. Then, the probability that precast has better quality is given by:

$$PPBQ = \int_{PPMC-4}^{PPMC+5.5} PP(Q) \times CPC(Q) \times dQ^{*} \qquad (2)$$

where: PP(Q) = probability that precast has quality Q

$$CPC(Q) = \int_{PPMC-4}^{Q} PC(Q)dQ$$ = cumulative probability for competitor (probability that competitor has quality with a value less than Q)

PC(Q) = probability that competitor has quality Q .

For example, for Q = A (see Fig. 28), the probability that precast has better quality equals the probability that precast has the value A or PP(A) times the probability that the competitor has a value less than A or CPC(A).

Since we cannot integrate with respect to Q with DYNAMO, Equation (2) was made discrete, and then the various terms were added. The values for the cumulative standardized normal distribution were taken from tables of Reference 53.

The expected difference in quality between precast and competitor is given by Equation (3):

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*For $Q < PPMC - 4$, $CP(Q) \sim 0$. For $Q > PPMC + 5.5$, it turns out that for all values in the model, $PP(Q) \sim 0$.

$$\int_{PPMC-4}^{PPMC+5.5} [Q - \int_{PPMC-4}^{Q} Q \times \frac{PC(Q)}{CPC(Q)} \, dQ] \times PP(Q) \times CPC(Q) \times dQ \,, \tag{3}$$

and the expected per cent difference between precast and competitor is given by Equation (4).

$$\int_{PPMC-4}^{PPMC+5.5} [\frac{Q}{\int_{PPMC-4}^{Q} Q \times \frac{PC(Q)}{CPC(Q)} \, dQ} - 1] \times PP(Q) \times CPC(Q) \times dQ \,. \tag{4}$$

Equation (4) has been made discrete and given in DYNAMO as the sum of ten terms. The expected values of Q for the various cuts in the cumulative normal standardized distribution have been derived from tables and have been substituted into the equation.

The variable PDQ (per cent difference in quality) measures the actual differences in the levels of product performance and marketability between the precast and conventional concrete. However, the architect would assess the quality of precast concrete on the basis of the differences in quality he perceives rather than on the actual differences. The model assumes a two-year delay in perceiving existing actual quality differences.

4.5.7 Production and Assembly Technology

Technology in this model is regarded as a coefficient: The higher the level of technology, the higher the output per unit of input. The formulation of the production and assembly technology (PAT) section is based on the same principles as the product performance and marketability section; namely, PAT versus time is a sigmoid curve. The growth of PAT slows down to a constant rise of 0.15 arbitrary units of technology per year after technology has reached maturity.

The level of PAT is raised by planned change through R & D and might also be affected by revolutionary change.

Planned change is proportional to money allocated for R & D to raise the level of PAT and depends on the present level of PAT.

A three-year delay is assumed before funding can produce implementation of research effort.

A deflator, derived from Fig. 27, takes into account the differences in purchasing power of the dollar during the 25 years that the model runs. This deflator multiplies the money spent for R & D so that money spent at later times, when the dollar has lost some of its value, can be discounted.

The distinction between level of production and assembly technology on one hand, and the level of product performance and marketability, on the other, is that the first has a direct influence on product cost, while the latter determines product quality.

4.5.8 Savings

The model calculates the mean values of precast cost per square foot* and conventional concrete cost per square foot for all three main markets (low-cost housing, high-cost housing, non-housing buildings). On the assumption that these costs are distributed normally and have a standard deviation of 1, and by following exactly the same steps as for quality, the model derives the probabilities that precast is better

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*This is the cost of the fraction of construction that has been prefabricated and not the total development cost of a building. For example, if the precast concrete industry prefabricates only structure and skin, this is the cost to construct structure and skin per square foot.

than the competitor in terms of costs and per cent difference in cost per square foot.

In these terms, the per cent savings for the total development cost is the per cent difference in cost per square foot, as derived above, times the per cent of the total development cost that the cost of prefabricated square foot represents plus per cent savings due to shortened development time.

According to Table 12, total construction costs amount to 70 per cent of total development costs.

According to Table 6, structure and skin amounts to 37 per cent of total construction costs for low-cost housing.

Figure 29 shows the entire development period for a conventional concrete project and for a project where structure, skin, and finishings were prefabricated.

Table 13 derives the per cent savings due to shortened preconstruction and construction times.

For example, for prefabrication of only structure and skin in the low-cost housing market, per cent savings for the whole project are:

PSAVGS1 = PDCPSF1 x 0.7 x 0.37 + 0.03 .

These are the actual savings. However, the architect would assess the precast concrete performance based on his perception of per cent savings. The model assumes a one-year delay in perceiving per cent savings.

4.5.9 Architect's Preference Function

As Fig. 6 shows, the architect is the person to decide the share of the market that precast concrete is going to occupy. His decision is based on his perception of per cent savings and differences in quality between precast and conventional concrete in the three main precast markets.

Table 14 shows the per cent of the market that the architect would assign to precast concrete for various levels of per cent savings and differences in quality as well as for different markets. These percentages are assumed to be the architect's answer to the following questions:

"We want you to design a specific building type, say, a low-cost apartment building. You are given the expected price and quality differences between a conventional concrete solution and a precast concrete solution. Ignore the fact that perhaps you do not have any experience with precast structures but remember what limitations precast concrete imposes (for example, certain restrictions in geometry, etc.). Considering all the above, how often would you use precast concrete?"

4.5.10 Demanded Precast Market

The demanded share of each of the main markets (low-cost housing, high-cost housing, non-housing buildings) depends on the share of the market assigned by the architect through his preference function. The latter function is based on per cent savings and differences in quality between precast and competition. The required share of the market is the share assigned by the architect times the probability that the per cent savings assumed by the preference function would be realized times the probability that the differences in quality assumed by the preference function would be realized. However, the preference function deals only with positive values for savings and differences in quality (that is, it deals only with cases where precast concrete is both cheaper and has better quality than conventional concrete). To account for cases where one of the axes in Table 14 is negative (that is, where precast concrete is cheaper but of lower quality or cases where the precast concrete is of higher quality than the competitor but more expensive), the following assumptions have been made:

- In the case of low-cost housing, precast concrete would gain 10 per cent* of the cases where it is cheaper but is of lower quality than conventional concrete.
- In the case of high-cost housing, precast concrete would gain 10 per cent* of the cases where it is better but more expensive than conventional concrete, and
- In the case of non-housing buildings, precast concrete would gain 5 per cent of the cases where it is cheaper and of lower quality; and 5 per cent of the cases where it is of higher quality but more expensive.

The required shares of the main precast concrete markets derived above are modified due to the following constraints:

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*This figure is a crude estimate representing our best judgment in the absence of any data.

In addition, the model assumes that no gains in the market are credited to precast low-cost housing when more expensive than conventional, and no gains in the market are credited to precast high-cost housing when of lower quality than conventional.

- Geographic accessibility:

  The model assumes that only 60 per cent* of sites are accessible to precast concrete; that is, even if the architect preferred precast concrete 100 per cent of the time, he would be economically justified to use it only up to 60 per cent of the time.

- Novelty of precast concrete:

  The fact that precast concrete is a "new" product might hinder its use, even in cases of geographic accessibility, in two ways:

  (a) The architects who are already familiar and comfortable with conventional concrete might show some inertia in trying a new product. Table 15 shows that, as of 1971, 75 per cent of the architects that have used building systems do not use them as frequently as possible.

  (b) Precast concrete may be perceived as not being sufficiently tested in the field. The lifetime of a conventional building is about fifty years. Precast concrete has started to be used to a significant extent only after World War II; therefore, its life is shorter than the lifetime of a building.

To account for the relatively young age of precast concrete, a variable called Novelty Multiplier (NM) has been incorporated in the model. This variable rises rapidly in the 60's to reach the value of one in 1985 (Fig. 30).

In the case of low-cost housing and in addition to the influence of the variables discussed above, public policy can exert influence

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*Reference 44 assumes that only up to 50 per cent of sites are accessible to building systems.

in promoting building systems. This can be achieved by preferential treatment in terms of federal loans to communities that use building systems. The model assumes that starting in 1973, public policy would cause an increase of 10 per cent in the demand for low-cost housing based on precast concrete. In our judgment, this represents a plausible figure.*

To the demand for precast concrete derived as discussed above, we should add the fraction of precast concrete output that sells without architectural sanctioning. This is the case of precast components that sell to the bridge market, of precast components (as opposed to precast concrete building systems) that sell to the building market, and of precast concrete building systems whose use has been dictated by the scarcity of labor. A variable called MLTP has been incorporated in the model to account for the precast concrete sales that do not require architectural sanctioning. The level of this variable, besides being proportional to scarcity of labor, is also proportional to the level of precast concrete technology and to the product novelty. (Here again, lack of experience with, say, precast bridge beams could exclude their use.)

The emphasis of the model is on building systems. However, the model has to account for the total output of the precast concrete

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*From the results and discussion in Chapter 5, it can be judged that the results obtained by use of the model are not very sensitive to this assumption. As long as the assumed figures are non-negative and of the same order of magnitude as the present assumption, differences in the assumed influence of public policy would accelerate or decelerate but would not arrest industrial growth.

industry so that it can be used to properly calculate economies of scale, capital requirements, etc. For this, the total output of the precast concrete industry has been divided into three categories:

1. Building systems: The demand for building systems, in ft^2/year, is the demanded share of the market times the total market for all main building markets. In addition, the demand for multi-unit housing has been increased by 27.5 per cent (see Table 16) to account for the industry output of single-family dwellings.
2. Precast components required for the building market, for example, the selling of precast concrete slabs to a conventional steel frame structure: This output is proportional to the sum of the three main markets (that is, proportional to the part of the market wherein concrete is competitive).
3. Precast components required for the non-building market: This output is proportional to the bridge market which is the main precast concrete customer in this category. Since this market is given into millions of dollars (as opposed to the rest of the markets that are given in millions of square feet), the demand is multiplied by a conversion coefficient which equals unity over (cost of components per square foot) to convert it into square feet.

Finally, the total demand--the required capacity of the precast concrete industry--is the sum of the demand for building market and for precast components in the non-building market.

4.5.11 Forecasting System

The forecasting system included in the model predicts the demand for precast concrete three years ahead. This is about the period of time intervening between a decision to increase the capacity of the industry (in terms of plant and equipment) to the time the new capacity has been installed. An overview of the system is presented in Reference 18. The basic principles of the system are:

- demand can vary due to two reasons: random variations and trends;
- the higher the smoothing constant SCN (where $0 < SCN < 1$), the more weight is given to the most recent observations and the more are older observations discounted.

To implement the forecasting system, the following steps are taken:

(a) The present demand is smoothed to get rid of random effects.

(b) The trend is smoothed to get rid of random effects.

(c) Forecasted demand for this year is the sum of smoothed demand for this year and of a function of the smoothing constant times the trend. Forecasted demand expressed in this manner takes care both of random variations and of trends. The function of the smoothing constant (which multiplies the trend) accounts for the lagging of forecasted over actual demand in a ramp function (see Reference 18).

(d) The desired (or demanded) capacity in n time units would then equal the forecasted demand during the current year plus n times the trend during the same year. The model assigns new values to the variables every 1/100 of the year (DT = 0.01 of the year is the fundamental time unit of the model), and, therefore, three years is the equivalent of 300 time units in the model. Thus, n = 300.

(e) The model keeps the forecasted demand in the beginning of the year for a three-year period through the levels DPC1, DPC2 and DPC3. In this way, DPC3 is the demand that was forecasted for this year three years ago.

(f) The difference between DPC3 and the forecasted demand for this year (FORD) is the error of the forecast.

(g) The smoothing constant is proportional to the sum of errors over the absolute sum of errors. Thus, if errors are biased in one direction, the sum of errors over the absolute sum of errors would tend to $\pm$ 1, and the value of the smoothing constant would be near 1. This would result in giving the most recent observation high weight, thereby correcting the error.

4.5.12 Production Capacity of the Precast Concrete Industry

The level of production capacity of the precast concrete industry decreases through physical depreciation of the plant and equipment and increases through a variable called change in precast capacity (CPC). As Table 17 shows, for financial purposes. the life of a precast concrete factory is taken to be at most 16 years; this coincides with physical depreciation of plant and equipment. Since CPC is non-negative, whenever the desired capacity of the industry is less than the actual capacity, rather than selling out part of its capacity, the industry is assumed to increase physical depreciation of the plant by cutting down maintenance to 60 per cent of what is required. In spite of the fact that precast concrete potentially can be far less seasonal than conventional concrete, as of now, it still exhibits seasonality in demand (though the latter is not quite as pronounced as it is with conventional construction). Therefore, excess capacity is required so that the peak in demand can be covered (Reference 37). The model assumes that 40 per cent of excess (i.e., above average) capacity is required by the industry. This means a utilization of about 71 per cent which is very well within industrial practice.*

The model assumes that the industry builds the capacity required three years hence within a three-year period, and this practice is subject to the constraint that in no year should the capacity exceed 1.4 times the demand.

4.5.13 Actual Precast Market

The actual precast concrete market achieved in the current year is the minimum of the required and the existing capacity.

4.5.14 Per Plant Capacity, Production

The capacity of the average precast concrete plant is derived by dividing the total capacity of the industry into the number of plants.

Figure 31 shows the assumed number of plants as a function of total precast concrete capacity.

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*Reference 13 states that the utilization of factories producing building systems is between 0.6 and 0.9.

Figure 5 records the existing number of precast concrete plants in each state in the U. S. in 1971. This compilation contains the only data available regarding the number of such plants. Knowledge of the number of plants and the approximate capacity of the industry in 1971 (about 140 million square feet) gives one point on the graph in Fig. 31. To derive the rest of Fig. 31, the following assumptions have been made:

1. A concrete plant can serve an area extending radially about 200 miles around it (Reference 37). This is approximately the area that a mobile home plant can serve. Therefore, it has been assumed that precast concrete plants would follow the pattern of mobile home plants reaching a total of eight hundred which is the approximate number of mobile plants in existence today.
2. As the industry grows and the average precast concrete plant grows in capacity, there are economies of scale realized, and the entrance of many new small plants in the industry is thereby prohibited. This point accounts for the shape of the curve in Fig. 31 indicating a decelerating growth rate.

The production of the average plant is the actual precast concrete market achieved divided by the number of existing plants.

4.5.15 Total Revenue

Table 18 shows that the after-tax profit ratio in the concrete industry is about 5 per cent. This leads to profits of about 10 per cent before taxes, and, therefore, total revenue is assumed to be 1.1 times total costs.

Total costs are derived from demanded rather than actually sold square footage. To correct for this error, the figure for total costs is multiplied by 1, if required is less than actual capacity, whereas it is multiplied by precast (existing) capacity over required capacity if precast capacity is less than required capacity.

4.5.16 <u>The Share of Main Building Markets Belonging to Precast Concrete</u>

This is the ratio of actual sales of precast concrete building systems (in square feet) over the total building market as given in Figs. 21, 23, and 24.

4.5.17 <u>Economic Performance</u>

The model calculates the cost of both conventional concrete construction and precast concrete building systems construction for low- and high-cost housing and non-housing building. In addition, the model calculates the cost of precast concrete components.

4.5.17.1 <u>Risk</u>

The general instability of the construction industry makes the precast concrete industry a risky investment.* The risk of investing in the precast concrete industry is determined by the housing or the non-housing building market, depending on whether the sales of the industry are greater in the former or the latter.

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*Quote from Reference 72, p. 343, "The high level of instability in the construction industry in general, and, in the housing industry in particular, is derived directly from the use of monetary as opposed to financial policy as a means of regulating the economy. This high level of instability has made it necessary for firms to minimize their fixed overhead with the obvious consequences that little or no technical staff capability has been developed in the industry, except where the demand for housing has been somewhat isolated on an individual or regional basis."

Risk in the model is measured in arbitrary units on a scale from zero to five. Risk for a given market is determined by two factors:

1. Does the market oscillate?

   As Fig. 7 shows, residential construction used to oscillate while also exhibiting no average growth from 1950 to 1970.

   Figure 21 shows the market for multi-unit housing. In the early sixties, the data indicate that the market might oscillate around the 315 million square foot level.

   Investment in capital intensive operations in the industry looks risky considering the rate of return it brings. The value of risk is determined by the table TRISk1.* However, after 5 years of continuously surpassing the 315-million-square-foot level ($c > 5$), investment in the industry looks less risky, and the value of risk is determined by the table TRISk2. Finally, after 10 years of continuously surpassing the 315-million-square-foot level ($c > 10$), investment in the industry looks safe, and low levels of risk are obtained from table TRISk3.

2. What is the growth of the market?

   The value of risk from all three tables mentioned above is inversely proportional to the perceived growth of the market.

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*Tables TRISk1, TRISk2, and TRISk3 give the assumed values of risk (in arbitrary units of risk) for the various forms of market outlook discussed above.

4.5.17.2 Cost of Capital

Both interest and depreciation time* depend on the level of risk. Interest values are taken from Reference 14 and depreciation time is taken from Table 17.

Capital for the required fixed assets in the current year is proportional to the per cent of construction that is to be industrialized (or prefabricated), inversely proportional to the level of production and assembly technology, proportional to the expected product quality, and proportional to the cost per square foot of capacity as a function of the plant capacity, times the added capacity per plant in square feet.

There is no data available on how much more capital would be needed for fixed assets as the precast concrete industry moves from the production of structure and skin alone to production of structure, skin, and finishings and, from there, to total systems. Therefore, in our investigation of the optimal time for the industry to move from one end of the prefabrication intensity to the other, we investigated two sets of assumed values: one, that values in the table TPIM are 1 to 1.4 to 1.6 and two, that the values in TPIM are 1 to 1.6 to 1.9.

Figure 32 gives the capital requirements for fixed assets for various plant capacities. The figure is scaled down so that capital requirements for a plant capacity of 60,000 square feet equals 1. For a given plant capacity, the capital requirements derived from

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*This is depreciation time for financial purposes as opposed to physical depreciation.

Fig. 32 are divided by the plant capacity to give the capital required for the production of one square foot. This figure is multiplied by the industrial equipment cost index (1967 = 1) given in Fig. 33 times (940,000/6) where 6 is the coefficient derived from table TCA (Fig. 32) for a plant capacity of 540,000 ft^2, and 940,000* is the capital required for fixed assets in the U. S. A. in 1967 for a plant that has production capacity of 540,000 ft^2.

The capital for required fixed assets (RFA), derived as described above, would charge the square foot produced** with interest and depreciation of capital.

The precast concrete industry as of now tends to be labor intensive, and it will, by definition, continue to be so until the cost of capital per square foot becomes less than the cost of labor per square foot. When this point is reached, the required fixed assets would be multiplied by variable CVLCMC (= Capital Versus Labor Cost Multiplier for Capital) which then takes a value larger than 1, and a decrease in manhours would more than offset the higher investment in fixed assets. The product RFA** times CVLCMC would be the total capital invested in fixed assets in the current year.

The total capital on which the industry would have to pay interest and depreciation charges is the total amount of capital invested in

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*For the derivation of the coefficient $940,000, see Appendix B.

**RFA was derived based on the required capacity. However, actual production is usually less than capacity. We take this difference into account in the variable CRFAPSF (= cost of required fixed assets per square foot).

the current year plus the total amount of capital outstanding as of the year before minus the fraction of last year's outstanding capital that has been depreciated in the current year.

Besides the interest and amortization that the industry has to pay on the total outstanding capital derived above, the annual capital cost should also include interest on working capital. Working capital according to Reference 14 is taken to be 3 per cent of production cost.

The total annual cost is divided into the building systems for low- and high-cost housing and non-housing buildings, and into precast components (for the bridge and building market), according to the amount of manhours required per product category.

4.5.17.3 Cost of Labor

The required labor in the factory in terms of manhours per square foot is inversely proportional to labor productivity, inversely proportional to the level of technology, proportional to the expected product quality, dependent upon the ratio of capital to labor costs, dependent upon the plant capacity, and dependent upon the fraction of construction that is fabricated in the plant.

Labor productivity has been assumed to increase at a rate of 1.5 per cent a year.* (This is 50 per cent more than the rate of increase in productivity in conventional construction.)

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*For the derivation of the formula for productivity, see Appendix C.

As of now, and due to the high cost of capital, the industry tends to be labor intensive. However, if cost of capital relative to cost of labor declines, it would be profitable for the industry to move towards more capital intensive operations. This would result in less demand for labor. In this case, required manhours per square foot (in the factory) are multiplied by a factor CVLCML (= Capital Versus Labor Cost Multiplier for Labor), with the latter taking values less than one.

Figure 34 gives the manhours required in the factory for a spectrum of plant capacities. The figures are normalized so that one manhour is required for the production of 60,000 square feet per year.

For given plant capacity, the manpower requirement derived from Fig. 34 is divided by plant production to get manhours per square foot and multiplied by (64,680/6.5), where 6.5 is the required manhours for the production of 540,000 square feet as derived from Fig. 34 and 64,680 is the manhours required in the U. S. for the production of 540,000 square feet.*

Finally, the higher the per cent of construction that is prefabricated, and as long as the industry does not move towards more capital intensive operations, the higher the amount of manhours per square foot required in the factory. Tables TRLF1, TRLF2, and TRLF3 list our assumptions for the required increase in manhours per square foot as the industry moves from prefabrication of structure and skin

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*For the derivation of the requirement of 64,680 manhours for the production of 540,000 ft, see Appendix B.

to prefabrication of structure, skin, and finishings and then to total systems in the three main building systems categories.

The required manhours per square foot on site are inversely proportional to labor productivity, inversely proportional to technology, proportional to expected product quality, and proportional to the percentage of construction that is prefabricated. For example, for building systems where only structure and skin is prefabricated, on-site labor would only have to erect and join the system. For building systems where structure, skin, and finishings are prefabricated, on-site labor would have to erect and join the structure as well as do the necessary on-site finishing work. Appendix D shows the derivation of the increase required in on-site manhours as the industry moves from prefabrication of structure and skin to prefabrication of structure, skin, and finishings to total systems.

The resistance of organized labor to prefabrication of construction is expressed by forcing the precast concrete industry to hire labor over and above its needs. An example is the crew of ten men that escort concrete boxes and panels. Reference 2 argues that featherbedding in conventional construction among blue-collar workers costs anywhere between 15 to 40 per cent of the construction payroll dollar. The assumption in our model is that, in the long run, free market conditions operate; labor resistance then declines from a level of forcing the precast concrete industry to hire 30 per cent manhours above its needs in 1960, to hiring 10 per cent manhours above its needs in 1985.

Labor cost per square foot is the sum of hired manhours per square foot of production in the factory times the hourly wages in the factory and hired manhours on site (per square foot of construction) times the hourly wages for conventional construction. Figures 35 and 36 give the indices of union hourly wages for manufacturing and construction, respectively.

4.5.17.4 Cost of Materials

The cost of materials on a per-square-foot basis is proportional to the cost of materials in 1967 times the construction materials price index (1967 = 100) and proportional to the per cent of total construction that is industrialized. There are savings in the cost of materials associated with price discounts for plant productions that exceed one million square feet per year.

The cost of materials for structure and skin in 1967 equals $3.015/ft^2$ as derived in Appendix B. The construction materials price index (base 1967) is shown in Fig. 37.

Increased requirements for materials for structure, skin, and finishings and total systems as compared to material requirements for only structure and skin are derived in Appendix D.

Economies in materials in the precast concrete industry can be achieved through:

- elimination of vandalism and waste
- utilization of smaller cross sections of structured elements than in conventional concrete due to more careful design under controlled conditions and use of high-strength materials.

Diseconomies in materials in the precast concrete industry are attributed to larger cross sections of the elements than in conventional concrete due to the fact that the members have to withstand the strains of transportation and erection, due to standardization and also due to the fact that precast concrete structures are generally structurally determinate.

The model assumes that the economies and diseconomies in materials mentioned above offset each other and that the only net economies realized are those attributed to price discounts through volume purchases.

Table 19 shows price discounts in construction materials due to volume purchases.

4.5.17.5 Overhead Costs

The factory operating overhead (in dollars) is inversely proportional to the level of technology, proportional to the expected product quality, proportional to the per cent of construction that is prefabricated, and dependent upon plant capacity. In addition, it includes the industrial funds spent on R & D* per plant.

There are no data available on the extent of increase in overhead cost as the industry moves into prefabrication of higher percentages of constructon. In our investigation of the optimal time required for movement of the industry from prefabrication of structure and skin to

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*It is possible that a precaster may have developed his own building system. However, the model covers the usual case where he leases a system. In this case, there are companies working on the development of systems which they then lease to precasters. The amount of money that a precaster pays for renting the system indirectly supports the R & D effort for the development of the system; therefore, this amount is considered part of the industrial funds spent on R & D per plant.

prefabrication of structure, skin, and finishings and then to total systems, we have made the two hypotheses shown in the table below:

	Overhead costs as percentage of the overhead cost required for the prefabrication of structure and skin	
	Hypothesis 1	Hypothesis 2
Overhead cost to prefabricate structure and skin	100	100
Overhead cost to prefabricate structure, skin, and finishings	140	160
Overhead cost to prefabricate total systems	160	190

Figure 38 gives the factory operating overhead required as a function of plant capacity. The numbers are normalized so that the factory operating overhead for a plant capacity of 60,000 square feet is one. For a given plant capacity the number derived from Fig. 38 is multiplied by 357,000/6.24, where 6.24 is the overhead required for a capacity of 540,000 square feet, as derived from Fig. 38, and 357,000 is the annual factory operating overhead required in a plant in the U. S. in 1967.* The whole function is multiplied by the consumer price index taken from Fig. 27 (1967 base is 1).

Transportation cost and site overhead are inversely proportional to the level of technology, proportional to the per cent of construction prefabricated in the factory, and dependent upon the construction equipment price index as given in Fig. 39 (1967 base is 1).

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*See Appendix B for the derivation of this figure.

Site overhead is here defined to include the rental and operation of equipment for lift and secure operations (see Table 20)--the rest of on-site functions are performed by on-site labor as derived in the labor sector.

Transportation and site overhead costs as defined above are assumed to be independent of product category but are not independent of the per cent of construction that is prefabricated; that is, on a square-foot basis, it is more costly to transport a box system (usually a total system) than to transport a component system (usually prefabrication of only structure and skin). On the other hand, it is equally expensive to transport a box system for a low- or high-cost house or for a non-housing building.

Overhead cost per square foot is the sum of factory-operating overhead, transportation, and site overhead costs. Factory-operating overhead is allocated to the various product categories according to their factory labor needs.

4.5.17.6 Total Precast Cost

Total precast cost is the sum of capital cost for production, labor cost in the factory and on-site, material cost and overhead cost, all on a per-square-foot basis.

CONVENTIONAL CONCRETE INDUSTRY

4.5.17.7 Cost of Labor

The required manhours per square foot of conventional concrete construction are inversely proportional to labor productivity, proportional to the fraction of total construction under investigation here and dependent on the competition with precast concrete construction.

The rate of increase in productivity of the conventional concrete industry is assumed to be one per cent per year (Reference 54). The formula for productivity is derived in Appendix C.

Appendix D derives the required increases in manhours per square foot to go from the construction of structure and skin to that of structure, skin, and finishings, and then to total systems.

In response to increased competitiveness of the precast concrete industry, as evidenced by its share of the market, the conventional concrete industry turns to mechanization. The higher cost of mechanization is more than offset by decreases in the labor force.

Finally, the required manhours per square foot are multiplied by hourly labor wages prevailing in the conventional concrete industry (Fig. 36) to yield the labor cost per square foot of conventional concrete construction.

4.5.17.8 Cost of Materials

As explained by the materials sector of the precast concrete industry, the cost of materials is the same in both conventional and precast concrete construction. The only possible exception is the case where the annual production of a precast concrete plant exceeds one million square feet, in which case there are price discounts in materials.

4.5.17.9 Overhead Costs

Equipment cost in conventional construction is proportional to the construction equipment price index given in Fig. 39 and to the degree of mechanization in the conventional concrete industry.

Construction equipment used on site is basically the same in both precast and conventional concrete construction. The only difference is that in the case of precast concrete construction, the equipment should have capacity to carry higher loads. This results in higher equipment cost.

The degree of mechanization, as has been discussed in the labor sector of conventional construction, is proportional to the success of the precast concrete industry. The more successful precast construction is, as evidenced by its share of the market, the more forcefully conventional concrete responds by attempting to enhance its economic performance through increased mechanization.

Overhead cost in conventional construction is taken to include equipment cost plus the cost of handling and operating the equipment, all of which are taken to be proportional to equipment cost. In addition, overhead cost is proportional to the fraction of construction under investigation.

Appendix D derives the increases in required overhead for the construction of structure, skin, and finishings and installation of the attendant mechanical and electrical equipment, relative to overhead requirements for the construction of only structure and skin.

4.5.17.10 Total Cost in Conventional Construction

Total cost in conventional construction is the sum of labor, material, and overhead costs, all on a per-square-foot basis.

4.5.18 Control Cards

The model runs from 1960 to 1985. The fundamental time unit after which the value of variables in the simulation are changed is 0.01 of a year.

4.6 Concluding Remarks

A simulation model of the precast concrete industry has been developed. The variables which determine the state of the precast concrete industry were treated in the model not as independent entities, but as dynamically interacting elements. Figure 20 shows the interactions between the model variables in a graphical form. In the model every assumption made about the interactions of elements is explicit and written in a precise form open to inspection and criticism. After scrutinizing, discussing, and revising the assumptions in order to obtain agreement with best current knowledge, implications of these assumptions for the future behavior of the precast concrete industry are traced. The results obtained by testing specific policies and economic conditions are presented in the next chapter.

CHAPTER 5

MODEL ANALYSIS

5.1 Introduction

In this chapter the validity and usefulness of the model constructed in this study is assessed. To assess these characteristics of the model, the following tests have been performed:

1. First, the ability of the model to trace historical data has been tested. This test provides a condition (that must be met by a valid model) which is necessary but not sufficient since the appropriate fortuitous combination of faulty data and structure characteristics could conceivably produce the same apparent system behavior.
2. Next, the ability of the model to assess the impact of the pertinent issues has been examined. This was done by conducting the following tests:
   - The overall model behavior has been evaluated on the basis of current general knowledge of the characteristics of the industry as well as by testing such behavior for internal consistency.
   - The response patterns of specific, isolated segments of the model were also evaluated with respect to internal consistency as well as consistency with our current understanding of these specific segments of the industry.
   - Whenever the question arose whether assumptions or estimates, not solidly founded on data, affected the output significantly, a sensitivity analysis was performed.

- The literature on the precast concrete industry contains very few estimates of the future performance of the industry. These few independent estimates were compared with the predictions of the model.

In this chapter we discuss the model response to ten well-defined sets of inputs. For reasons of simplified presentation, the first input-output set (or "run") plays the role of a reference against which the response to other inputs is later compared. We will call this reference the "standard experiment."

5.2 Model Reproduction of Historical Data

The available historical data on the precast concrete industry is very meager and limited to information on sales volume of the precast concrete industry (see Fig. 8) and on cost of conventional construction.

The sales volume of the precast industry over the period 1960-1972 is shown in Fig. 40, where data derived by the model are plotted, together with the published data. The same information appears in numerical form in Table 21. At no time do the results of the model deviate by more than 15 per cent from the historical data on total revenue.

A comparison of the cost per square foot of conventional construction, as derived by the model, with actual cost data from the literature is shown in Fig. 41 and Table 22. It can be seen that the deviation of results obtained by use of the model from actual data is nowhere larger than about 7 per cent.

In the absence of any other coherent historical data, the results of the model were tested against pieces of isolated information. In performing such a test, the data which had been used to structure the model were excluded.

The model assumes that the conventional concrete industry will resort to increased mechanization in response to increased competitiveness of the precast concrete industry. Results obtained by use of the model show that, prior to 1974, the competitiveness of the precast concrete industry is not sufficient to force conventional construction to undergo increased mechanization. This result is in accordance with Reference 7 which shows that orders for machinery in conventional construction have not risen in the 60's.

- The plant production of the twenty top prefabricated housing plants in the country averaged 500,000 ft^2 in 1969 (44). This is about three times the production of the average plant derived by the model. Given the distribution of plant sizes in the industry (a few large plants and a large number of small plants), these figures (actual data and model output) are reasonably consistent.
- Reference 44 argues that significant cost savings cannot accrue from the prefabrication of structural components alone. This is in qualitative accordance with the findings of the model (Table 30).

To conclude: Given the scarcity of data on the precast concrete industry and given that much of the existing data were used to construct the model equations, there is little independent data available against which we can compare the output of the model. In few possible cases, however, comparison of model output with independent data is within the acceptable range.

5.3 The "Standard" Experiment

The model equations in Appendix A describe the standard experiment. In this experiment we expect that the assumed policies of the industry, government, and labor will be continued, and the market demand for multi-unit housing remains rather stable.*

The results obtained are presented in Figs. 42 - 48 and in Tables 23 - 30.

An increase in the total revenue of the industry, more dramatic than the one experienced in the past five years, is shown in Fig. 42. Figure 43 and Table 23 show the projected demand for the various categories of products. The increase in demand for the industry's products in the 1970's is more pronounced in the building systems category. In fact, while lagging behind all other precast products in the early 60's (Fig. 43 and Table 23), precast concrete building systems become the predominant output of the industry in the 1970's This is because building systems need architectural sanctioning to gain market acceptance, and it is only in the early 70's that the quality of precast exceeds that of its competitor, conventional concrete (Table 24).

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*The inputs for this experiment are shown in graphical form in Figs. 21, 23, 24, 27 and 30 to 39. These are historical data and projections of demand for multi-unit housing, for non-housing buildings and for the bridge market, manufacturing and on-site labor wage indices, as well as material, equipment, and consumer price indices.

Notice also that only in the middle 70's does the expected cost of precast construction become less than that of its competitor (Table 24 and Fig. 37).

A more detailed analysis of the performance of precast concrete building systems is presented in Fig. 45 and Table 25. Shown here is the share of the market that precast concrete occupies in low- and high-cost housing and in non-housing buildings, as well as the total market share that precast concrete building systems enjoy in all of the main building markets of the industry. These results reflect the strong influence of product quality in the high-cost housing market. After 1971, when the probability that the precast product will have a higher quality exceeds 50 per cent (Table 24), the share that precast concrete occupies in the high-cost housing market experiences a dramatic growth. On the other hand, the low-cost housing market is seen to be very sensitive to cost. In the 70's, when precast concrete becomes competitive in terms of cost, the share of precast concrete in the low-cost housing market exhibits a substantial growth. These findings provide us with useful independent checks of the general qualitative validity of the model since the sensitivity of a high-cost product market to quality and of a low-cost version to cost are well known.

In the late 70's and in the 80's, when the probability is very high that precast concrete is competitive both in terms of cost and quality, the share of the market that precast concrete occupies in low-cost housing is substantially higher than that occupied in high-cost housing. The reason for this is that the upper limit of the share of the market that precast concrete can achieve in high-cost housing is less than what it can achieve in low-cost housing, due to the fact that the inherent limitations of precast concrete (such as restrictions in geometry, etc.) is a much greater disadvantage in the design of expensive buildings.

A significant increase in the share of the market that precast concrete occupies is also predicted by the Long-Range Planning Committee of PCI (58). Unfortunately, in the published report of the committee, there is no definition of precisely what has been considered the "market" of precast concrete; for this reason, our findings cannot be compared with the predictions of the PCI Committee on a quantitative basis.

The cost-time relations of structure and skin products made of precast concrete are presented in Fig. 46 and Table 26. This cost is the same for all precast product categories* (i.e., precast concrete building systems for low- and high-cost housing as well as non-housing buildings; and precast concrete components). Only after the industry moves into prefabrication of finishings does the cost of precast concrete differ from one product category to another.

Capital costs in the precast concrete industry decrease in the late 70's and in the 80's due basically to two reasons:

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*Of course, the cost of structure and skin forms a different percentage of total construction cost in the different building categories (see Table 6) resulting in different savings in each case.

1. Lower interests and higher amortization times (Table 27) as both lenders and management become confident of a stable market growth.
2. Economies of scale attained as the production of the average precast plant increases from a value of 119,000 ft^2 in 1960 to 386,000 ft^2 in 1985 (Table 27). As discussed in Chapter 2, economies of scale are the result of more efficient technology employed at higher volumes of output as well as of better quality managerial talent that larger plants can afford.

The cost of labor employed by the precast concrete industry is shown in Fig. 46 and reported in Table 26, whereas data for conventional construction are shown in Fig. 47 and reported in Table 28. In all of the figures and tables above, the reported costs are for one square foot of structure and skin. Substantial savings in labor costs can be seen in the case of precast concrete.* Additional detail on the source of savings in labor costs is provided in Fig. 48 where the requirements in terms of manhours are shown. As can be noted in this figure, there is a significant decrease in required manhours in precast construction. This is one of the sources of savings. Savings also result from the fact that labor wages in the factory are far below the wages for on-site construction. Such a difference in labor wages makes very attractive an attempt to decrease on-site manhours for the erection and joining of precast concrete products. Indeed, inspite of the fact

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*In fact, it is only due to savings in labor costs that precast concrete is--when it is--competitive in terms of cost.

that required manhours on site are less than manhours required in the factory, on-site labor cost surpasses factory labor cost due to higher wages (see Table 29).

No savings in materials are realized with precast concrete (Tables 26 and 29) since production in the plant has not reached the amount of one million square feet annually (Table 27) which must be exceeded before the purchasing firm can qualify for price discounts.

There are economies of scale that moderate the growth of overhead (Fig. 46 and Table 26); such growth results from increased cost of living (see Fig. 27)

In 1975, the expected cost of precast concrete for the first time becomes less than that of conventional concrete (Fig. 44; Table 24) while, at the same time, precast concrete has a chance of about 80 per cent of possessing higher quality (Table 24).

The cost of precast concrete in 1976 is somewhat unexpectedly high. This is due to the fact that the forecasting system of the industry (assumed in the "standard" run to be a projection of the past growth rate in demand) has anticipated a high demand for the 1976 products and the industry has, accordingly been building the necessary capacity during the early 70's. However, the softening of the market after 1973 (see Fig. 21) is expected to cause a decrease in the utilization factor of plants with an attendant jump in the cost.

The cost of conventional concrete construction, in terms of one square foot of structure and skin is shown in Fig. 47 and

Table 29. The rate of growth of labor costs decreases after 1973. This is so because the conventional concrete industry resorts to mechanization in order to meet the growing challenge of precast concrete construction. Increases in overhead (due to increased mechanization) are more than offset by decreases in labor cost. It follows from the model that competition in construction lowers costs (and price).

Finally, Table 30 gives the perceived per cent savings through choice of precast concrete construction in low-cost housing. It is interesting to note that, according to the model, perceived savings are not sufficient, even by 1985, to cause expansion of the low-cost housing market: Precast concrete merely replaces conventional concrete throughout the period examined.

Summary and Conclusions

The standard experiment presents an assessment of the performance of the precast concrete industry, determined by use of the model under the assumption of continuation of the present industrial, governmental, and labor policies and under conditions of stable market demand. The purpose of this model run (or experiment) was to serve as a benchmark, or baseline, against which the results arising from policy changes and changes in market conditions can be compared.

The results of the standard run were examined in detail to determine whether they are internally consistent and whether they conform to the actual performance of the industry. Whenever possible, model results amounting to predictions about the future were compared with independent predictions from the literature.

The results show growth of the industry in the future, which is even more dramatic than what the industry is currently experiencing. The building systems market (as opposed to the building components market or to the bridge market) seems to become the main market for the industry. Savings over conventional construction are realized only in labor costs. However, these savings are significant enough to make precast concrete more competitive in terms of cost than conventional concrete in the mid 70's. Yet, savings up to 1985 are not significant enough to grant market expansion. Research seems to be particularly rewarding in the area of improved erection and joining systems, since, under the present labor policies, on-site wages far surpass those in the factory.

The output of this model experiment seems consistent and acceptable. The model seems reasonably sensitive to the economic forces which determine the performance of the industry. None of the results obtained by use of the model violates our current understanding of the industry.

5.4 Fluctuations in the Demand for Multi-Unit Housing

The inputs in this model experiment differ from the inputs of the "standard" experiment only in that the non-oscillating demand shown in Fig. 21 (and assumed in the "standard" experiment) has been replaced by the oscillation in demand for multi-unit housing shown in Fig. 22.

The assumed oscillations in demand start in 1972 after a period of continuous and dramatic growth of the multi-unit residential market in the late 60's and early 70's. In projecting the growth of the early 70's, the model forecasts that the industry will call for an increase in capacity. After the assumed temporary decline of the multi-unit housing market in 1972, the demand for precast concrete building systems, as computed by the model, declines, and so does the utilization factor. This causes precast concrete to become prohibitively expensive, thereby losing additional ground. Meanwhile, the industry attempts (and later succeeds) to rid itself of excess capacity so that the utilization factor may increase. Success in rise of the utilization factor improves the position of the industry in subsequent years. This coincides with the upturn of demand for multi-unit housing in 1976. The forecasting systems built into the model projects the growth rate prevailing during the period 1975-1978 to subsequent years; when, finally, the industry manages to build up its capacity, the market declines again, and the cycle repeats itself until 1985.

Discussion and Conclusions:

After an unexpected decline of the market, the industry will find itself in the undesirable state of having excess capacity (or low utilization factors). However, if ups and downs in demand do, in fact, become a well-established pattern of the market, the industry would, in reality, adapt by preparing itself to cope with the situation.

The results of this model run are therefore unrealistic insofar as the industry is assumed to insist in following a forecasting system which has repeatedly proved itself inadequate over thirteen years of use (1972-1985).

The results of this model run, although unrealistic, have been useful in pointing out two things:

1. The industry is very sensitive to low-utilization factors. (The same conclusion has been arrived at by Bishop, Reference 13 on the basis of a non-dynamic cost model without feedbacks.) It follows that the forecasting of demand and the planning of capacity are of critical importance to the industry.
2. The forecasting system in the model, which operates by projecting the growth rate of the previous years with emphasis on growth behavior during the most recent years, while adequate* for non-oscillating demand, is inadequate when market demand oscillates.

Accordingly, in subsequent runs, and in order to study the actual effect of fluctuations in demand for multi-unit housing on the industry, the model has been modified to permit a high, stable utilization factor--presumably the result of adequate forecasts.

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*As evidenced by the results obtained from the standard experiment and as will be seen from the results of subsequent experiments with non-oscillating demand.

5.4.1 Fluctuations in the Demand for Multi-Unit Housing. The Utilization Factor of the Precast Concrete Industry Remains Constant at 75* Per Cent

In spite of perfect planning, the interest rate on loans to the industry (or the required return on owners' equity) increases after 1976, when the lenders (or owners) once more see an oscillating market exhibiting negligible overall growth (see section on risk in Chapter 4). Figure 49 shows the results of this model run in terms of total revenue. For comparison, results for total revenue obtained with the standard run (where market does not oscillate) are included in the same figure. It can be seen that the total revenue of the industry decreases if demand for multi-unit housing oscillates; however, the effect is not significant due to the following reasons:

1. The industry plans perfectly; the utilization factor is set at a constant, high level by the industry.
2. The cost of capital--which is the only cost that is increased by the perceived increased risk of the industry--is by 1976 a small fraction of the total cost of precast concrete construction (Table 26); therefore, its effect on total precast concrete cost is not dramatic.

Summary, Conclusions, and Model Capabilities

On the assumption of a stable utilization factor, the model results are realistic and of great interest. According to these

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*This is the utilization factor around which the industry normally operates (Reference 13).

results, as time advances and the average size of the plants increases, and as the capital cost forms a smaller fraction of the total cost,* market conditions that affect the capital cost do not have a very significant effect on the industry. Given the assumptions of the model, this seems to be a highly likely (and useful) result. But this is the output to a specific set of assumptions. The policy maker can change the assumptions on, say, what part of cost is subject to economies of scale and thereby can cover a number of additional cases. In later sections, we study the effect of an oscillating market congruent with changes in industrial, governmental, and labor policies.

5.5 Changes in Per Cent of Construction that is Prefabricated

One of the basic questions faced by the precast concrete industry is what percentage of construction may be fabricated in the factory and how this percentage may change with time.** A model experiment was constructed to address this issue. The assumptions in this case differed from those of the standard experiment only in that the industry, from the beginning of 1976 on, is assumed to prefabricate not only structure and skin but finishings as well.

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*The model assumes that there are economies of scale in terms of capital and overhead requirements as well as required manhours in the factory. Since there are no economies of scale in materials (at least for plant production of less than a million square feet) and on-site labor (for joining and erection of the precast members), capital, overhead, and factory labor consequently play a less and less significant role in total cost performance.

**See Chapter 2.

The results appear in Figs. 50 - 52 and Tables 31 - 35. Most of the tables record results obtained from 1976 on, since the results from 1960 to the end of 1975 are identical to those achieved with the standard experiment. (The latter appear in Tables 23 to 30.)

The total revenue of the precast concrete industry is presented in Fig. 50 both for the case where the industry keeps prefabricating structure and skin only (results obtained by the standard experiment) and for the case under study, where beginning with 1976, the industry moves to prefabricate finishings as well. It can be seen that the total revenue experiences a substantial growth as soon as the industry moves to prefabrication of finishings. This is due to two reasons:

1. A higher percentage* of the total cost per square foot is sold to the construction market.
2. The industry has increased its share of the market (in comparison with the standard experiment) (see Table 31).

The higher share of the market that the industry now enjoys is a result of its being more competitive in terms of both cost and quality in all product categories (compare the results shown in Table 32 to those shown in Table 24):

- Higher revenue is associated with an increase in funds for R & D and a concomitant improvement in product quality; product quality

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*As Table 6 shows, while structure and skin alone comprise about 30 per cent of the total construction cost, structure, skin, and finishings come out to be about 60 per cent of the total construction cost.

in turn, contributes to a higher share of the market which causes a higher revenue.

- A higher competitiveness in terms of cost, relative to the standard model, is attributed to labor savings arising from the prefabrication of labor-intensive finishings (see Table 7). Since high-cost housing utilizes the most expensive finishings (Table 6), it is the main beneficiary (see Table 32).

It is interesting to observe (Table 32) that, in the early 80's, the probability that precast concrete is less expensive than conventional concrete drops for most product categories. This is due to a turn towards mechanization that conventional concrete undergoes in response to the increased competitiveness of precast concrete; the result is an enhancement of the economic performance of conventional construction which narrows the respective gap between precast and conventional construction.

The time-dependence of cost of one square foot of conventionally built high-cost housing is shown in Fig. 51 and Table 33. The jump in cost occurring in 1975 (Fig. 51) is due to the fact that from that time on, costs include finishings as well rather than just structure and skin. A detailed record of manhours required for the conventional construction of one square foot of structure, skin, and finishings of high-cost housing also appears in Table 33. The cost of precast concrete construction of high-cost housing is shown in Fig. 52. Again, the jump in costs in 1975 is due to the fact that, from that date on, the cost of finishings is included in reported costs. The same costs from 1976 on, together with the manhour requirements in the factory and on site, appear in Table 34. The data recorded in Fig. 52 and Table 34 show that the increase in requirements for capital and overhead,* generated as the industry moves to prefabricate finishings, does not have a significant effect on the performance of the precast concrete industry. This is so because, by 1975, capital plus overhead form a relatively small fraction of the total cost.** (Of course, the statement above is as correct as the assumption of a 40 per cent increase in requirements for capital plus overhead as the industry moves to prefabricate finishings. Subsequent model experiments investigate the effect on the precast industry of different assumptions about capital and overhead increases.)

Furthermore, savings in labor, which accrue as the labor-intensive finishings (see Table 7) are fabricated in the factory, more than offset the increased requirements for capital and overhead. The net result is that, by prefabricating finishings as well, precast concrete increases its economic competitiveness.

It is interesting to trace how the various cause-and-effect relationships determine the performance of the industry. As precast concrete becomes more competitive through labor savings, it gains a larger share of the market; this favorable condition permits the realization of economies of scale that partly offset the

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*As compared to those of the standard model on Table 26.

**See footnote on p. 112.

increased requirements for capital and overhead. The latter makes the industry more competitive; and the cycle repeats itself.

On the other hand, part of the cost gap between precast and competitor (favorable to the former) is bridged by the resort to mechanization practiced by the conventional concrete industry.

The net result of going through both feedback loops (economic performance--market--economic performance, and cost competitiveness--mechanization of conventional construction--cost competitiveness) is that the quality of construction increases while its cost decreases.

The per cent savings achieved through precast concrete construction in the low-cost housing market appear in Table 35. In the 80's perceived savings are enough to grant a moderate expansion of the low-cost housing market.

Summary, Conclusions, and Discussion

The results of this model experiment show that it would be profitable for the precast concrete industry to move to prefabrication of finishings by 1975. Such a move would make the products of the industry more competitive in terms of both cost and quality and would also increase the total revenue of the industry through an increased share of the market and through production of a higher percentage of construction.

Reference 11 also predicts--presumably because it finds it profitable for the industry--that, by 1975, the percentage of the building that is prefabricated would increase.

The results of this model experiment were consistent and logically appealing. They were, of course, based on a specific set of assumptions. Among those are numerical assumptions for increases in required capital and overhead which would enable the industry to prefabricate finishings in the plant. These numbers represent our best judgement since there is no published data on which to base them.

It would, consequently, be desirable to determine the sensitivity of our results to these numerical assumptions. To determine the latter in subsequent model experiments, we assumed higher (but possible) requirements in terms of capital and overhead as the industry increases the percentage of construction it fabricates and observe the change in results obtained.

5.6 Change in Per Cent of Construction that is Prefabricated. Requirements for Capital and Overhead Greater than those Hypothesized in the Standard Model

To investigate how sensitive the results obtained in section 5.5 are to specific assumptions for capital and overhead requirements, a model experiment was performed the input of which deviated from the inputs of the standard experiment as follows:

1. Capital and overhead requirements increase by as much as 60 per cent (rather than by 40 per cent previously) as the industry moves to prefabrication of finishings and by an additional 30 per cent (rather than 20 per cent previously) as the industry moves to total systems.*

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*To implement the above the Tables TPIM and TPIML of the standard experiment were replaced by: TPIM = 1/1.6/1.9 and TPIML = 1/1.6/1.9.

2. The industry adds to its capabilities prefabrication of finishings in 1975 and moves to total systems by 1980 (none of these moves is assumed in the standard experiment).

The results obtained are as follows:

The increased requirements for capital and overhead as the industry starts prefabricating finishings in 1975 make the industry less competitive in terms of cost. As a result, the market for precast products experiences a decline. This leads to low utilization factors that further worsen the economic competitiveness of the industry. After the decline of its market, the industry starts eliminating its excess capacity so that in a three-year period the utilization factor is normal, and the industry becomes competitive again (see Tables 35 and 36).

In 1980, when the industry moves to total systems, a similar effect is observed: Increased requirements for capital and overhead lessen the economic advantages of precast construction; this causes a decrease in demand for precast products which leads to low utilization factors with a resulting worsening in competitiveness. The next step for the industry is to eliminate excess capacity and reestablish appropriate utilization factors.

It is interesting to note that the decrease in demand for the products of the industry in the early 80's can only be traced by following the pattern of required output of the industry and not that of the total revenue achieved by the industry (Table 35). The reason is that, even though the square footage of sales has experienced a decline, the industry now sells a higher fraction of total construction cost which more than compensates for loss sales.

By comparison, Table 36 shows the total revenue and square footage of sales achieved in the standard model.*

A comparison of the results from the present model experiment after 1976 with those achieved by use of the standard model shows that the industry is worse off both in total revenue and square footage of sales in the brief period 1976 - 1977. However, in the long run (and long run seems to be the three-year period during which the industry can eliminate excess capacity), and in terms of total revenue, the industry is better off by prefabricating finishings and by installing mechanical and electrical equipment. In fact, after 1980, the total revenue is higher than that obtained in the standard experiment even in cases where the square footage sold is less than that under standard conditions (see revenue data for years 1981 and 1982 in Table 35).

The costs of precast and conventional concrete, from 1976 to 1982, and for the three main building markets are shown in Table 36. In this table the effect of closing the gap in costs between precast concrete and conventional concrete can be clearly seen. For example, in 1980, the difference in cost of precast and conventional concrete in the low-cost housing sector is $\$1.372/ft^2$, while in 1981 the difference becomes only $\$0.777/ft^2$. Table 35 shows the effect of these

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*The tabulated results start in 1976, since the output before that date for the model experiment under consideration is identical to that of the standard model.

differences in cost on the square footage of precast concrete sold.

It is interesting to compare the cost of conventional construction for high-cost housing shown in Table 36 with that shown in Table 32 for the years 1976 to 1980 (where the comparison is meaningful). The cost of conventional construction in the model experiment currently discussed is higher than under the conditions of Section 5.5 because the share of the market that precast concrete enjoys is less than that enjoyed under the conditions of Section 5.5; the reduced competitiveness of precast concrete prevents forcing conventional concrete to resort to mechanization, thereby decreasing its cost.

Summary and Conclusions

While, in the long run, it seems beneficial for the industry to move to prefabrication of finishings and to total systems, in the short run, high requirements for capital and overhead impairs the performance of the industry. This is due to the fact that high capital and overhead requirements decrease the economic competitiveness of the product so that the share of the market the precast concrete occupies decreases and the utilization factor is small. The small magnitude of the utilization factor--which does not increase until the industry gets rid of excess capacity--further impairs the performance of the industry.

It would be interesting to see what would be the effect of high requirements for capital and overhead when the latter is considered separately from the effect of a low utilization factor. Assume, for example, that, while moving to prefabrication of finishings, the industry is aware of an initial decline in demand* for its products. The industry has, therefore, arranged for an increase in its capacity so that such a decline in demand will not impair its utilization factor. Before turning to the investigation of this assumption, we should state that:

- A move towards total systems could certainly benefit from the efforts of PCI towards standardization. In Reference 58 the Long-Range Planning Committee of PCI recommends the standardization of precast concrete products in such a manner (e.g., dimensions of standardized product) that integration with mechanical and electrical systems would be possible.
- The results of the model are internally consistent and acceptable on the basis of our understanding of the industry

5.7 Changes in Per Cent of Construction that is Prefabricated. Requirements for Capital and Overhead Greater than those Hypothesized in the Standard Model. Utilization Factor Constant at 75 Per Cent. Fluctuations in the Demand for Multi-Unit Housing

What would be the effect on the industry if not only costs for fixed assets and overhead for prefabrication of finishings were higher than those hypothesized in the standard model but, in addition, demand for multi-unit housing oscillated?

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*Of course, it is possible, as we have seen in this model experiment, for the total revenue of the industry to rise even though the total industrial output experiences a decline. This is due to the fact that the industry sells a higher percentage of construction under the conditions of this experiment.

To investigate this possibility a model experiment was conducted whose assumptions differed from those of the standard experiment in the following respects:

1. In 1975 the industry moves to prefabrication of finishings (in addition to prefabrication of structure and skin).
2. A 60 per cent increase in capital for fixed assets and overhead is required for the industry to move to prefabrication of finishings (same assumption as in the model experiment discussed in Section 5.6).
3. After 1972, the demand for multi-unit housing starts oscillating with a six-year period, following the pattern of demand for residential construction (the input for the market is shown in Fig. 22).*
4. As we have seen previously in this chapter, the factory utilization factor is of primary importance to the precast concrete industry. To isolate the current model experiment from the predominant effects of factory utilization, we have assumed factory utilization to remain permanently at 75 per cent. (This assumption will not affect the level of interest on loans paid by the industry, which is assumed high as a result of lack of confidence in the market.)**

The model runs from 1960 to 1980.***

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*As Table 23 shows, multi-unit housing is the main market for precast concrete.

**See section for risk, Chapter 4.

***However, only from 1976 on are results recorded (Tables 38 and 39) since results from 1960 to 1975 are identical to results of previous tuns, which have been recorded in Tables 21, 23, and 30.

A strong recommendation to the industry to initiate prefabrication of finishings under the conditions of the model experiment emerges from the data in Table 38. The table lists compatively results obtained by use of the current model and those obtained under identical conditions except that the industry prefabricates only structure and skin. (See Section 5.4.1)

Findings: The prefabrication of finishing brings modest gains to the industry in terms of square footage of sales but significant increases in total revenue. The latter increase is mainly attributed to the higher per cent of the cost of square foot of construction that is prefabricated.

The results listed in Table 38 also permit comparison of results obtained with the current model with those obtained under similar conditions except for a non-oscillating market for multi-unit housing. Once the industry achieves an acceptable utilization factor, oscillating demand causes a decrease in both square footage of sales and in total revenue. The decrease is not significant. This can be attributed to two factors:

1. The assumed high fixed utilization factor eliminates most of the effect of an oscillating demand.
2. High interest rates, resulting from lack of confidence in the market, affect only that fraction of the total cost which is capital; however, by 1974, when interests jump to 19 per cent, the cost of capital forms a small fraction of total cost (the effect of high interest in the middle 70's is discussed in more detail in the ensuing model experiment).

The perceived per cent savings for the three main building markets is recorded in Table 39. It can be seen that, in the late 70's, the perceived per cent savings in the low-cost housing market are just on the verge of being sufficient to sustain a market expansion.

Conclusions

Even when the demand for multi-unit housing fluctuates, and provided that the utilization factor is maintained at 75 per cent, we find once more that it will be profitable for the precast concrete industry to move to prefabrication of finishings by 1975.

Once more, results of this model experiment appear consistent and defensible on the basis of our knowledge of the industry.

5.8 Changes in Per Cent of Construction that is Prefabricated. Requirements for Capital and Overhead Greater than those Hypothesized in the Standard Model. Fluctuations in the Demand for Multi-Unit Housing. The Government Guarantees Low-Interest Loans to the Industry.

Given that market expansion in the case of low-cost housing can only be achieved through substantial savings, and given that the government is interested to achieve such an expansion,* a model experiment was conducted to study the effect of government-guaranteed loans at low interest** on the cost of precast concrete construction of low-cost housing.

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*The main purpose behind the governmental effort to industrialize construction in the late 60's and early 70's was to lower the price of low-cost housing and thus increase effective demand (Reference 72), i.e., to bring about an expansion of the market. The problem arose because excessive costs have excluded many needy customers from the low-cost market.

**See Chapter 2.

The inputs to this model experiment differ from those of the standard experiment model in the following respects:

1. In 1975, the industry starts prefabricating finishings (in addition to structure and skin).
2. Requirements for capital for fixed assets and overhead increase by 60 per cent as the industry proceeds to prefabrication of finishings.
3. Starting in 1972, the multi-unit housing market oscillates with a six-year period (Fig. 22).
4. Also starting in 1972, the government grants to the industry loans at 6 per cent interest.

Results from this experiment, recorded in Table 40, show some increase in both total revenue and square footage of sales when compared with the results obtained without the benefit of government-granted loans (see Table 38). The increase is not dramatic because the cost of capital (the only beneficiary from the policy of low interest) forms only a small fraction of total cost in the mid 70's* (see Table 41). For the same reason, perceived per cent savings in low-cost housing (Table 41) show only a slight increase due to the grant of low-interest loans.

It is interesting to note that the governmental policy of granting low-interest loans to the industry benefits high-cost housing the most. This is so because capital cost is allocated proportionately to the number of required manhours (see section on cost of capital,

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*See footnote on page 112.

Chapter 4). Since high-cost housing makes the greatest demands on manhours, it bears most of the capital cost; therefore, it benefits most from capital cost savings.

We note, in addition, that even though more savings are realized in the high-cost housing sector (Table 41), low-cost housing remains the greater customer of precast concrete building systems (Table 42). This is so because low-cost housing occupies a much larger share of the total multi-unit housing market.

Conclusions

It is very interesting to note that a governmental policy of low-interest loans to the industry would not have significant effects on the industry at this stage of development and, furthermore, would mainly benefit high-cost housing. These results are entirely plausible under the given set of assumptions. They lead to the conclusion that, if the government wants to specifically decrease the cost of low-cost housing through a low-interest loan policy, it should impose a set of conditions, say, on the allocation of capital costs to products, if the policy is to have any effect. The model is flexible enough to permit further investigation of this governmental policy under different sets of assumptions.

5.9 Allocation of Funds for R & D: From 1974 on, 85 Per Cent of R & D Funds are Spent to Improve the Technical Performance and Marketability of the Product.

As discussed in Chapter 2, the industry has not yet solved the problem of the most profitable allocation of funds for R & D which can be posed as follows: What percentage of funds allocated for R & D should be spent, and specifically when, to promote the technical performance and marketability of the product; and what percentage should be spent to promote production and assembly technology?

To answer this question, a model experiment was conducted in which it was hypothesized that, starting in 1974, the industry allocates 85 per cent of its R & D funds in an effort to increase product performance and marketability. Only 15 per cent, therefore, of the R & D funds are to be spent towards improvement of production and assembly technology. This was the only assumption in which the current model differed from the standard model.*

Research aiming at increasing product performance and marketability would include market research to identify consumer needs and preferences. It would also aim at increased product performance both from the technical and the aesthetic point of view. On the other hand, research for production and assembly technology was taken to mean research aiming at reducing product cost.

The results of this model experiment are recorded in Table 43: The probability that precast concrete has higher quality (i.e., higher product performance and marketability) than its competitor is, as expected, consistently higher than that obtained with the standard model (recorded in Table 24). By contrast, the probability that precast concrete has lower cost than its competitor is consistently lower

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*In the standard model it was assumed that 50 per cent of funds were spent to improve product performance and marketability while the remainder were spent to improve production and assembly techology.

than that obtained by use of the standard model (Table 24). The net result is a decrease in total square footage of sales as compared to that of the standard model (Table 23). Therefore, in the late 70's and 80's, the industry is better off with a more balanced allocation of funds for R & D.

The difference in performance between the current and the standard model is not significant: (In the current model, performance is consistently, but not significantly, worse.) Figure 53 reveals the reason: Funds invested in R & D bear fruit only after three years; therefore, a decision taken in 1974 starts showing significant results only by 1977. By that time, and according to the assumptions of the model, the levels of both product performance and marketability on one hand, and of production and assembly technology on the other, are well-advanced towards maturity. Since the model assumes a sigmoid increase in product performance and marketability, with rate of increase of the latter slowing down as the product approaches maturity, money spent at later stages of technological progress have lesser effect on a unit basis than money spent when the technology is young. As Fig. shows, the level of product performance and marketability by 1985 (after having received 85 per cent of R & D funds since 1974) is not dramatically different from the level of production and assembly technology in 1985 (after the latter has been receiving 15 per cent of R & D funds since 1974).

5.9.1 Allocation of Funds for R & D: From 1960 on, 85 Per Cent of R & D Funds are Spent to Improve the Technical Performance and Marketability of the Product

The next step was to study the effect of allocating 85 per cent of R & D funds to elevate product performance and marketability at an early stage of the game, when the levels of product performance and marketability and of production and assembly technology are both far from approaching maturity. The year chosen for implementation of this industrial policy was 1960. Again, this was the only assumption that made the current model different from the standard one.*

The levels of production and assembly technology on one hand, and of product performance and marketability on the other, are shown in Fig. 54. Comparison with Fig. 53 (which shows the results of the previous experiment in which the same policy was implemented fourteen years later) shows the significance of time as a component of policies of fund allocation: Under the conditions of the current model, the difference between the two levels is now quite significant.

Comparison of Fig. 55 with Fig. 26 shows that the product performance and marketability obtained under the conditions of the current model are consistently higher than those achieved under the conditions of the standard model. These conclusions are consistent with the results recorded in Table 44 which were obtained under identical conditions. The probability that precast concrete has better quality than its competitor is consistently higher in the current model than it is

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*See footnote on page 127.

in the standard model (Table 44). The probability that precast concrete has lower cost than its competitor is consistently lower than it is in the standard model (compare Tables 24 and 44). The net result, as seen through square footage of sales (Table 44), differs with time. From 1960 to 1966, the precast concrete industry is better off by preferentially promoting product performance and marketability. From 1967 on, a balanced allocation of funds for R & D would benefit the industry more (compare Tables 23 and 44). The decline in demand for products of the industry in the 70's and 80's would be even more significant than is shown in Tables 23 and 44 were it not for a concurrent decline in economic performance of conventional construction (relative to the standard experiment: Compare Tables 28 and 44): The latter is simply not being forced strongly enough by the competitiveness of precast concrete to improve its economic performance through a resort to mechanization.

Summary and Conclusions

Basically, the choice is between promoting the performance of the product in terms of quality and marketability on one hand, and lowering its cost on the other. The results indicate that the optimal policy of the industry varies as a function of time.

Once more, the results are internally consistent and compatible with our current understanding of the industry. The decision maker can use the model as a laboratory to test different sets of inputs.

5.10 Labor Policies

What would be the effect on the precast concrete industry of an equalization of factory labor wages to those of on-site construction?

What if, at the same time, the manpower requirements of the industry, both for on-site labor and for factory labor, increased? Such an increase in required manhours could be the result of a reduction in working hours per week, longer coffee breaks, longer vacation, and so forth.*

To investigate the possibility mentioned above, a model experiment was conducted the assumptions of which differ from those of the standard experiment in the following respects:

1. From 1974 on, labor wages in the factory equal the labor wages assumed for on-site labor.
2. Also, from 1974 on, there is a 10 per cent increase in manpower requirements of the industry both for on-site and factory labor.

The sudden increase in labor force and labor wages in 1974 resulted in a decline in the economic competitiveness of the industry; the latter caused a drop in demand for precast concrete products, which caused low utilization factors. The latter accelerated the existing decline in the economic competitiveness of the industry. To isolate the industry from this effect, a second model experiment was conducted with the additional assumption of a fixed utilization factor of 75 per cent. In this way, the effect of a change in labor policy could be studied independently from the effects caused by having a factory operate far below capacity.

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*As discussed in Chapter 2, these assumptions correspond to the conditions achieved by unions in England where manpower requirements for building systems are higher than those necessary for conventional construction in the U. S. (see Table 45). In addition, in England, wages on site equal those in the factory.

The results of the second model experiment are recorded in Table 46. Comparison with the results of the standard model recorded in Table 26 shows a jump in labor cost as well as in total cost of the precast product. The effect of the resulting decline in economic competitiveness can be seen as a drop in square footage sold when compared with the standard model (Table 23). This drop would be even more dramatic if conventional concrete construction were to use increased mechanization to reduce its cost. However, since precast concrete is less competitive under the labor policy assumed in the current model, there is no strong incentive for conventional construction to replace labor with machines and improve thereby its cost performance. For this reason, labor cost and total cost of conventional construction, shown in Table 46, both are higher than in the standard experiment (Table 28).

Summary and Conclusions

According to the results of the model, labor-restrictive policies--if separated from low-factory utilization--would restrict but not prevent the growth of the industry. Once more, model results are acceptable in terms of consistency, and of being in accordance with our knowledge of the industry.

The model offers the flexibility of testing the effect of a great variety of labor policies which may be under study for implementation either by themselves or in combination with other governmental and industrial policies.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A model of the precast concrete industry has been constructed in order to evaluate the consequences of issues facing the industry. The model is flexible enough to allow the decision maker or investigator to experiment conveniently with a wealth of inputs (or proposed policies) and thereby acquire outputs (anticipated policy results) which can aid him in choosing the appropriate policy.

The validity of the model was indicated by a series of tests of the ability of the model to conform to certain criteria, including:

- The ability of the model to trace historical data.
- The sensitivity of the model to the issues.
- The consistency of results obtained.
- The acceptability of model results in view of our current understanding of the industry.
- The level of agreement (or lack of it) between predictions obtained by using the model and independent predictions on the future of the industry appearing in the literature.

Although not constituting a definite proof of the validity of the model, the extent to which the model conforms to the above criteria is a strong indication that it is valid.

A series of model experiments were performed the results of which are the response of the model to a specific set of inputs. The inputs used were well-defined economic conditions or else were governmental, industrial and labor policies directly concerning the structure, function, and performance of the precast concrete industry.

On the assumption that the model represents this industry adequately, it is possible to deduce from these experiments the following conclusions concerning the precast concrete industry:

1. The performance of the precast concrete industry seems to be strongly dependent on factory utilization. It follows that the correct forecasting of demand and the corresponding planning of capacity are of utmost importance to the industry.
2. Provided a stable, high, utilization factor is secured, the structure of the precast concrete industry and the economic environment in which it operates make it very likely that the precast concrete industry will continue to grow and acquire an increasing share of the construction market. Such growth was observed under each set of inputs tested: Restrictive labor practices, non-optimal industrial practices, and adverse market conditions decreased the rate of industrial growth under each set of inputs but, in each case, came short of arresting growth.
3. Once precast concrete building systems (as opposed to components) achieve architectural sanctioning through their quality and cost performance, they will become the predominant output of the precast concrete industry.
4. Even in cases where larger savings can be realized through prefabrication of high-cost housing, low-cost housing seems to dominate the market of precast concrete building systems. This

apparent paradox can be resolved by recalling that the precast concrete industry mainly supplies to the multi-unit housing market which consists almost overwhelmingly of low-cost housing.

5. As plant production increases with time, there are economies of scale realized in some of the components of the total cost. The result is an increase in relative importance of these components of the cost which are not affected by economies of scale. Consequently,

   a. Deliberate attempts to decrease the cost of processes not subject to economies of scale would become increasingly effective as time advances: Example is on-site labor cost which can be decreased through study leading to better erection and joining methods.

   b. An attempt to decrease the cost of processes that are subject to economies of scale would have a relatively less dramatic effect as time advances. An example is afforded by low-cost interest loans granted by the government in an attempt to decrease the cost of capital of the industry.

   Similarly, the oscillation of the market in the middle 70's will not have a significant effect on the industry; such oscillation would primarily affect the cost of capital which by being subject to economies of scale will, by that time, constitute a small fraction of the cost.

6. Another finding of the thesis is that a policy of government-granted low-interest loans to the industry would bring greater

benefit to high- (rather than low-) cost housing. This is so because capital requirements are relatively higher in high-cost housing and, therefore, a decrease in costs of capital would have a greater impact in the latter sector of the housing industry.

7. If one assumes that the industry prefabricates only structure and skin (rather than, additionally, finishings or total systems), it is unlikely that the accrued savings would be sufficient to cause a market expansion of low-cost housing even by 1985.

8. The industry will benefit by moving to prefabrication of finishings and of total systems. In this way (and provided that the industry operates at high and stable utilization factors), more savings, relative to conventional construction, can be realized. Therefore, such a move seems to pave a promising way to an increase of the effective demand for low-cost housing. Under a possible future policy of prefabricating an increased percentage of the construction, total revenue will increase even in cases where the square footage sold declines temporarily (i.e., in cases where the utilization factor is low). This will be due to the fact that the industry would be selling a higher fraction of total construction cost.

9. On the assumption that the level of performance (i.e., cost and quality) versus time is a sigmoid curve, R & D funds to promote preferentially either cost performance or quality performance would have a more dramatic effect when allocated much before

performance approaches maturity. The optimum policy depends on the time. (Under an optimum policy, allocation of R & D funds maximizes the total revenue of the industry.)

10. Factory labor wage increases (large enough to equalize factory wages with on-site wages) occurrring at a time when the industry has established itself, can cause a deceleration in the increase in demand for precast concrete products but cannot, by itself, arrest the growth of the industry.

11. The more competitive precast concrete construction becomes, the more will its competitor, the conventional concrete industry, resort to mechanization in an effort to reduce its costs: Competition works, therefore, in this instance, for the benefit of the consumer.

CHAPTER 7

RECOMMENDATIONS FOR FUTURE WORK

A continuation of the profitable use of the model as a laboratory for testing the effect of future policies on the performance of the precast concrete industry would require studies along the following two directions:

1. Refinement of the model by incorporation in it of data which may become available in the future. A steady, continuous refinement of this kind, based on use of increasingly accurate information on the structure and performance of the industry would improve the validity of the assumptions of the model; and the confidence that the decision maker would place on the results of the model would become correspondingly deeper.
2. Expansion of the model to build in it the capacity of addressing new issues which the industry may have to face in the future in the context of an evolving economy. A reverse process, namely, a contraction in its area of applicability (leading to simplification), could become useful in the event that the industry manages to solve, in the future, one or more of its current problems which, naturally, contribute to the complexity of the model in its present form.

Furthermore, as additional data on the industry become available, it will become useful to undertake a more detailed analysis of certain issues which the model is currently equipped to handle only in a general way. Taking as an example of such an improvement a more detailed analysis of allocation of funds for R & D, we can consider investigating not only how many funds should be allocated to improvement of production and assembly (as done in this work) but, in addition, investigate specific research programs, say, how much money should be allocated to research aimed at improved erection and joining techniques.

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BIOGRAPHY OF THE AUTHOR

Stamatia Frondistou- Yannas was born in Athens, Greece, on May 13, 1943. After receiving the Diploma from Pierce College in 1961 (a private gymnasium which provides education at the high school level), she remained to complete a one-year university-level program in Liberal Arts which is administered by this college.

In 1962, she entered the National Technical University of Athens after performing successfully in the nationwide entrance examination. While there, she studied in the School of Civil Engineering and received the Master's Degree after completion of the five-year program. Following graduation, she was employed for about a year and a half as a Design Engineer in the Public Power Corporation of Greece and designed several buildings costing totally about $1,500,000. During this period she was also a self-employed consulting civil engineer and was in charge of a number of projects, including design of a nine-story apartment building in Athens.

Following her arrival in the United States in 1969, she registered in the Graduate School of the Massachusetts Institute of Technology. In 1970, she obtained a Master's Degree in Civil Engineering after completing a thesis entitled "Polymer Latex Modified Mortar," performed under the supervision of Professor S. Shah. Her current work on the simulation of the precast concrete industry was performed under the supervision of Professor F. Moavenzadeh and was executed in parallel with work leading to a Master's Degree in the Sloan School of Management which she expects to earn during this year. Her research work in the Sloan School of Management of M.I.T. has been performed under the supervision of Mr. A. L. Pugh, III.

Stamatia Frondistou- Yannas is a Member of the honorary professional Society of Sigma Xi and of the Professional Technical Bureau of Greece. During 1971, she was a Fellow of the Ford Foundation. She is the co-author of a paper entitled "Polymer Latex Modified Mortar," published by the "Journal of the American Concrete Institute," 69, 61 (1972).

The author is married and lives with her husband in Newton Centre, Massachusetts.

TABLE 1 – List of Products

Refer to Column No.	Type of Product	No. of Plants Producing U.S.	Canada	Total
	GIRDERS, BEAMS AND JOISTS			
1	RECTANGULAR BEAM	158	20	178
2	RECTANGULAR JOIST	50	13	63
3	V BEAM	20	6	26
4	KEYSTONE JOIST	68	8	76
5	L BEAM	108	19	127
6	INVERTED T-BEAM	120	23	143
7	LEDGER BEAM	31	14	45
8	T BEAM	22	9	31
9	T JOIST	51	16	67
10	I JOIST	14	2	16
11	AASHO I-BEAMS	98	17	115
12	STATE I-BEAM	70	14	84
13	BUILDING I-BEAMS	22	3	25
	STEMMED UNITS			
14	SINGLE-T	114	21	135
15	BULB-T	11	3	14
16	DOUBLE-T	168	22	190
17	TRIPLE-T	2	1	3
18	MULTI-T	3	2	5
19	F SLAB	25	6	31
20	CHANNEL SLAB	76	13	89
21	SINGLE-Y	39	3	42
22	FLEXTEE	6	–	6

Refer to Column No.	Type of Product	No. of Plants Producing U.S.	Canada	Total
	CORED UNITS			
23	AASHO BOX SLAB (AASHO-PCI Standard)	62	5	67
24	STATE BOX SLAB (State Highway Standard)	37	9	46
25	AREA BOX SLAB (Railroad Standard)	16	–	16
26	EXTRUDED CORED SLAB	63	9	72
27	WET CAST CORED SLAB	71	13	84
	PILES			
28	PILE CAP	32	1	33
29	TRIANGULAR PILE	2	1	3
30	AASHO SQUARE PILE	83	4	87
31	AASHO SQUARE, CORED PILE	33	–	33
32	AREA SQUARE, CORED PILE	12	–	12
33	HEXAGONAL PILE	2	11	13
34	AASHO OCTAGONAL PILE	44	5	49
35	AASHO OCTAGONAL CORED PILE	5	2	7
36	ROUND PILE	1	–	1
37	CYLINDER PILE	8	2	10
38	SHEET PILE (SOLID & HOLLOW)	44	2	46
	ARCHITECTURAL UNITS			
39	WINDOW SILL	40	12	52
40	MULLION	35	11	46
41	LINTEL	19	13	32
42	WALL PANEL-SOLID	124	25	149
43	WALL PANEL-INSULATED	86	22	108

TABLE 1
[CONTINUED]

	Type of Product	No. of Plants Producing U.S.	Canada	Total
44	WINDOW FRAMES	75	17	92
45	CONCRETE FORM	16	3	19
	MISCELLANEOUS UNITS			
46	PLANK (OR SOLID) SLAB	102	11	113
47	L STADIUM SEAT	22	2	24
48	SQUARE COLUMN	125	15	140
49	RECTANGULAR COLUMN	101	15	116
50	POWER TRANSMISSION POLE	8	–	8
51	LIGHT POLE	15	1	16
52	CRIBBING	15	2	17
53	RAILROAD CROSSTIE	1	1	2

NOTATION

The abbreviations that are used in identifying the available products are:

Rect.	Rectangular
R.R.	Railroad
Ext.	Extruded
W. C.	Wet Cast
Sq.	Square
Hex.	Hexagonal
Oct.	Octagonal
Tran.	Transmission
Triang.	Triangular
Insul.	Insulated

SOURCE: REF. 55

TABLE 2

How 207 Modular Box Firms Sell Their Products

	Percentage of Manufacturers
Sell to any qualified builder-developer	71.4
Sell to franchise dealer-erectors	35.4
Produce for own company use	16.0
Manufacture and put in place for others	31.6
Other methods	10.2

Source: Reference 8

TABLE 3

Product Categories and Plants

(Survey Results Based on 239 Plants)

All products	Produced by	65	plants or	27	%
Building products and bridge elements	Produced by	78	plants or	33	%
Building and architectural products	Produced by	39	plants or	16	%
Building products only	Produced by	41	plants or	17	%
Bridge and piles only	Produced by	16	plants or	7	%
Total		239	plants or	100	%

Same as above, only broken down into three major product categories:

Building products	Produced by	222	plants or	93	%
Bridge elements and piles	Produced by	99	plants or	41	%
Architectural products	Produced by	104	plants or	45	%

Precast concrete plants associated with allied products:

Concrete block	Produced by	53	plants or	22	%
Concrete pipe	Produced by	48	plants or	20	%
Ready-mix concrete	Produced by	49	plants or	20	%

Source: Reference 56

TABLE 4

Market for Concrete Building Systems

Building Types		Per cent
Single family		21.6
Garden apartments and townhouses		26.6
Medium rise		27.6
High-rise (over eight floors)		24.2
	Total	100.0

Source: Reference 44

TABLE 5

Type A Proposals for Operation Breakthrough

Proposer Organization

Type of Organization	Per cent of Total
Corporation	40
Consortium	11
Private Company	16
Education Facility	4
Professional	29

Source: Reference 77

TABLE 6

Total Construction Cost Breakdown (Percentage)

Conventional Project

	Low-Cost Housing	High-Cost Housing	Non-housing Buildings
Structure and skin	37	25	27
Finishings	25	37	31
Mechanical and electrical	28	28	32
Total	90	90	90

Note: It has been assumed that only up to 90 per cent of total construction cost can be prefabricated. The rest is foundations and other work that is generally done on site.

Sources: References 26, 36, 65

TABLE 7

Breakdown of Total Construction Cost (per cent)

	Structure and Skin	Finishings	Mechanical and Electrical
Labor	38	46	45
Materials	52	44	45
Overhead	10	10	10
Total	100	100	100

Source: Reference 26

TABLE 8

Model Equations

Number of Variables		Linear	Nonlinear
	2 - 10	Intuitive Solution (a)	Analytical Solution (c)
	$10 - 10^5$	Analytical Solution (b)	Simulation (d)

Note: In the table above, a technique is listed in the most complex region where it applies; that is, each one of the mentioned techniques can also be applied to less complex regions. Thus simulation can be used in all four regions, analytical techniques can be used in regions a, b, and c, and intuitive solutions can only be used in region a.

Source: Reference 47

TABLE 9

Results of a Survey of Producers of Factory-Built Homes

Predominant Material Used in the System	Building Types: Garden Apartments, Townhouses, Clusters
Wood	51.50 %
Concrete	16.16
Steel	13.70
Aluminum	4.82
Other	13.82
Total	100.00 %

Source: Reference 44

TABLE 10

Market where Precast Concrete is Competitive

1. Housing with more than 5 family units in the low-cost range

2. Housing with more than 5 family units in the high-cost range

3. Non-housing buildings:

   a. Non-housekeeping residential buildings

      - Hotels and motels
      - Dormitories
      - Nurses' homes
      - Other group housing

   b. Commercial buildings

      Store and other mercantile buildings
      Warehouses (other than manufacturer-owned)
      Office and bank buildings
      Commercial garages and service stations

   c. Educational and science buildings

      School and college classroom buildings
      Laboratories
      Libraries and museums

   d. Hospitals and other health-care buildings

4. Non-building construction (bridges)

TABLE 11

Prefabrication in Nonbuilding Construction

Sidewalks
- Precast concrete panels

Driveways
- Precast concrete panels

Pavement
- Precast concrete panels

Light and telephone poles
- Precast concrete
- Metal

Towers
- Metal

Railings and landings
- Metal
- Wood
- Precast concrete

Fences
- Metal
- Wood
- Concrete block panels
- Brick panels
- Precast concrete
- Plastic

Railroad ties
- Precast concrete

Swimming pools
- Wood
- Plastic
- Canvas
- Concrete

Piers
- Steel
- Precast concrete

Breakwaters
- Precast concrete

Tunnel sections
- Precast concrete

Manhole units
- Precast concrete

Bridges
- Steel - complete unit
- Steel
  - Piles
  - Piers
  - Decking
  - Trusses
- Precast concrete
  - Piles
  - Piers
  - Slabs
  - Beams
  - Columns

Source: Reference 11

TABLE 12

Total Development Cost Breakdown

Conventional Project

		Percentage
Land costs		9
Total construction costs		70
Architect and engineering fees, insurance, bonding, permits		5
Legal costs		1
Real estate taxes	(3 years)	1
Financing	(15 years)	8
Administrative	(3 years)	6
		100 %

Sources: Reference 24

TABLE 13

Preconstruction and Construction Times, Percent Savings

Due to Shortened Development Period

	Value of PIC	Preconstruction time (months)	Construction Time (months)	Expenses Proportional to Time (Real Estate Taxes + Financing + Administrative)	Savings Due to Shortened Development Period (per cent)
Conventional project	—	18	18	15* %	0
Prefabrication of frame and shell	1	0.8 x18 = 14.4	0.8 x18 = 14.4	—	0.2 x0.15 = 0.03
Prefabrication of frame, shell and finishings	2	0.6 x18 = 10.8	0.6 x18 = 10.8	—	0.4 x0.15 = 0.06
Total systems	3	0.4 x18 = 7.2	0.4 x18 = 7.2	—	0.6 x0.15 = 0.09

*derived from Table 11

Source: Reference 71

TABLE 14

Architect's Preference Function

a. Low-cost Multi-unit Housing

0.1

PPDQ (perceived per cent difference in quality)

0	0.55	0.60
0.1	0.70	0.75
0.2	0.85	0.90

PPS1

(perceived per cent savings in the low-cost housing market)

b. High-cost Multi-unit Housing

0.1

PPDQ (perceived per cent difference in quality)

0	0.60	0.70
0.1	0.65	0.75
0.2	0.70	0.80

PPS2

(perceived per cent savings inthe high-cost housing market)

c. Non-housing Multi-story Buildings

0.1

PPDQ (perceived per cent difference in quality)

0	0.575	0.65
0.1	0.675	0.75
0.2	0.775	0.85

PPS3

(perceived per cent savings in the non-housing building market)

TABLE 15

1971 Usage Patterns of Building-Systems Among Those Professionals Who Have Already Used Building Systems

Response Obtained	Architects	Engineers	G.C.'s	All
Widely used and widely accepted	23.1 %	33.3 %	42.5 %	32.4 %
Used, but not as frequently as possible	75.0	63.9	47.5	63.4
Not ready for use, nor are they perfected	1.9	1.4	7.5	3.0
No answer	--	1.4	2.5	1.2
	100	100	100	100
Outlook for Next 12-24 Months Among Previous Users:				
Extremely optimistic	26.9 %	30.6 %	35.0 %	30.5 %
Expect to use more often due to cost savings/labor shortage	65.4	61.1	52.5	60.4
Don't expect to use, until it proves to be a better way of doing things	7.7	8.3	12.5	9.1
	100.00	100.00	100.00	100.00

Source: Reference 63

TABLE 16

Factory Built Housing

Building Types	Housing types featured by designers and producers of factory-built housing, in per cent of systems in 1970	Per cent of factory-built houses that have concrete as the predominant material	Per cent of houses that make use of concrete as the predominant material	
Single family	38	12.7	0.38 x 0.127 = 0.0483	
Garden apartments and townhouses	37	16.16	0.37 x 0.1616 = 0.0596	} 0.1755
Medium rise	15	41.2	0.15 x 0.412 = 0.0619	} 0.1755
High-rise (over 8 floors)	10	54	0.10 x 0.54 = 0.0540	} 0.1755
Total	100		0.2238 = 0.1755 x 1.275	

Source: Reference 44

TABLE 17

Life of a Precast Concrete Factory

Assumption	Life, years		
	Buildings	General Plant	Process Plant
Short life	3	3	3
Medium life	10	5	5
Long life	30	15	7

Note: About 30 per cent of fixed assets are invested in buildings and other permanent work, 30 per cent in general equipment, such as cranes, concrete batching plant and steam raising boilers and 40 per cent in the actual production process.

Summary: Long life: $0.30 \times 30 + 0.30 \times 15 + 0.4 \times 7 = 16.3 \sim 16$ years

Short life 3 years

Source: Reference 14

TABLE 18

Net Profits in Contract Construction

(in millions of 1973 dollars)

	Contract Construction		
Year	Business Receipts	Net Profits	Profit Ratio
1960	53,888	2,915	5.4
1961	58,664	3,197	5.4
1962	62,655	3,319	5.3
1963	68,007	3,563	5.2
1964	72,493	3,960	5.5
1965	82,396	4,610	5.6

Source: Reference 20

TABLE 19

Volume Discounts

Material	Retail Cost in Small Quantities	Retail Cost in Carload Lots
Gypsum board	1	0.75 - 0.85
Plumbing fixtures	1	0.93
Lumber	1	0.86
Shingles	1	0.98
Appliances	1	0.92
Doors	1	0.95
Kitchen cabinets	1	0.77
Insulation	1	0.92
Electrical fixtures	1	0.95 - 0.97

Source: Reference 24

TABLE 20

Equipment Rentals

	Crane Capacity	Cost per Month	Installed ft^2 per Month	Cost per ft^2
Long span concrete panels 10 - 15 tons	90-ton truck mounted	$ 5,000		
Short span concrete panel 4 to 7 tons	10-ton climb ing crane	$ 4,000 to $ 5,000 + Set up		
Heavy box 35 to 40 tons	2 - 150-ton crawler	$20,000 to $25,000 $ 2,000-$5,000 Set up	$45,000 estimated	$ 0.44 to $ 0.56

Source: Reference 24

TABLE 21

Total Revenue of the Precast Concrete Industry*

(millions of dollars)

Period	Total Revenue Derived by the Model	Total Revenue Historical Data	Per cent Difference
1960	149.9	150	< 1 %
1961	189.3	200	5.35
1962	238.1	255	6.34
1963	280.8	295	4.82
1964	330.0	325	1.54
1965	361.1	400	9.72
1966	382.8	450	14.9
1967	427.0	500	14.6
1968	516.1	550	6.16
1969	636.3	650	2.11
1970	682.3	725	5.88
1971	866.3	780	11.05
1972	1142.2	1000	14.22

*Results of the standard experiment

TABLE 22

Cost of Structure and Skin Built Conventionally ($\$/ft^2$)

Time	As Derived by the Model	Historical Data Based on the Department of Commerce Composite Construction Cost Index	Per cent Difference
1960	4.718	4.74	< 1
1961	4.772	4.80	< 1
1962	4.916	4.95	< 1
1963	5.126	5.01	- 2.31
1964	5.383	5.20	- 3.46
1965	5.532	5.30	- 4.35
1966	5.635	5.55	- 1.43
1967	5.786	5.76	∿ 0
1968	6.099	6.099	0
1969	6.476	6.56	1.28
1970	6.785	7.04	3.62
1971	7.098	7.64	7.1

TABLE 23

Precast Concrete Market-Results of the Standard Experiment

(millions of square feet)

Period	Building Systems	Components for Buildings	Components for the Non-building Construction	Total Market
1960	5.02	8.893	9.313	23.23
1961	7.39	12.215	9.198	28.80
1962	10.18	15.829	9.227	35.24
1963	13.68	19,763	6.942	40.38
1964	14.36	20.879	10.429	45.67
1965	15.89	23.057	10.200	49.15
1966	15.72	23.210	12.632	51.56
1967	17.89	23.878	14.734	56.50
1968	24.88	28.491	12.505	65.87
1969	29.42	31.438	16.686	77.54
1970	32.57	30.658	17.929	81.16
1971	45.94	35.913	18.741	100.60
1972	70.93	39.845	20.056	130.83
1973	84.49	41.557	20.386	146.43
1974	102.99	43.063	22.196	168.25
1975	115.34	44.242	23.206	182.79
1976	122.10	45.598	24.211	191.91
1977	147.91	47.347	26.328	221.58
1978	154.29	48.923	27.245	230.46
1979	161.61	50.415	28.132	240.16
1980	170.33	52.052	28.990	251.38
1981	177.41	53.401	30.141	260.95
1982	185.22	54.821	31.329	271.37
1983	192.49	56.210	32.476	281.18
1984	200.01	57.597	33.600	291.21
1985	208.82	59.134	34.639	302.59

TABLE 24

Probability that Precast Concrete has Better Quality and Probability that It Is Less Expensive than Conventional Concrete*

Period	Probability that Precast Concrete has Better Quality	Probability that Precast Concrete is Less Expensive
1960	0.18793	0.20958
1961	0.18665	0.19700
1962	0.18828	0.19228
1963	0.19527	0.19868
1964	0.20949	0.20050
1965	0.23264	0.20825
1966	0.26599	0.21476
1967	0.30912	0.22106
1968	0.35921	0.23382
1969	0.41256	0.24262
1970	0.46675	0.27139
1971	0.52517	0.30187
1972	0.60973	0.43363
1973	0.69665	0.47275
1974	0.75082	0.49002
1975	0.77525	0.53044
1976	0.78483	0.53265
1977	0.78864	0.65762
1978	0.79042	0.66328
1979	0.79142	0.67822
1980	0.79221	0.69785
1981	0.79262	0.71514
1982	0.79200	0.73503
1983	0.79065	0.75368
1984	0.78931	0.77325
1985	0.78848	0.79388

*Results of the standard experiment

TABLE 25

Share of the Market of Precast Concrete (per cent)*

Period	Share of the Low-cost Housing Market	Share of the High-cost Housing Market	Share of the Non-housing Building Market	Precast Concrete's Share of its Main Building Markets
1960	3.641	1.633	2.135	2.528
1961	4.450	1.987	2.606	3.171
1962	4.940	2.212	2.892	3.611
1963	5.439	2.483	3.218	4.078
1964	5.836	2.764	3.513	4.371
1965	6.364	3.187	3.942	4.771
1966	6.842	3.686	4.399	5.112
1967	7.350	4.297	4.932	5.702
1968	7.983	5.064	5.611	6.492
1969	8.639	5.888	6.327	7.181
1970	9.727	7.035	7.415	8.306
1971	10.941	8.347	8.653	9.680
1972	14.915	11.971	12,407	13.582
1973	17.322	14.513	14.836	16.002
1974	21.047	17.982	17.682	19.321
1975	23.347	20.018	19.722	21.465
1976	24.274	20.816	20.525	22.317
1977	28.538	24.204	24.115	26.212
1978	29.103	24.576	24.530	26.691
1979	29.852	25.170	25.154	27.366
1980	30.770	25.896	25.919	28.195
1981	31.611	26.553	26.616	28.936
1982	32.529	27.257	27.369	29.745
1983	33.396	27.908	28.073	30.493
1984	34.304	28.590	28.809	31.283
1985	35.279	29.325	29.602	32.135

*Results of the standard experiment

TABLE 26

Cost of Structure and Skin for Precast Concrete Construction (in $/ft²)*

Period	Cost of Capital	Cost of Labor	Cost of Materials	Cost of Overhead	Total Cost
1960	0.8095	1.0873	2.4452	1.5158	5.858
1961	0.9092	1.1088	2.4301	1.5271	5.975
1962	0.9687	1.1248	2.5258	1.5244	6.144
1963	0.9737	1.1360	2.6815	1.5296	6.321
1964	1.0053	1.1492	2.8792	1.5349	6.569
1965	1.0223	1.1543	2.9562	1.5462	6.679
1966	1.0283	1.1705	2.9783	1.5731	6.750
1967	1.0398	1.2108	3.0140	1.6055	6.870
1968	1.0338	1.2644	3.1786	1.6479	7.124
1969	1.0620	1.3290	3.3671	1.7020	7.46
1970	1.0446	1.4229	3.3912	1.7841	7.643
1971	1.0931	1.5388	3.3746	1.8222	7.829
1972	0.7879	1.6412	3.6726	1.8354	7.937
1973	0.8105	1.7236	3.8075	1.8561	8.198
1974	0.8547	1.7927	3.9137	1.8899	8.451
1975	0.8356	1.8338	4.0274	1.8874	8.584
1976	0.6791	1.9021	4.1387	2.1268	8.847
1977	0.5918	1.8341	4.2582	1.9372	8.621
1978	0.6023	1.8969	4.3783	1.9711	8.849
1979	0.6138	1.9537	4.4985	2.0095	9.075
1980	0.6257	2.0084	4.6325	2.0443	9.311
1981	0.6371	2.0639	4.7676	2.0827	9.551
1982	0.6498	2.1154	4.9028	2.1216	9.789
1983	0.6615	2.1638	5.0379	2.1634	10.027
1984	0.6723	2.2148	5.1731	2.2040	10.264
1985	0.6821	2.2669	5.3218	2.2427	10.513

*Results of the standard experiment

TABLE 27

Precast Concrete Industry*

Period	Interest Paid on Loans	Depreciation Time for Financial Purposes (year)	Production of the Average Plant (thousands of ft^2)
1960	0.18001	7.789	119.37
1961	0.17801	7.926	123.46
1962	0.17455	8.162	127.42
1963	0.17249	8.303	131.95
1964	0.17581	8.076	136.09
1965	0.18204	7.650	138.60
1966	0.18860	7.201	139.99
1967	0.19259	6.928	143.80
1968	0.18879	7.188	151.57
1969	0.18663	7.336	159.20
1970	0.18912	7.165	161.19
1971	0.18766	7.265	178.12
1972	0.12645	11.453	206.80
1973	0.12734	11.392	220.55
1974	0.12895	11.282	242.81
1975	0.13027	11.192	259.41
1976	0.07783	14.780	257.39
1977	0.07915	14.690	297.81
1978	0.08008	14.626	307.68
1979	0.08107	14.558	318.32
1980	0.08191	14.501	330.44
1981	0.08273	14.445	340.62
1982	0.08358	14.387	351.54
1983	0.08428	14.339	361.67
1984	0.08493	14.295	372.61
1985	0.08540	14.262	385.61

*Results of the standard experiment

TABLE 28

Cost of Structure and Skin for

Conventional Concrete Construction (in $/ft^2)*

Period	Cost of Labor	Cost of Materials	Cost of Overhead	Total Cost
1960	1.7732	2.4452	0.4994	4.718
1961	1.8252	2.4301	0.5167	4.772
1962	1.8737	2.5258	0.5168	4.916
1963	1.9211	2.6815	0.5237	5.126
1964	1.9718	2.8792	0.5324	5.383
1965	2.0323	2.9562	0.5439	5.532
1966	2.0959	2.9783	0.5612	5.635
1967	2.1902	3.0140	0.5814	5.786
1968	2.3105	3.1786	0.6102	6.099
1969	2.4766	3.3671	0.6341	6.476
1970	2.7307	3.3912	0.6629	6.785
1971	3.0173	3.3746	0.7058	7.098
1972	3.3031	3.6726	0.7288	7.705
1973	3.5212	3.8075	0.7763	8.105
1974	3.6645	3.9137	0.8416	8.420
1975	3.7512	4.0274	0.9181	8.697
1976	3.8468	4.1387	0.9815	8.967
1977	3.8859	4.2582	1.0573	9.201
1978	3.9554	4.3783	1.1169	9.451
1979	4.0655	4.4985	1.1721	9.736
1980	4.1916	4.6325	1.2263	10.050
1981	4.3139	4.7676	1.2807	10,362
1982	4.4446	4.9028	1.3378	10.685
1983	4.5695	5.0379	1.3975	11.005
1984	4.7017	5.1731	1.4581	11.333
1985	4.8386	5.3218	1.5219	11.682

*Results of the standard experiment

TABLE 29

Factory Labor Cost and On-Site Labor Cost

of Structure and Skin of Precast Concrete Construction*

Period	Factory Labor Cost ($/ft²)	On-Site Labor Cost ($/ft²)
1960	0.51000	0.5773
1961	0.52056	0.5882
1962	0.52731	0.5975
1963	0.53021	0.6058
1964	0.53495	0.6143
1965	0.52973	0.6246
1966	0.53605	0.6345
1967	0.55311	0.6577
1968	0.57717	0.6873
1969	0.60124	0.7278
1970	0.62886	0.7941
1971	0.67021	0.8686
1972	0.70166	0.9395
1973	0.71814	1.0055
1974	0.72842	1.0643
1975	0.72034	1.1134

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*Results of the standard experiment

TABLE 30

Perceived Per Cent Savings Through

Precast Concrete Construction in Low-Cost Housing*

Period	Perceived Savings
1960	3.8363
1961	3.7938
1962	3.7416
1963	3.7092
1964	3.7024
1965	3.6915
1966	3.7047
1967	3.7188
1968	3.7328
1969	3.7501
1970	3.7690
1971	3.8337
1972	4.1321
1973	4.4305
1974	4.5671
1975	4.6489
1976	4.7722
1977	5.0789
1978	5.3969
1979	5.4442
1980	5.4828
1981	5.5392
1982	5.5963
1983	5.6649
1984	5.7359
1985	5.8171

*Results of the Standard Experiment

TABLE 31

Total Output of the Precast Concrete Industry

(millions of square feet)

Period	Prefabrication of Structure and Skin	Prefabrication of Finishings also Since 1975
1972	130.83	130.83
1973	146.43	146.43
1974	168.25	168.25
1975	182.79	182.79
1976	191.91	262.57
1977	221.58	280.18
1978	230.46	292.64
1979	240.16	303.90
1980	251.38	316.87
1981	260.95	327.96
1982	271.37	339.47
1983	281.18	351.29
1984	291.21	363.08
1985	302.59	375.74

TABLE 32

Probability that Precast Concrete has Better Quality and Probability that It is Less Expensive than Conventional Concrete Prefabrication of Structure, Skin and Finishings

Period	Prob. that Precast Concrete has Better Quality for All Product Categories	Prob. that Precast Concrete is Less Expensive than Competitor in Low-cost Housing	Prob. that Precast Concrete is Less Expensive than Competitor in High-cost Housing	Prob. that Precast Concrete is Less Expensive than Competitor in Non-housing Buildings
1975	0.77525	0.53044	0.53044	0.53044
1976	0.7849	0.88269	0.97945	0.92297
1977	0.78954	0.86736	0.97370	0.90636
1978	0.79308	0.86805	0.97390	0.90583
1979	0.79581	0.88077	0.97844	0.91774
1980	0.79762	0.89619	0.98285	0.93187
1981	0.79864	0.90988	0.98552	0.94382
1982	0.79885	0.92379	0.98643	0.95534
1983	0.79871	0.93996	0.98356	0.96791
1984	0.79861	0.95395	0.98769	0.97739
1985	0.79868	0.96609	0.94974	0.98393

TABLE 33

Conventional Concrete Industry

Required Manhours and Costs for the Construction of One Square Foot of Structure, Skin, and Finishings for the High-cost Housing Market

		Cost ($/ft^2)			
Period	Required Mahours per Square Foot	Cost of Labor	Cost of Materials	Overhead Cost	Total Cost
1976	1.1583	10.056	9.312	2.6792	22.047
1977	1.0647	9.723	9.581	3.0146	22.318
1978	0.0182	9.754	9.851	3.2128	22.818
1979	0.9898	9.963	10.122	3.3797	23.464
1980	0.9666	10.238	10.423	3.5353	24.197
1981	0.9454	10.515	10.727	3.6878	24.930
1982	0.9257	10.820	11.031	3.8448	25.696
1983	0.9064	11.112	11.335	4.0083	26.456
1984	0.8876	11.420	11.639	4.1742	27.234
1985	0.8696	11.753	11.974	4.3441	28.071

TABLE 34

Precast Concrete Industry

Required Manhours and Costs for the Construction of One Square Foot of Structure, Skin, and Finishings in the High-cost Housing Market

Period	Required Manhours in the Factory	Required Manhours On Site	Cost of Labor	Cost of Capital	Cost of Materials	Overhead Cost	Total Cost
1976	0.20095	0.42858	5.4713	1.0635	9.312	3.2150	19.062
1977	0.19588	0.42183	5.6105	1.0701	9.581	3.2491	19.511
1978	0.19335	0.41533	5.7544	1.0856	9.851	3.3145	20.006
1979	0.19072	0.40899	5.9124	1.0980	10.122	3.3828	20.515
1980	0.18946	0.40265	6.0872	1.110	10.423	3.4458	21.067
1981	0.18789	0.39632	6.2556	1.1246	10.727	3.5136	21.621
1982	0.18610	0.39002	6.4281	1.1408	11.031	3.5829	22.183
1983	0.17751	0.38374	6.5408	1.1565	11.335	3.6372	22.670
1984	0.16954	0.37748	6.6633	1.1686	1.639	3.6871	23.158
1985	0.16133	0.37124	6.7896	1.1759	11.974	3.7336	23.673

TABLE 35

Perceived Per Cent Savings Through

Precast Concrete Construction in Low-cost Housing

Prefabrication of Structure, Skin, and Finishings

Period	Perceived Savings
1976	7.534
1977	10.336
1978	10.750
1979	10.734
1980	10.805
1981	10.927
1982	11.059
1983	11.230
1984	11.474
1985	11.751

TABLE 36

Total Revenue and Square Footage of Sales of the Precast Concrete Industry

	Standard Experiment		1975-1980: The industry prefabricates structure, skin, and finishings. 1980: The industry prefabricates total systems.	
Period	Total Revenue (millions of dollars)	Square Footage of Sales (in millions)	Total Revenue (millions of dollars)	Square Footage of Sales (in millions)
1976	1866.1	191.91	1668.0	87.87
1977	2101.3	221.58	1694.6	95.90
1978	2243.1	230.46	4584.9	282.69
1979	2397.4	240.16	4772.7	288.35
1980	2574.5	251.38	5030.0	295.98
1981	2741.6	260.95	5245.1	229.99
1982	2922.1	271.37	5369.4	237.03

TABLE 37

Conventional and Precast Concrete Construction Costs for Various Building Categories (in dollars per square foot)

Period	Precast Cost in Low-cost Housing	Precast Cost in High-cost Housing	Precast Cost in Non-housing Buildings	Conventional Concrete Cost in Low-cost Housing	Conventional Concrete Cost in High-cost Housing	Conventional Concrete Cost in Non-housing Buildings
1976	20.289 *	29.016 *	26.746 *	15.654	12.211	20.206
1977	18.989 *	27.216 *	24.960 *	16.204	24.134	20.918
1978	14.47	20.910	18.802	16.095	23.924	20.747
1979	14.80	21.392	19.229	16.171	24.002	20.823
1980	15.199	21.972	19.746	16.571	24.584	21.330
1981	24.272	34.854	32.586	25.049	37.525	34.484
1982	24.159	34.722	32.428	25.92	38.838	35.686

Note: Costs up to 1980 include the cost of structure, skin, and finishings.

Costs in 1981 and 1982 include the costs of structure, skin, finishings, and mechanical and electrical equipment.

---

*Costs are excessive due to low utilization factors.

TABLE 38

Required Capacity (RC) and Total Revenue (TR)

of Precast Concrete Industry, under Various Assumptions

	Model Assumptions which differ from those of the Standard Model					
	Demand Oscillates. Utilization Factor 75%. Industry prefabricates finishings as well. Cost of fixed assets and overhead 60% higher than standard model		Demand Oscillates. Utilization Factor 75%		Industry Prefabricates Structure, Skin, and Finishings. Cost of Fixed Assets and Overhead 60% than that of the Standard Model	
Period	RC (millions of square feet)	TR (millions of dollars)	RC (millions of square feet)	TR (millions of dollars)	RC* (millions of square feet)	TR* (millions of dollars)
1976	236.19	3543.2	195.51	1812.66	87.87**	1668
1977	257.66	3967.4	213.67	2023.9	95.90**	1694.6
1978	278.62	4392.9	232.07	2244.9	282.69	4584.9
1979	275.36	4492.7	225.99	2299.3	288.35	4772.7

*taken from Table 37

**Low required capacity is due to low utilization factors.

TABLE 39

Perceived Per Cent Savings with Precast Concrete

for the Various Building Categories

Period	Low-cost Housing	High-cost Housing	Non-housing Buildings
1976	0.08099	0.08192	0.07439
1977	0.09854	0.10472	0.09147
1978	0.10033	0.10710	0.09317
1979	0.10044	0.10733	0.09329

Assumptions which differ from those of the standard experiment:

- demand oscillates
- fixed utilization factor of 75%
- industry prefabricates finishings (in addition to structure and skin)
- cost of fixed assets and overhead are 60 per cent higher than in the standard experiment.

TABLE 40

Total Revenue and Square Footage of

Sales of the Precast Concrete Industry

Period	Total Revenue (Millions of Dollars)	Square Footage of Sales (Millions of Square Feet)
1976	3591.8	239.01
1977	4028.7	262.38
1978	4471.0	285.40
1979	4565.3	282.74

Assumptions which differ from those of the standard experiment:

- demand oscillates
- fixed utilization factor of 75%.
- industry prefabricates finishings (in addition to structure and skin)
- cost of fixed assets and overhead are 60 per cent higher than in the standard model
- industry pays 6 per cent interest on loans

TABLE 41

Costs and Savings in the Precast Concrete Industry

Period	Perceived Per cent Savings: Low-cost Housing	Perceived Per cent Savings: High-cost Housing	Perceived Per cent Savings: Non-Housing Buildings	Cost of Capital ($/ft²): Low-cost Housing	Cost of Capital ($/ft²): High-cost Housing	Cost of Capital ($/ft²): Non-housing Buildings	Total Cost in Low-cost Housing ($/ft²)
1976	0.08115	0.08426	0.07552	0.6311	0.8836	0.8573	13.486
1977	0.10036	0.10719	0.09350	0.5696	0.7974	0.7736	13.759
1978	0.10253	0.10958	0.09546	0.5262	0.7367	0.7147	14.028
1979	0.10315	0.11023	0.09609	0.5757	0.8060	0.7820	14.442

Assumptions which differ from those of the standard experiment:

- demand oscillates
- fixed utilization factor of 75%
- industry prefabricates finishings (in addition to structure and skin)
- cost of fixed assets and overhead are 60 per cent higher than in the standard model
- industry pays 6 per cent interest on loans

TABLE 42

Per Plant Production of Precast-Concrete Building Systems
for the Various Market Categories
(in thousands of square feet)

Period	Market Categories: Low-cost Housing	High-cost Housing	Non-housing Buildings
1976	119.76	24.138	83.26
1977	135.04	26.798	86.75
1978	149.50	29.154	90.09
1979	143.55	27.873	93.70

Assumptions which differ from those of the standard experiment:

- demand oscillates
- fixed utilization factor of 75 %
- industry prefabricates finishings (in addition to structure and skin)
- cost of fixed assets and overhead are 60 per cent higher than in the standard model
- industry pays 6 per cent interest on loans

TABLE 43

Performance of the Precast Concrete Industry in Terms of Square Footage of Sales, and Product Quality and Cost

Period	Square Footage of Sales (millions of square feet)	Probability that Precast has Better Quality than Conventional Concrete	Probability that Precast has Lower Cost than Conventional Concrete
1974	168.25	0.75082	0.49002
1975	182.79	0.77589	0.53002
1976	191.15	0.78827	0.52522
1977	221.42	0.79442	0.65268
1978	229.92	0.79725	0.6558
1979	239.17	0.79862	0.66865
1980	249.98	0.79938	0.68639
1981	259.23	0.79971	0.70244
1982	269.38	0.79927	0.72121
1983	279.01	0.79842	0.73885
1984	288.83	0.79768	0.75721
1985	300.07	0.79729	0.77712

Assumptions which differ from those of the standard experiment:

- starting in 1974, 85 per cent of R & D funds are invested in efforts to improve product performance and marketability.

TABLE 44

Performance of the Precast Concrete Industry in Terms of Square Footage Sold, Product Quality and Cost. Cost of Conventional Concrete Construction

Period	Square Footage Sold (millions of ft^2)	Probability that Precast has Better Quality than Conventional Concrete	Probability that Precast has Lower Cost than Conventional Concrete	Cost of Structure and Skin Built Conventionally ($\$/ft^2$)
1960	23.23	0.18793	0.20958	4.718
1961	28.80	0.18731	0.19666	4.772
1962	35.26	0.19479	0.18897	4.916
1963	40.51	0.21667	0.18781	5.126
1964	45.87	0.25620	0.17773	5.383
1965	49.49	0.31462	0.16971	5.532
1966	51.74	0.38948	0.15749	5.635
1967	56.43	0.47203	0.14886	5.786
1968	65.14	0.54975	0.14412	6.099
1969	75.18	0.61412	0.13766	6.476
1970	76.98	0.66363	0.14856	6.785
1971	93.27	0.70352	0.15129	7.098
1972	118.30	0.74652	0.24350	7.705
1973	128.79	0.77745	0.28706	8.139
1974	99.79	0.79062	0.07938	8.518
1975	96.17	0.79506	0.04538	8.881
1976	134.81	0.79660	0.31321	9.218
1977	210.28	0.79722	0.60300	9.369
1978	215.74	0.79771	0.59022	9.556
1979	226.24	0.79836	0.61123	9.821
1980	239.25	0.79899	0.64095	10.124
1981	250.23	0.79938	0.66530	10.427
1982	261.57	0.79898	0.68977	10.744
1983	272.31	0.79815	0.71256	11.059
1984	282.94	0.79744	0.73467	11.384
1985	294.95	0.79708	0.75815	11.730

Assumptions which differ from those of the standard experiment:

- Starting in 1960, 85 per cent of R & D funds are allocated in efforts to improve product performance and marketability.

In 1974 and 1975, and in terms of cost performance and square footage sold, the results of this model experiment are particularly discouraging. This is due to the fact that softening of the market after 1972 caused a decrease in demand for the products of the industry resulting in low utilization factors. The effect was accentuated by the cost performance of the industry which was worse than in the standard experiment. At the end of these two years (1974-75), the industry was finally able to rid itself of excess capacity and operate at normal utilization.

TABLE 45

Approximate Manhours per 1,000 ft^2 of Multi-family Dwellings

	U. S. Conventional Dwellings			Western Europe Industrialized Dwellings					
				England			Continent		
	Low	High	Average	Low	High	Average	Low	High	Average
On-site	850	1480	1165	1527	1850	1687	325	600	462
Off-site	128	170	149	375	375	375	200	400	300
Total	978	1650	1314	1900	2225	2062	525	1000	762

Note: Average manhours for industrialized buildings on European continent are 63 per cent below English average and 42 per cent below U. S. average for conventional construction.

Source: Reference 24

TABLE 46

Square Footage Sold by the Precast Concrete Industry. Labor and Total Costs of Precast and Conventional Concrete Construction

	Precast Concrete Industry			Conventional Concrete Construction	
Period	Square Footage Sold (millions of square feet)	Labor Cost ($\$/ft^2$)	Total Cost ($\$/ft^2$)	Labor Cost ($\$/ft^2$)	Total Cost ($\$/ft^2$)
1975	152.04	2.3098	8.886	3.8959	8.795
1976	199.17	2.1580	8.594	4.0253	9.086
1977	198.67	2.3311	9.003	4.0156	9.291
1978	206.12	2.4075	9.248	4.1006	9.551
1979	214.80	2.4788	9.492	4.2236	9.845
1980	225.28	2.5495	9.739	4.3600	10.167
1981	234.03	2.6204	9.993	4.4905	10.485
1982	243.46	2.6942	10.250	4.6311	10.815
1983	252.29	2.7627	10.507	4.7658	11.141
1984	261.44	2.8342	10.765	4.9087	11.477
1985	272.59	2.8989	11.027	5.0548	11.833

Assumptions which differ from those of the standard experiment

- From 1974 on, labor wages in the factory equal labor wages on site.
- From 1974 on, there is a 10 per cent increase in manpower of precast concrete industry.

TABLE 47

Labour Requirements for Superstructures of Two Blocks of Flats (i)

	Manhours per dwelling (ii)			
	A		B	
	Building constructed with average-quality panels and finished in the ordinary way		Building constructed with high-quality panels and designed to reduce work of finishing trades	
Panels delivered to site	256		235	
Site				
Erect, joint, and make good	149		126	
		405		361
Finishings				
Partitions and linings	51		25	
Plastering	89		58	
Joinery	166		43 (iii)	
Plumbing and heating	83		11 (iii)	
Painting and glazing	190		43	
Sub-total	579		180	
Specialists	88		78	
Finishings		667		258
Total		1,072		619

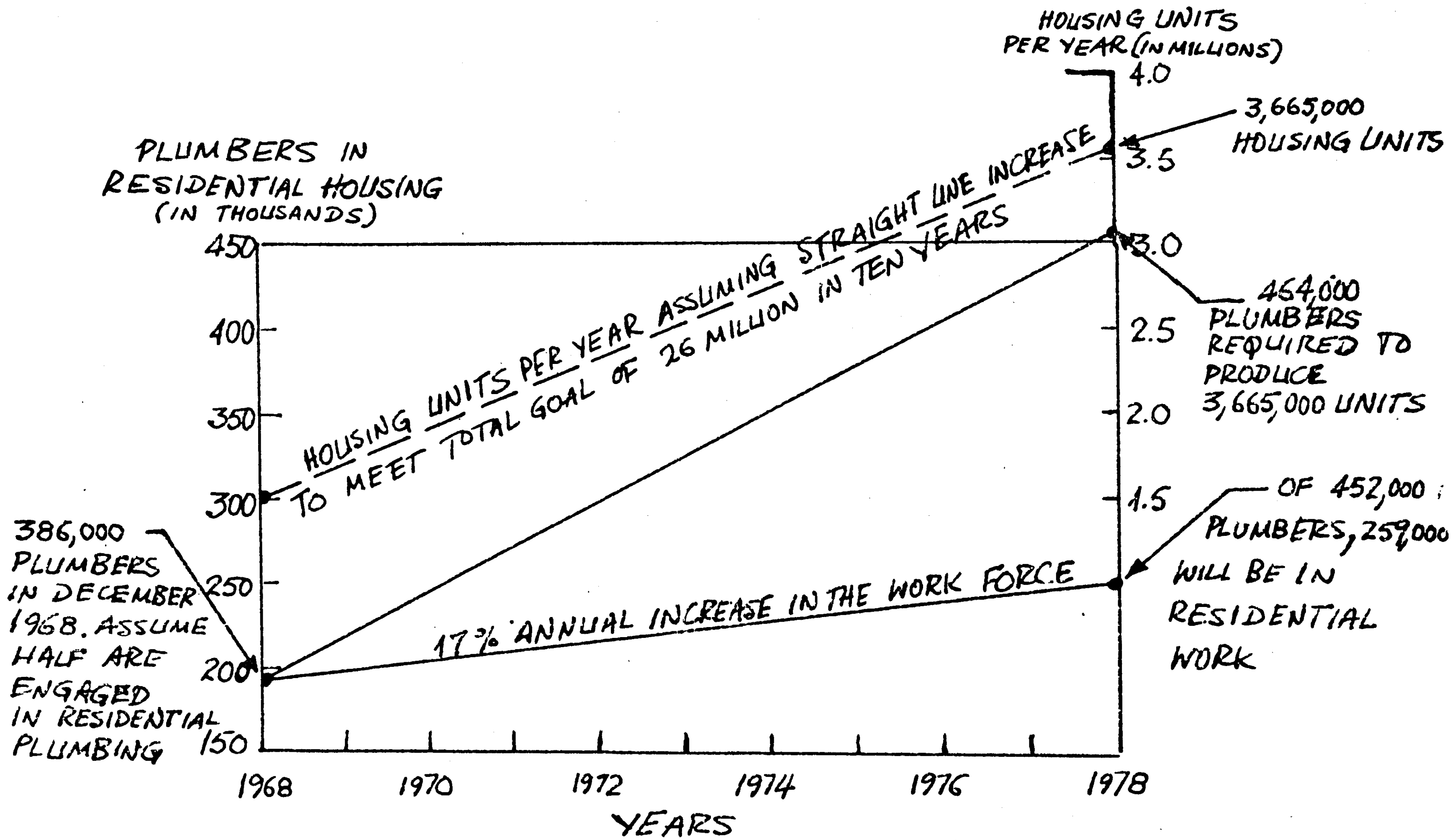
i) stairway access: three-roomed dwellings

ii) roughly 2,200 ft^2 of panel

iii) mostly prefabricated

Source: Reference 17

FIG.1 SHORTAGE IN 1978 : 205,000 PLUMBERS
(AFTER REF. 12)



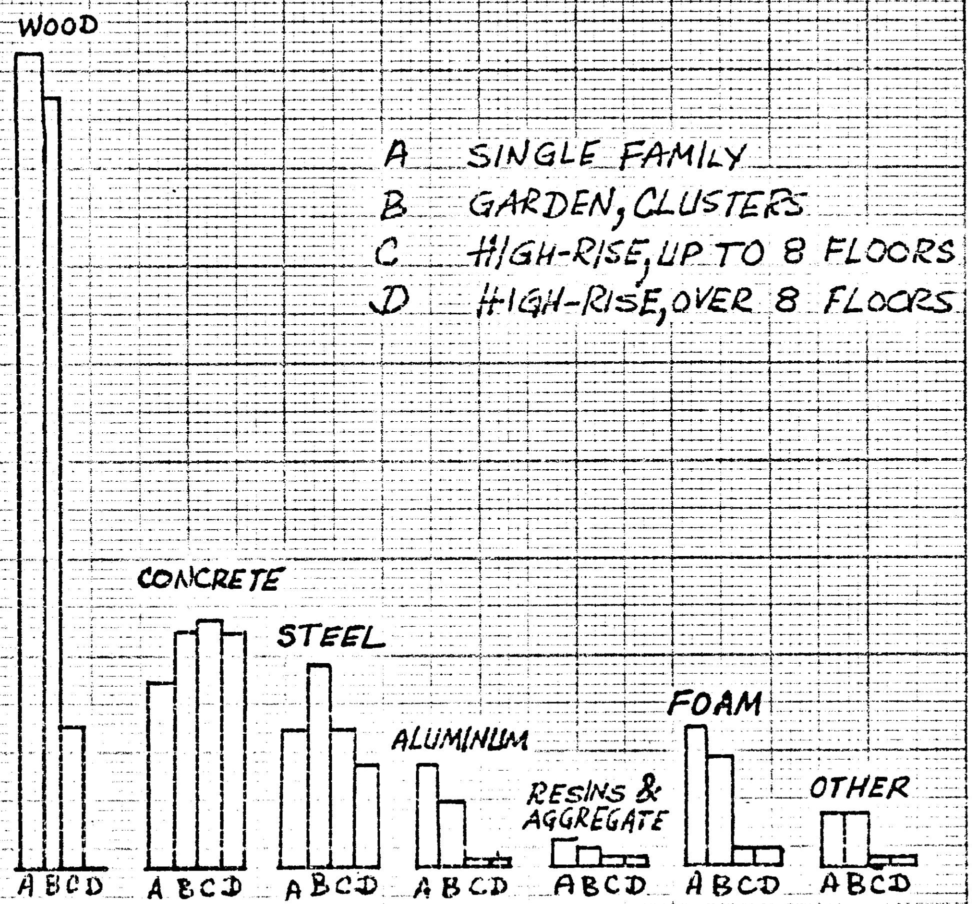


FIG. 2 BUILDING MATERIALS

PREDOMINANT MATERIAL USED IN THE SYSTEM FOR EACH BUILDING TYPE

SOURCE; REF. 44

FORM 4 T TECHNOLOGY STORE, H. C. S. 40 MASS. AVE., CAMBRIDGE, MASS.

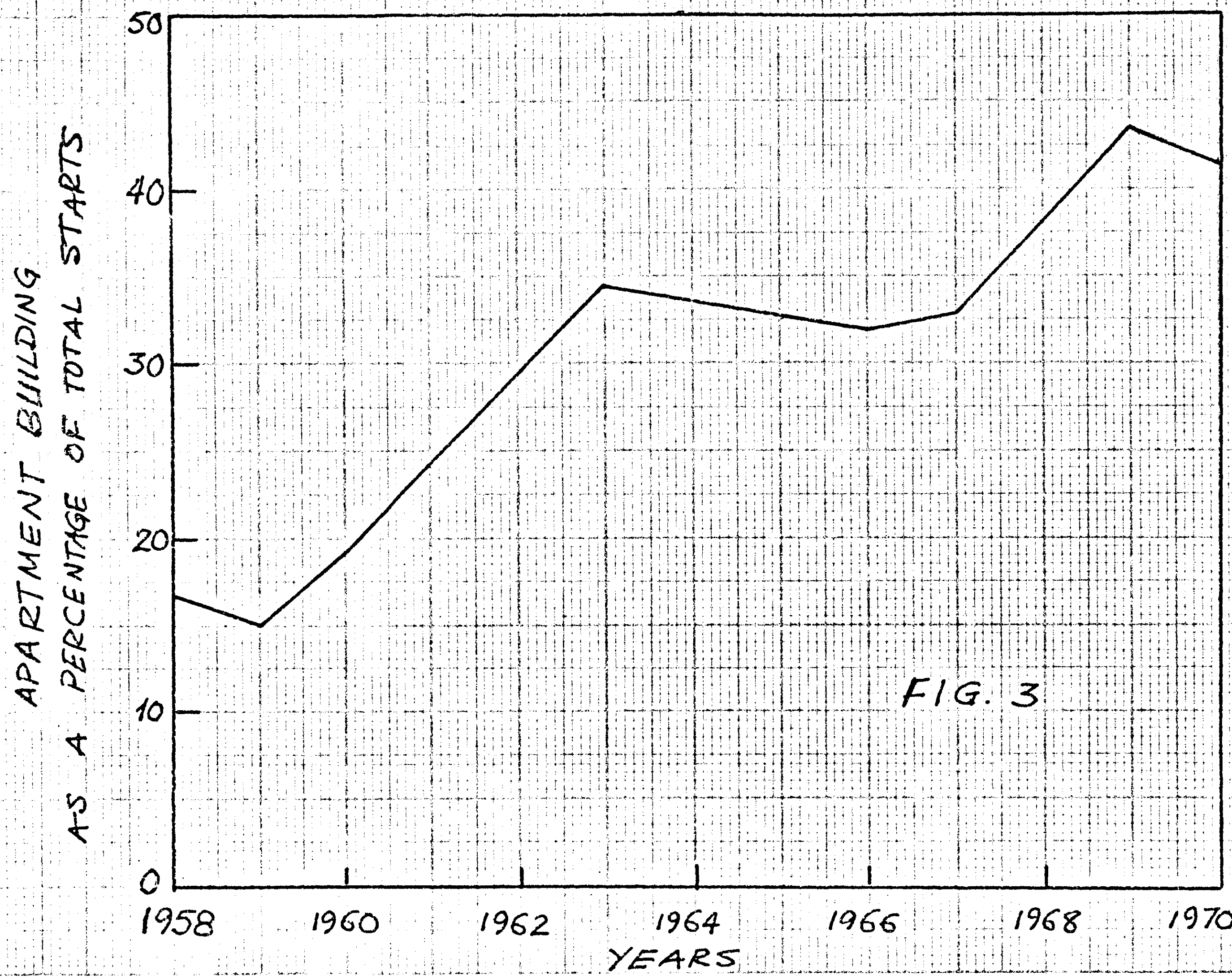


FIG. 3

FIG. 4

FIG.4 "NEWNESS" OF A SAMPLE OF 301 COMPANIES WHICH PRODUCED FACTORY-BUILT HOUSING PRIOR TO JUNE, 1970

SOURCE: REF. 44

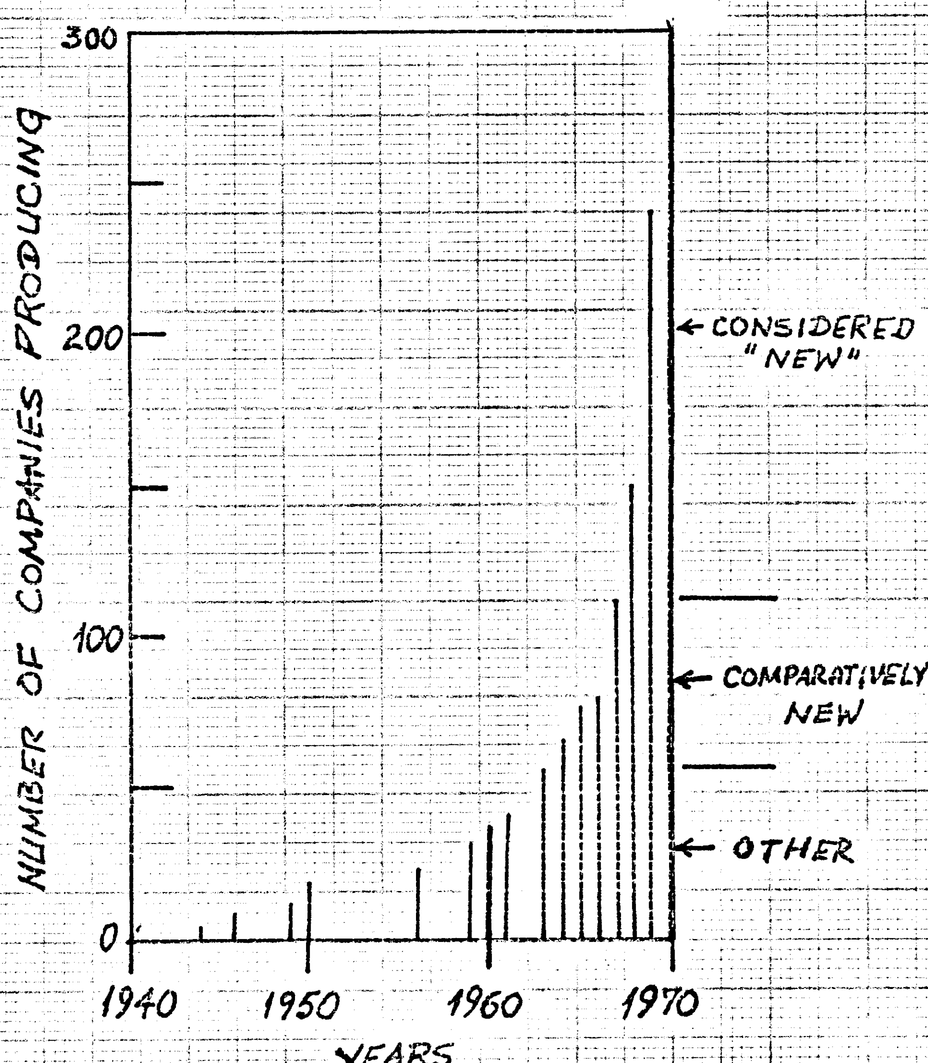
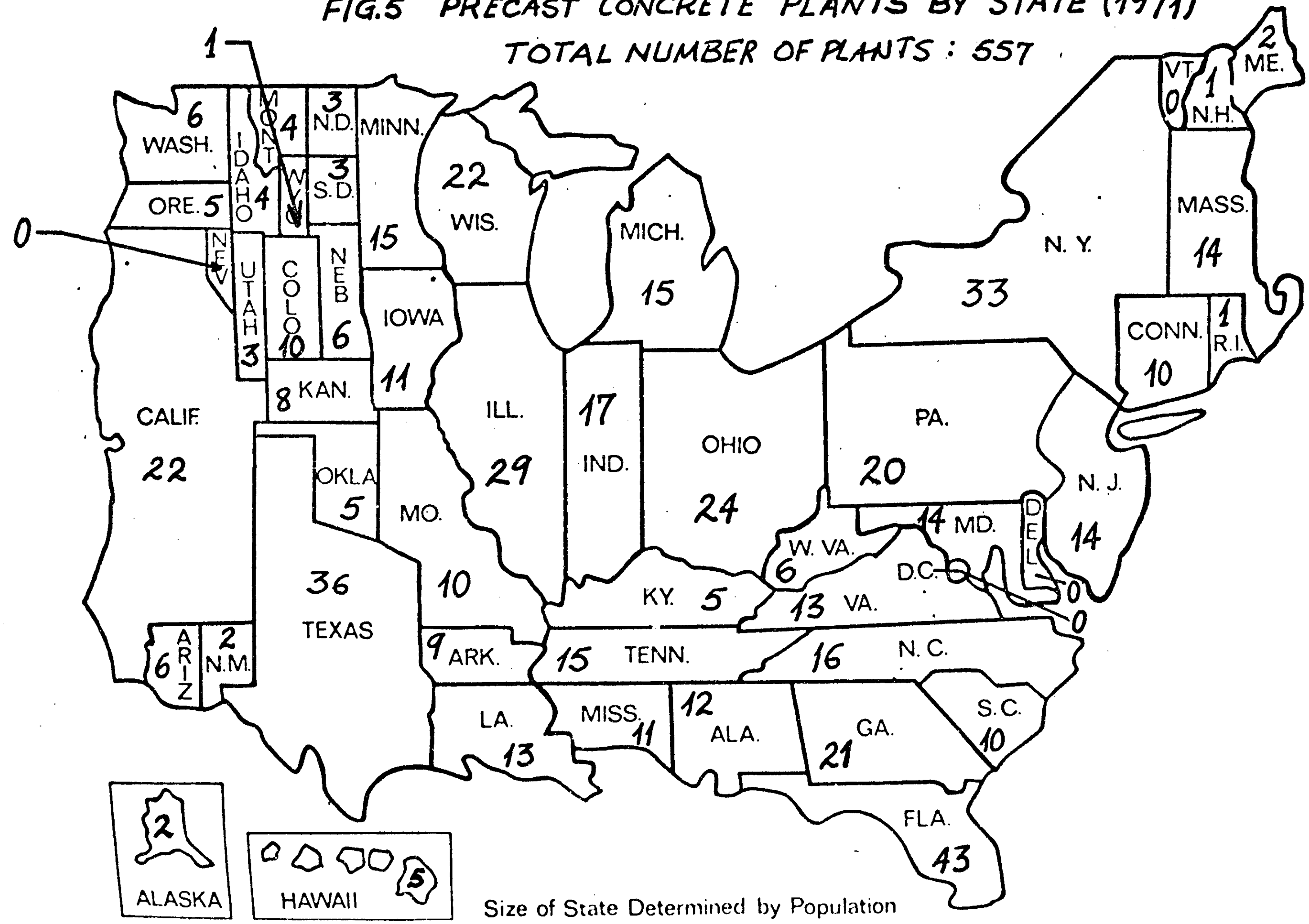
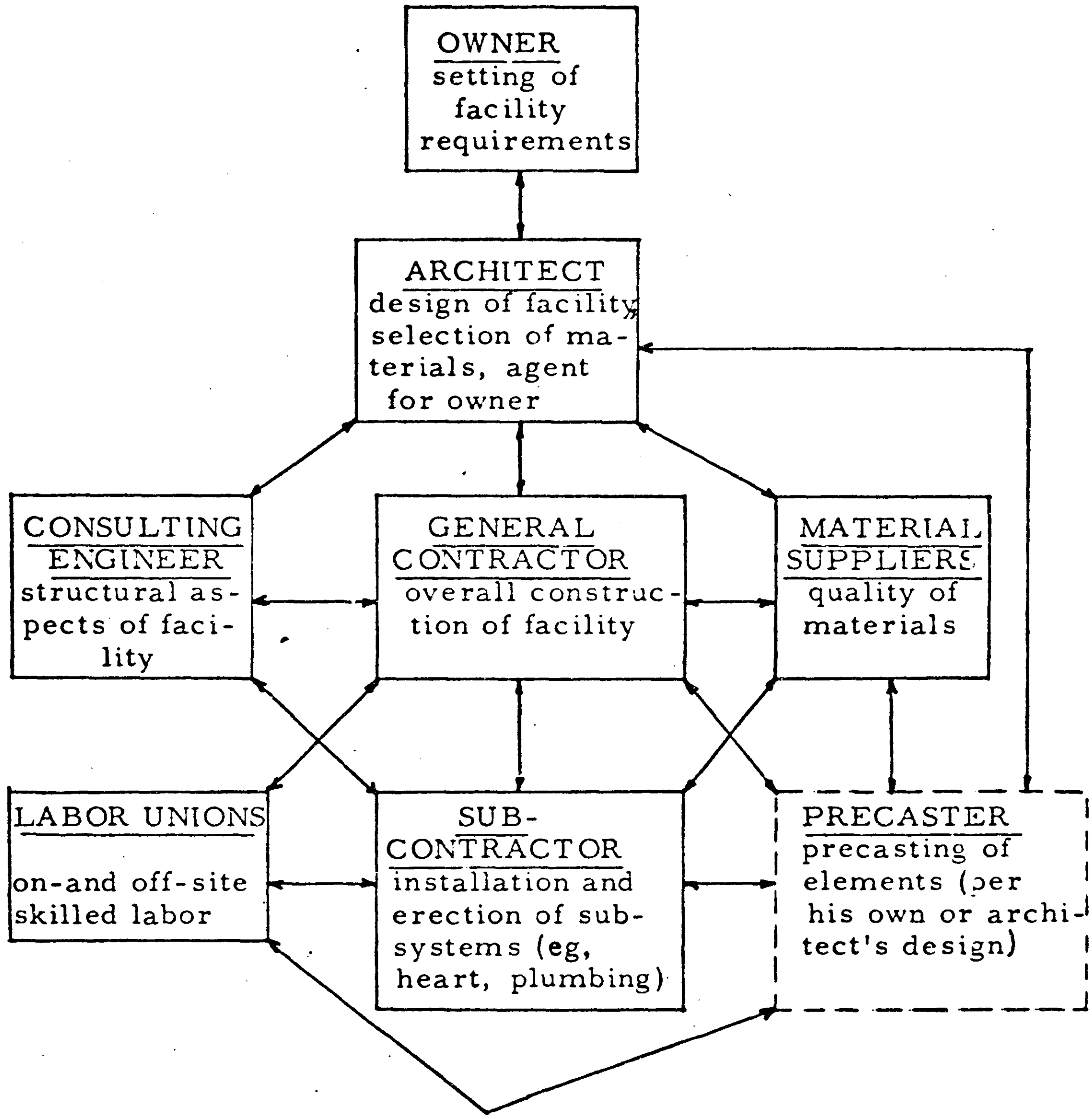


FIG.5 PRECAST CONCRETE PLANTS BY STATE (1971)
TOTAL NUMBER OF PLANTS : 557



SOURCE : REF. 65



NOTE: The Actors and their interactions in the precast concrete industry . Arrows indicate the flow of information and control.

Source: Reference No. 69

FIG. 6

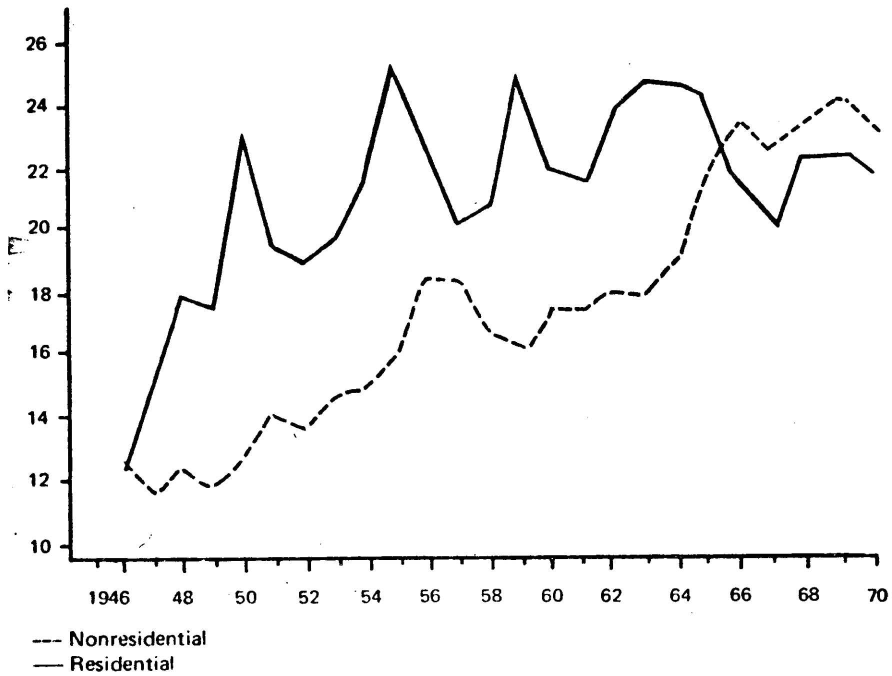
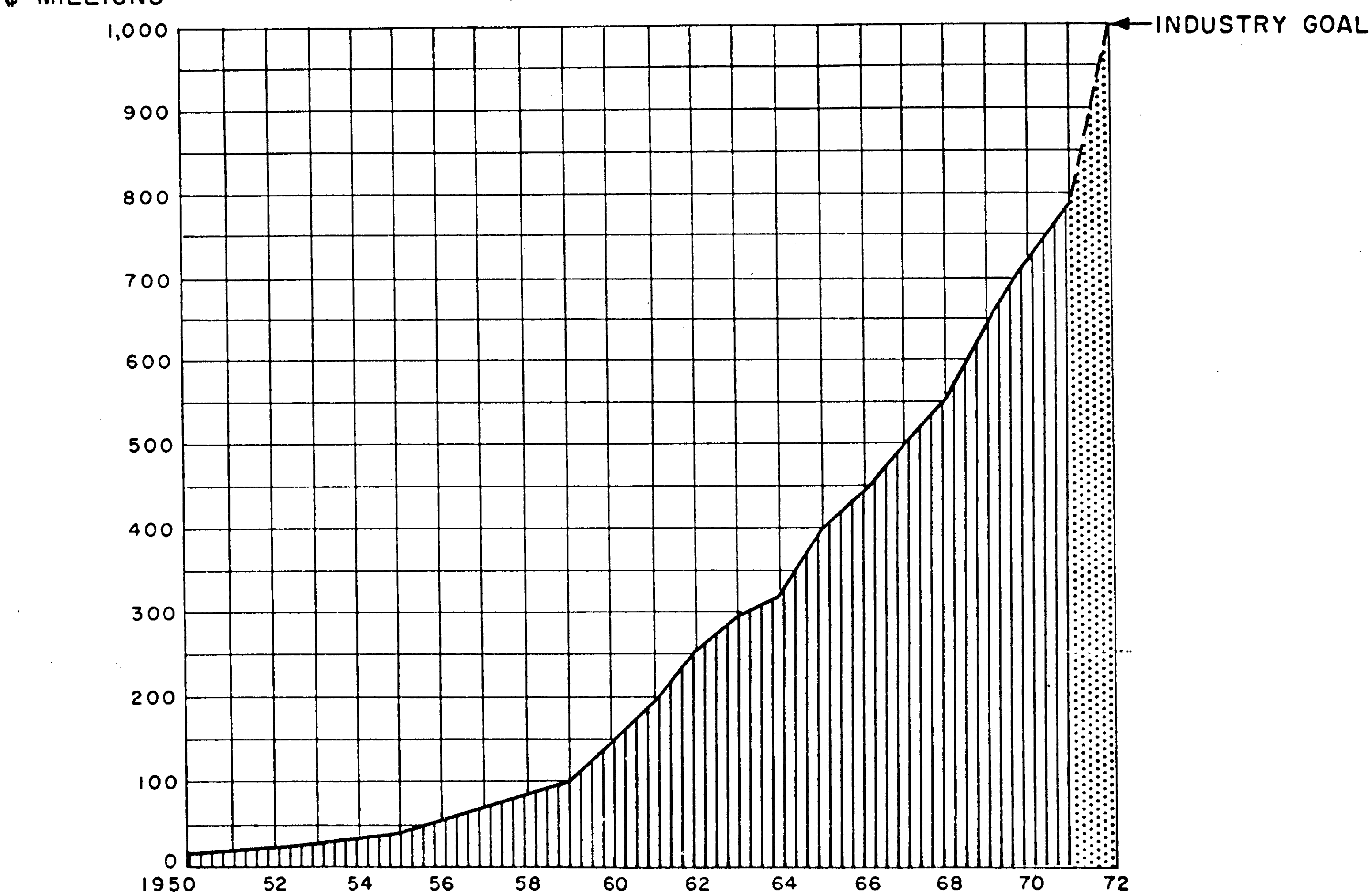


Figure 7 Gross Private Domestic Investment, Nonresidential and Residential Structures, 1958 Dollars (Billions), 1946-1970.

Source: *Construction Review* (monthly issued by Department of Commerce, Business and Defense Services Administration).

Note: It is necessary in these estimates to obtain constant dollar estimates through the use of price deflators, which are known to overstate the rate of inflation and thereby to depress unduly constant dollar output in recent years. These deflators are used because of the lack of better ones on a current basis. See Robert J. Gordon, "$45 Billion of U.S. Private Investment Has Been Mislaid," *American Economic Review* 59 (June 1969): 221-238; and George Jaszi, "Reply," *American Economic Review* 60 (December 1970): 934-939.

FIG. 8



SALES VOLUME - PRECAST AND PRESTRESSED CONCRETE

Post and Beam (Frame): Usually consists of prefabricated columns and beams with panels of either structural or nonstructural function. Components can be light enough for installation by men.

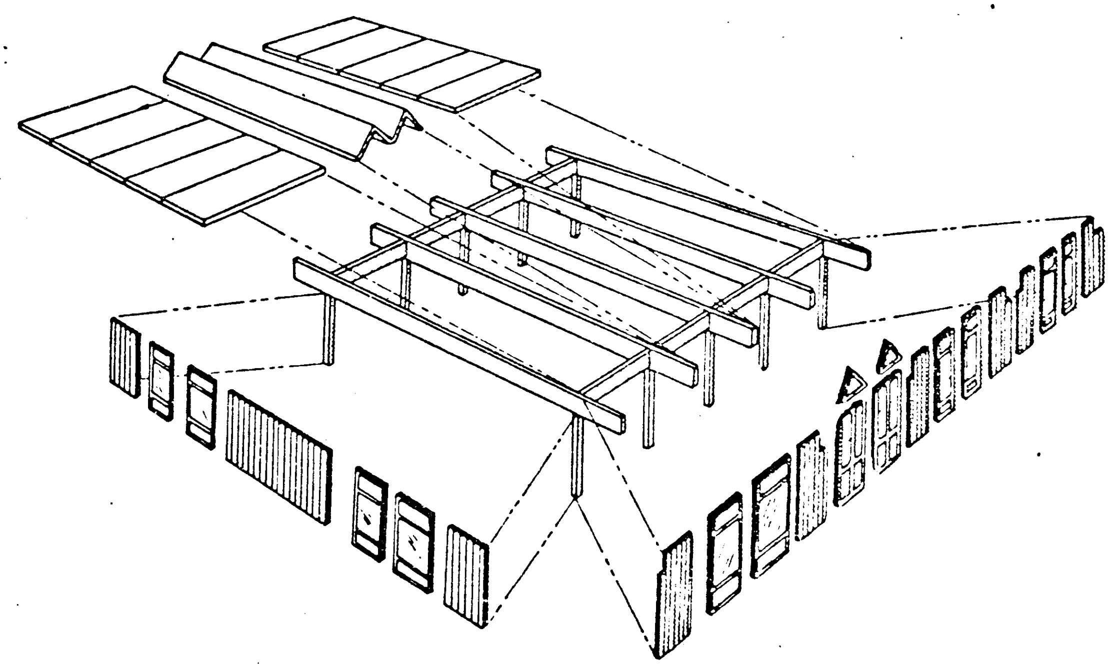


FIG. 9

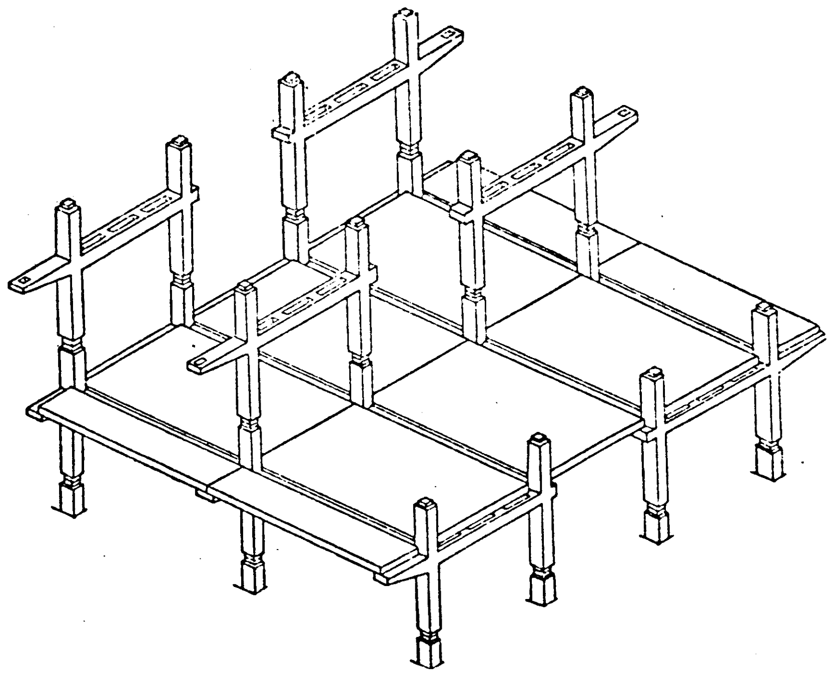


FIG. 10
PORTAL FRAMES

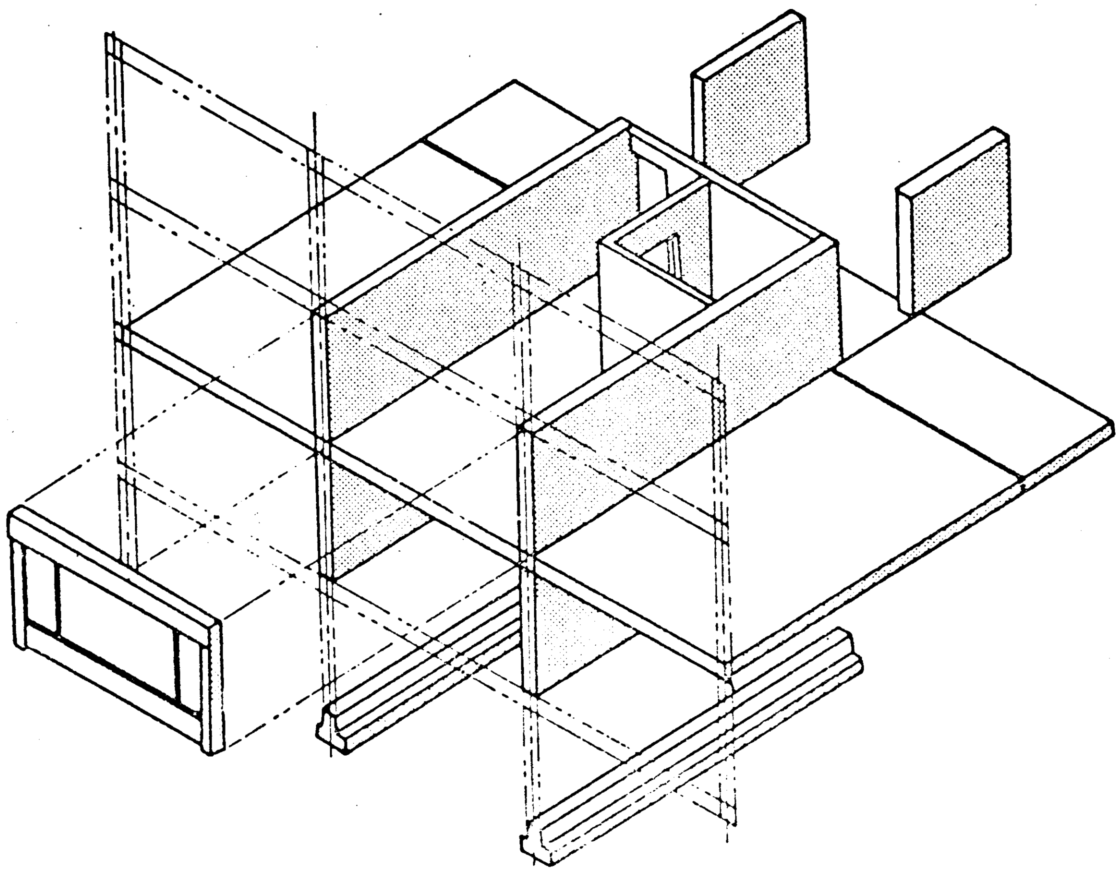


FIG. 11

PANEL OR SLAB SYSTEMS

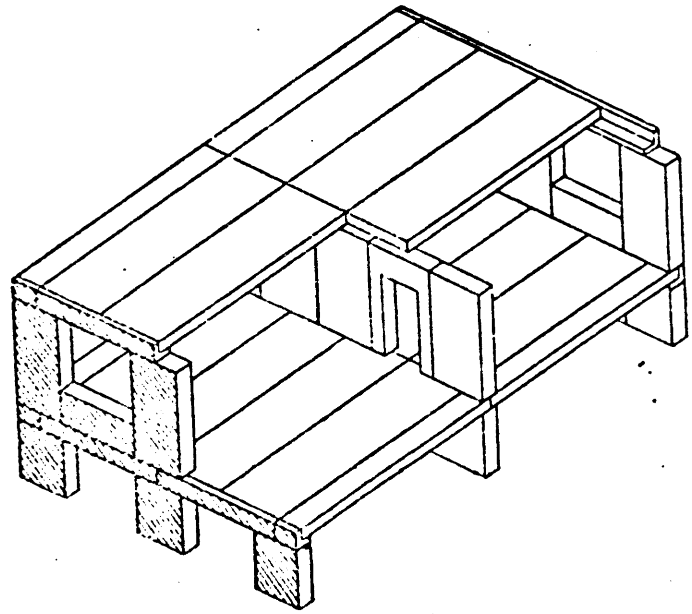
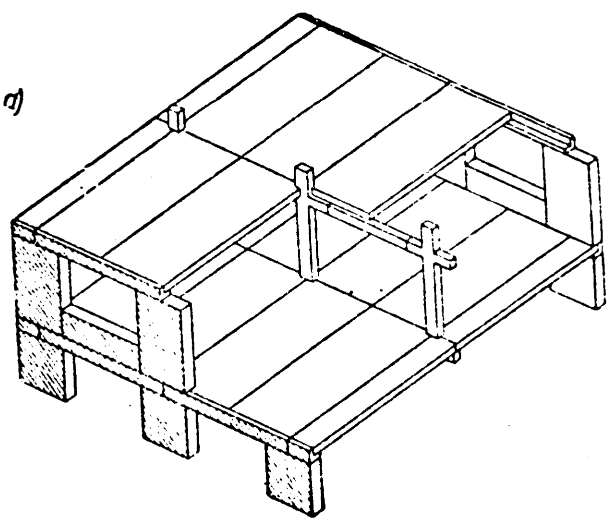


FIG. 12

LONGITUDINAL PANEL SYSTEMS

a)



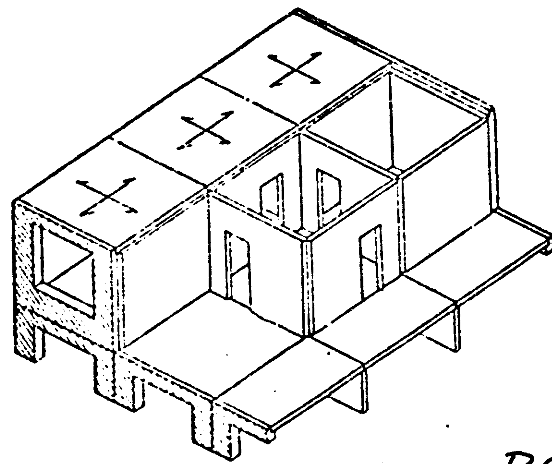


FIG. 13
BOTH-WAYS
PANEL SYSTEMS

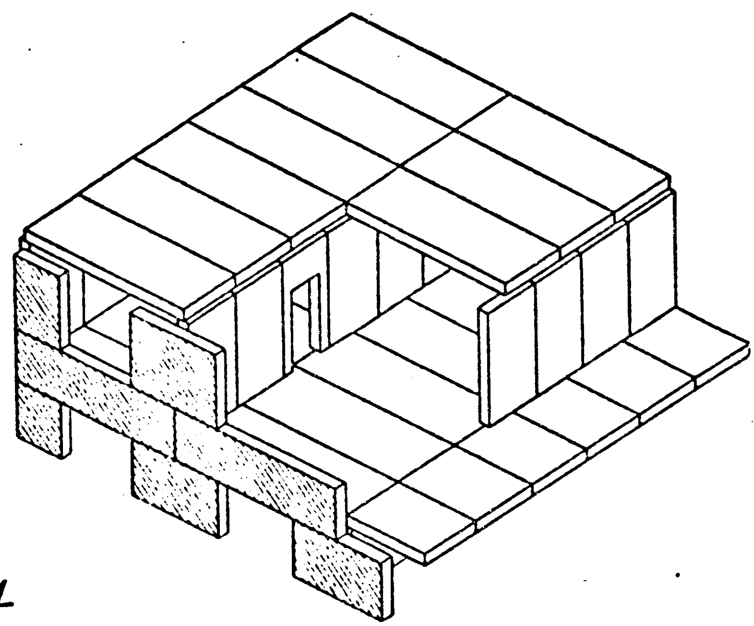


FIG. 14
TRANSVERSE PANEL SYSTEMS

Monolithic unit. Factory-produced, heavyweight boxes stacked together in checkerboard fashion in order not to be redundant in the wall structure. These units provide a high degree of finish and require a minimum amount of on-site erection time. Courtesy of *Engineering News-Record.*

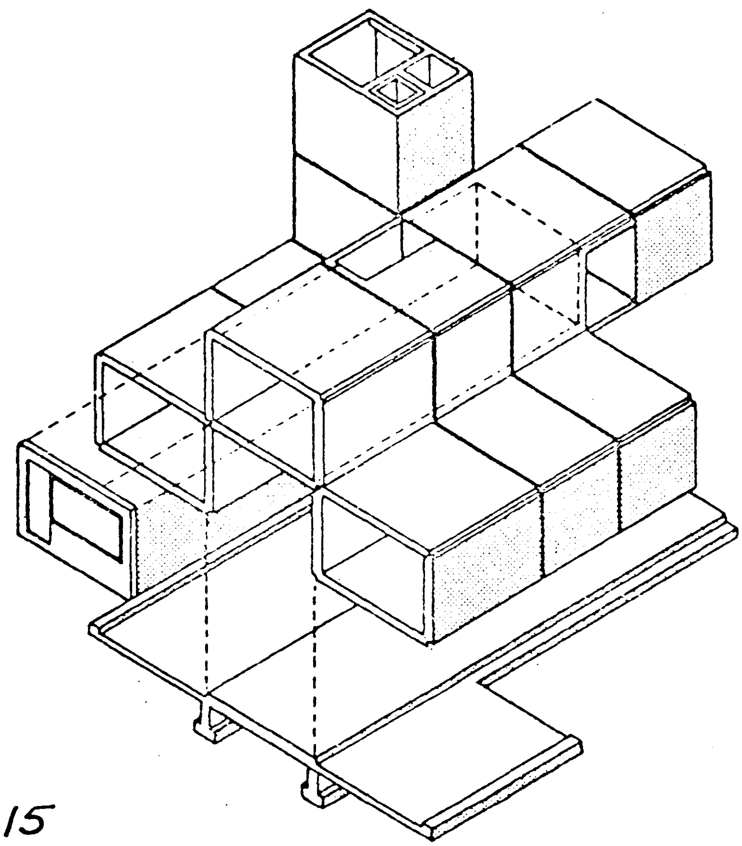
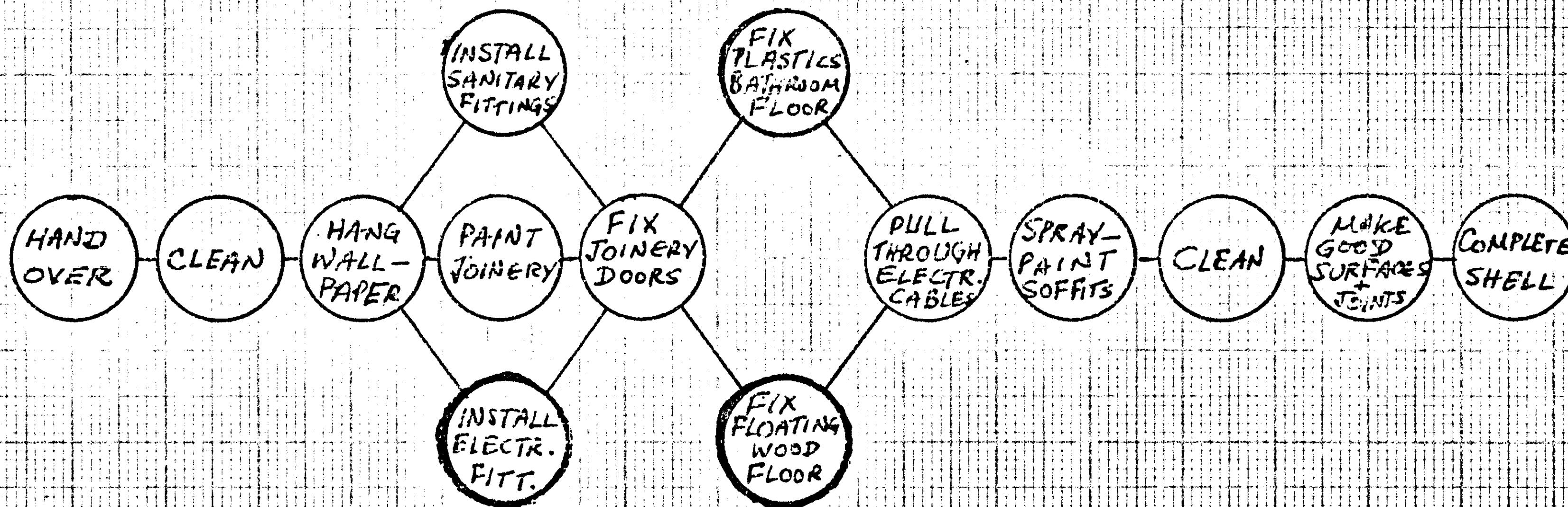


FIG. 15

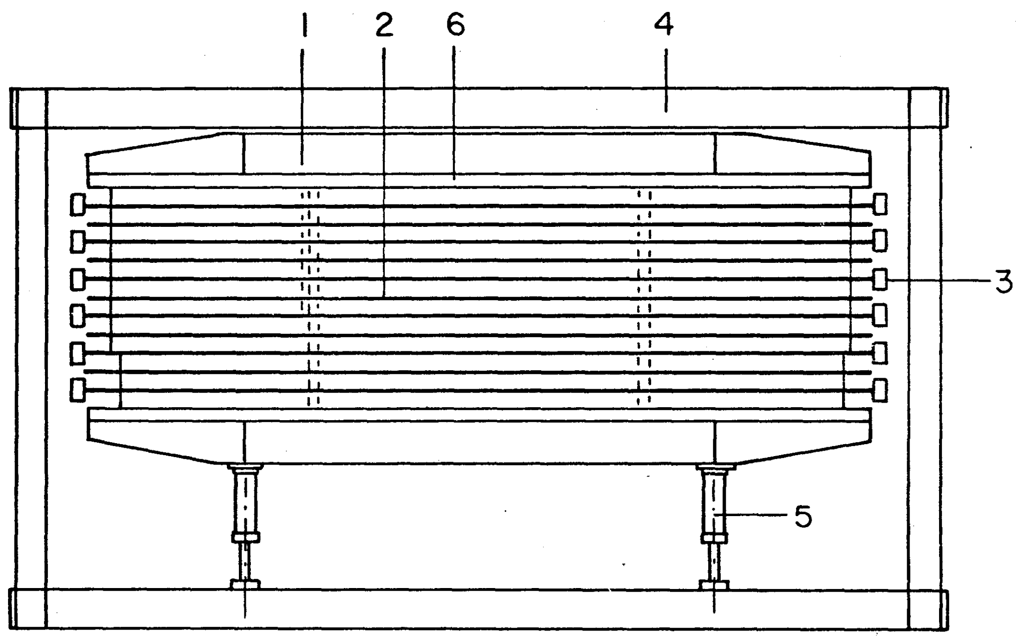
FIG. 16 SEQUENCE OF OPERATIONS FOR FINISHES AND SERVICES WITHIN EACH FLAT



SOURCE; REF. 15

Plan of battery mould with vibrators attached to the ends:

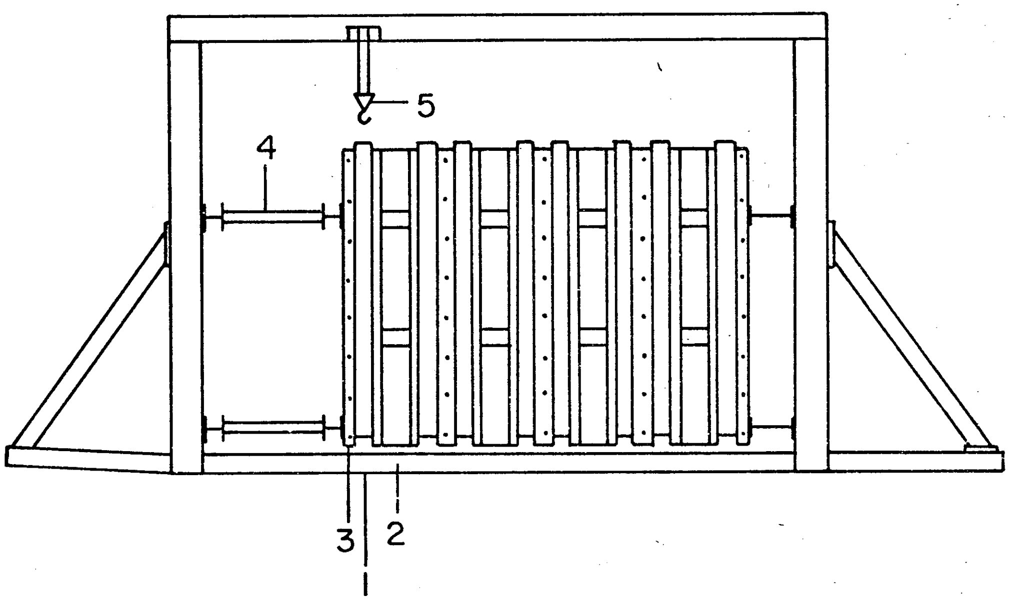
(1) precast concrete unit
(2) steel mould plate
(3) external vibrator
(4) battery mould frame
(5) hydraulic jacks
(6) end mould panel (mould type Luchterhand and others)



Source: Reference 37

Fig. 18

Cross-section through a battery mould with heating elements and vibrating elements; the latter are each equipped with five high-frequency vibrators:
(1) frame, (2) vibrating element, (3) heating element, (4) hydraulically powered thrust props for pushing the various parts of the mould together, (5) pulley block for assembling the mould (mould type MAN and others)



Source: Reference 37

Fig. 17

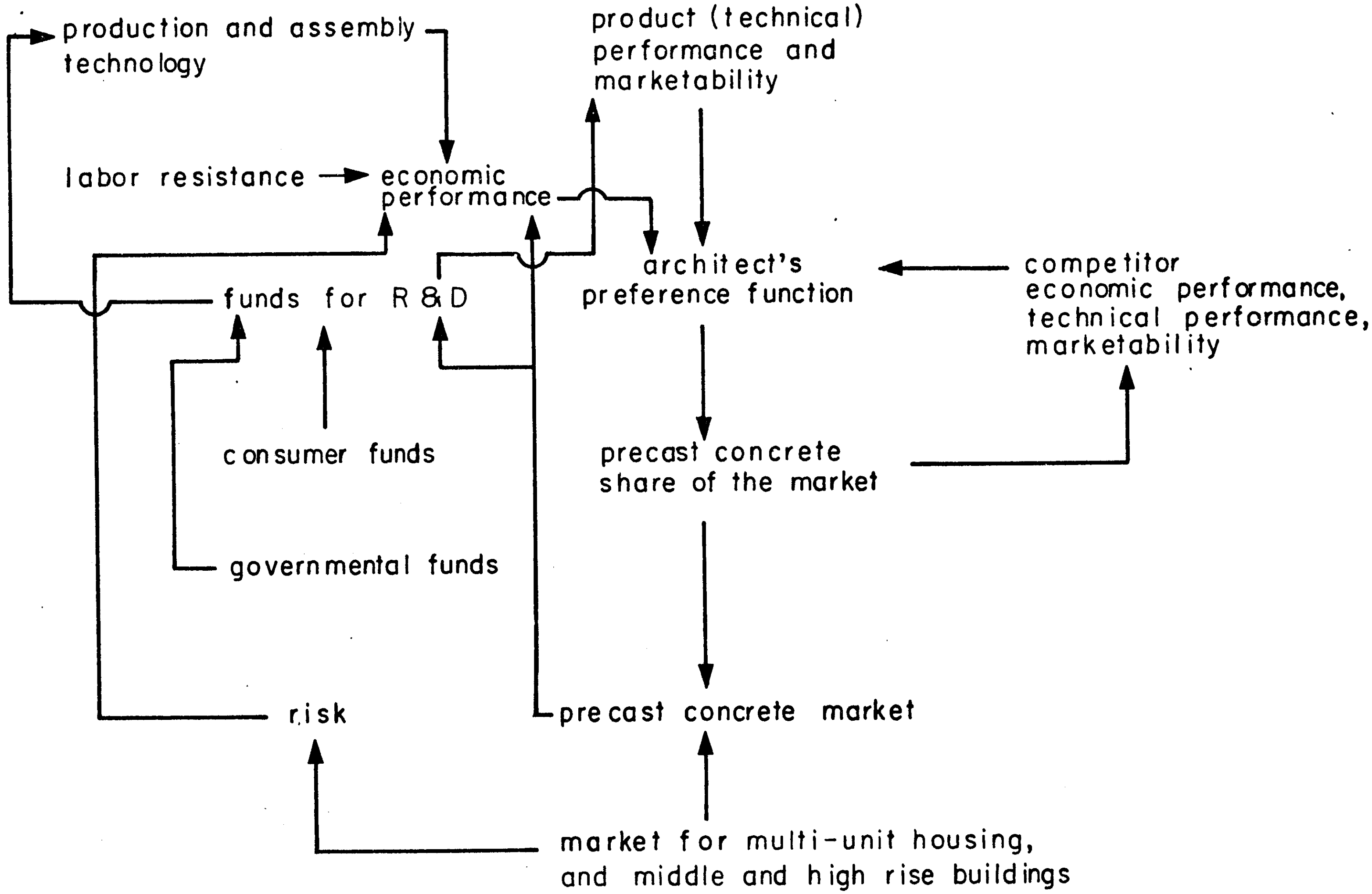


Fig. 19 Causal loop diagram of the precast concrete industry

FIG. 20a
PRECAST CONCRETE CONSTRUCTION
COST OF CAPITAL ($/FT²)

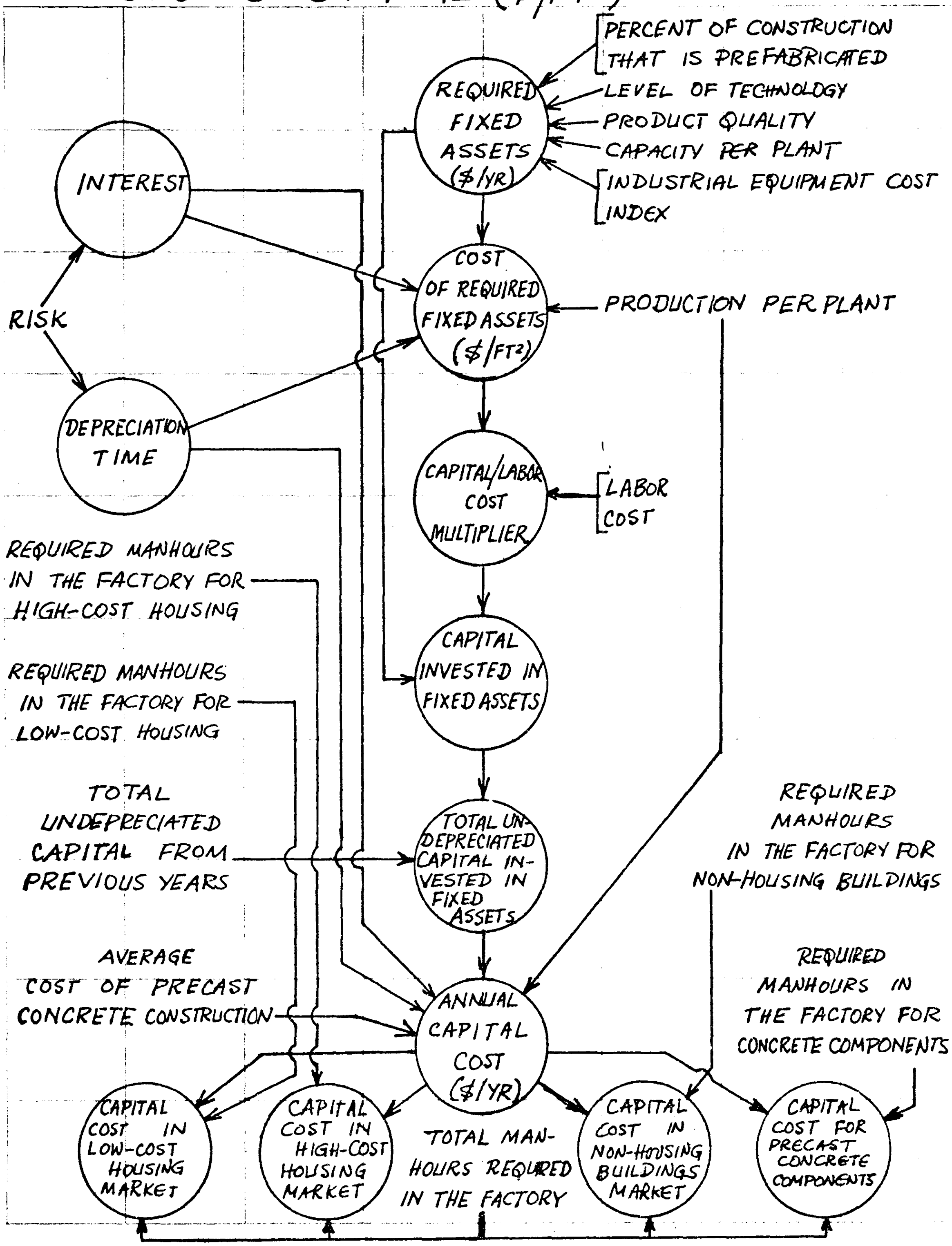
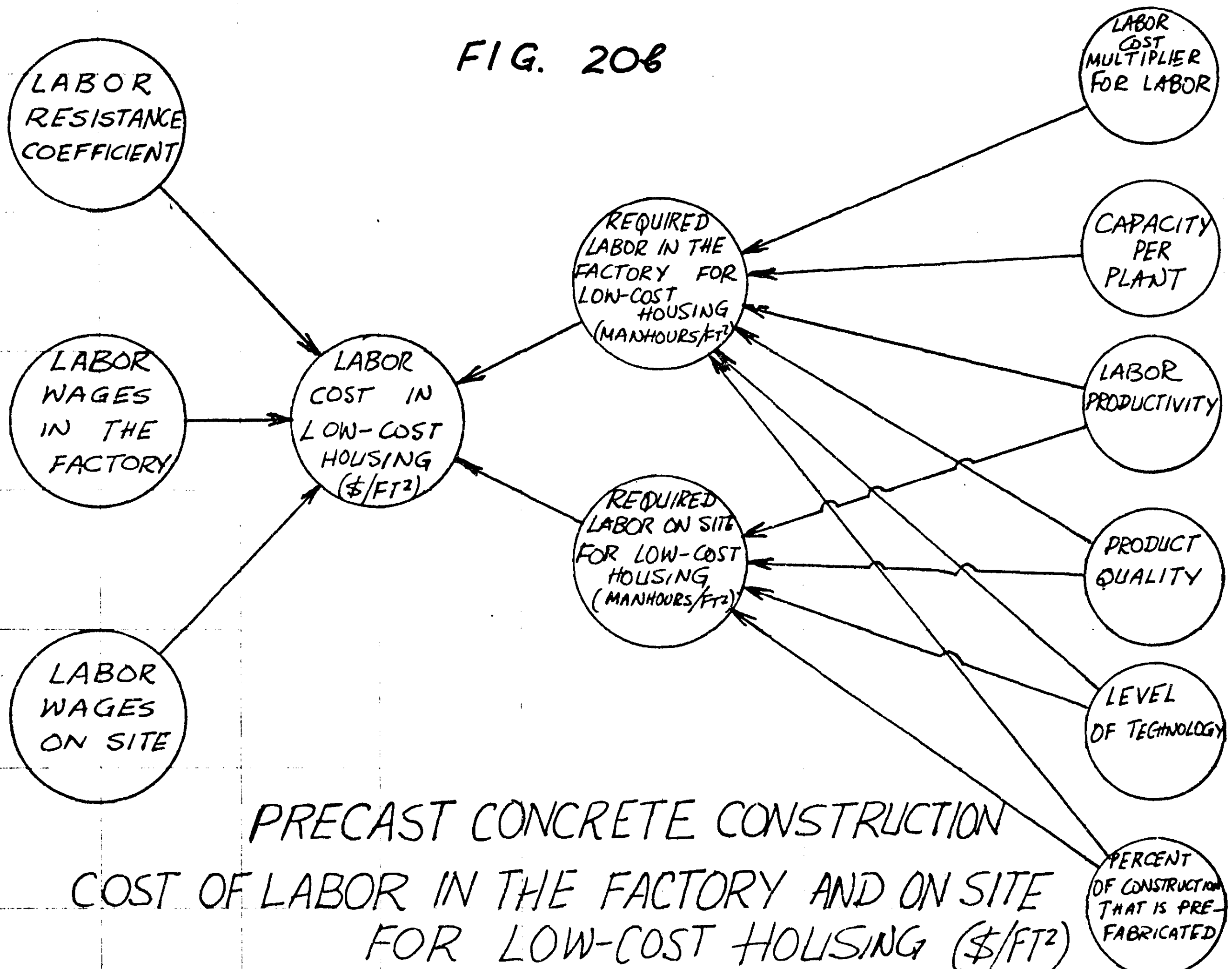


FIG. 208



PRECAST CONCRETE CONSTRUCTION

COST OF LABOR IN THE FACTORY AND ON SITE FOR LOW-COST HOUSING ($/FT²)

NOTE: SIMILAR DIAGRAMS APPLY ALSO FOR THE OTHER PRECAST CONCRETE MARKETS

PRECAST CONCRETE CONSTRUCTION
COST OF MATERIALS ($/FT²)

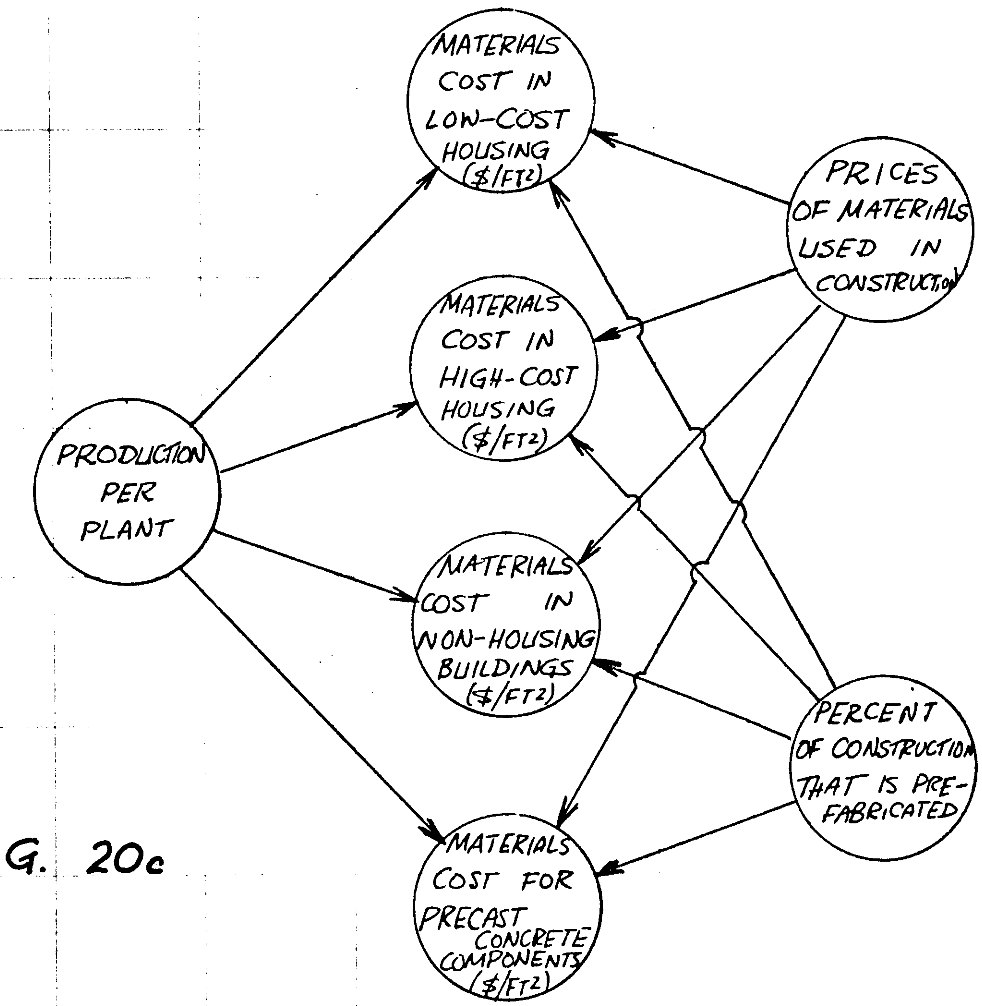


FIG. 20c

PRECAST CONCRETE CONSTRUCTION.

FACTORY OPERATING OVERHEAD, TRANSPORTATION AND SITE OVERHEAD

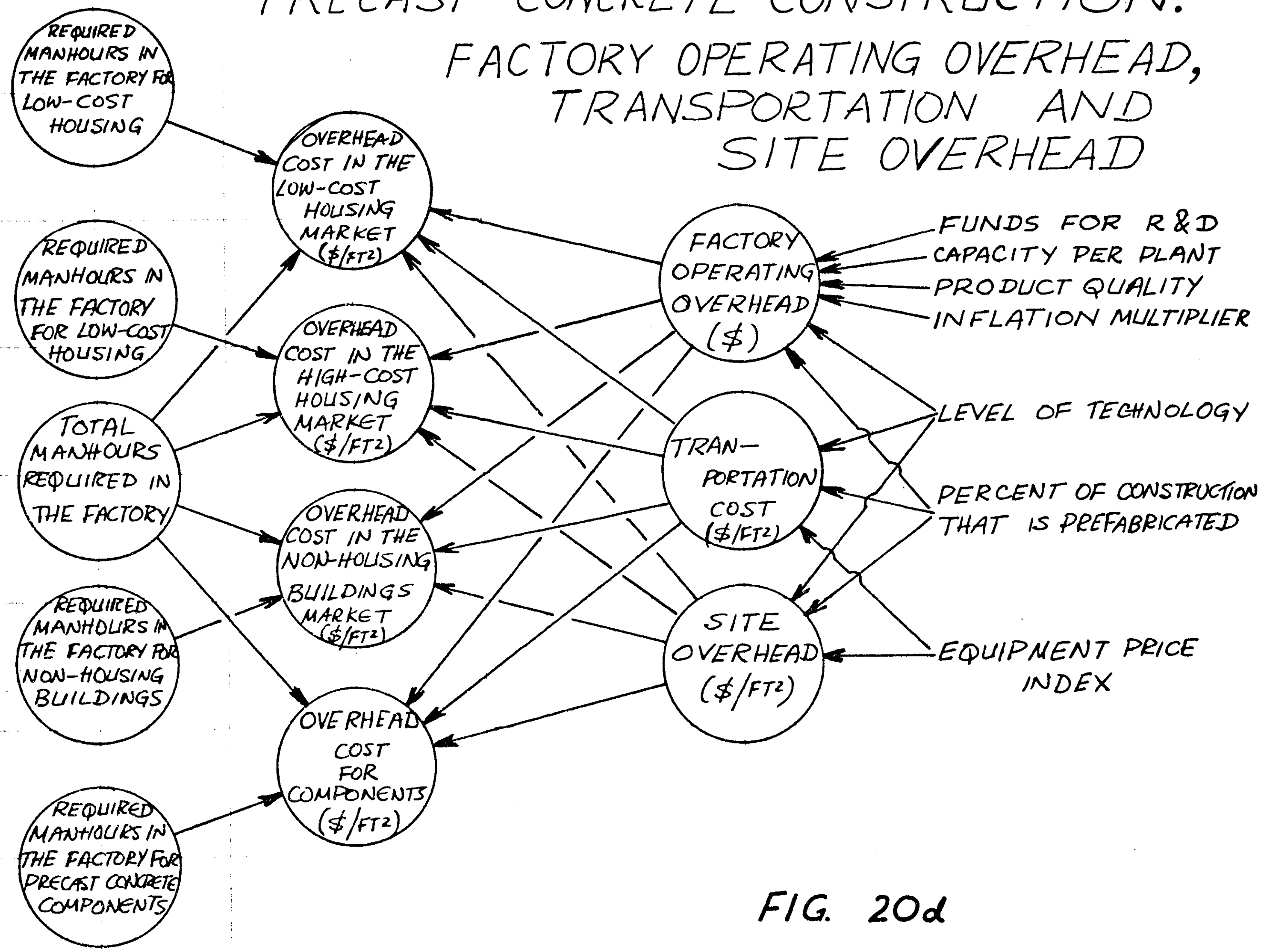
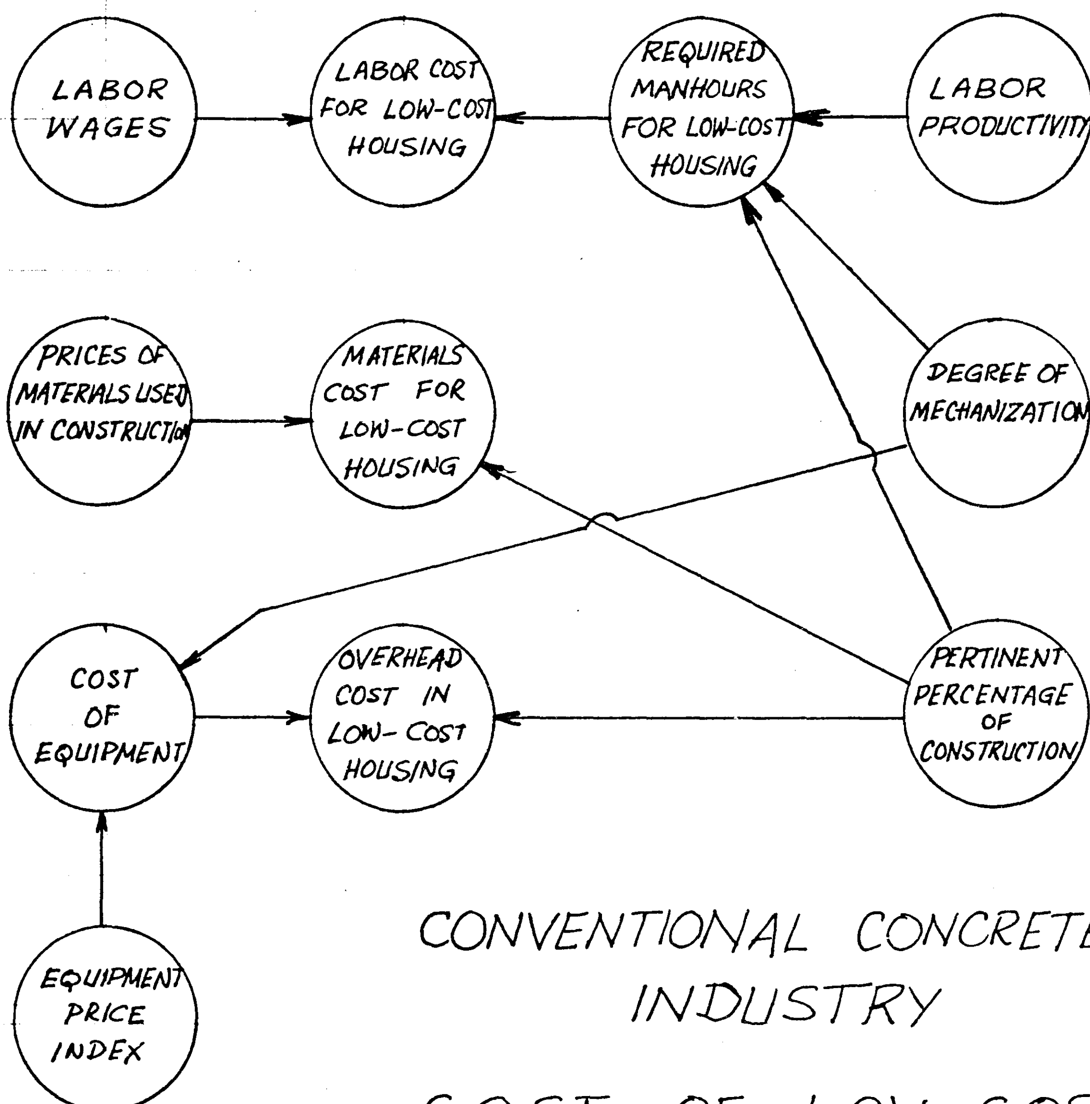


FIG. 20d

FIG. 20e



CONVENTIONAL CONCRETE INDUSTRY

COST OF LOW-COST HOUSING ($/FT²)

NOTE: SIMILAR DIAGRAMS APPLY TO HIGH-COST HOUSING AND NON-HOUSING BUILDINGS

FIG. 21

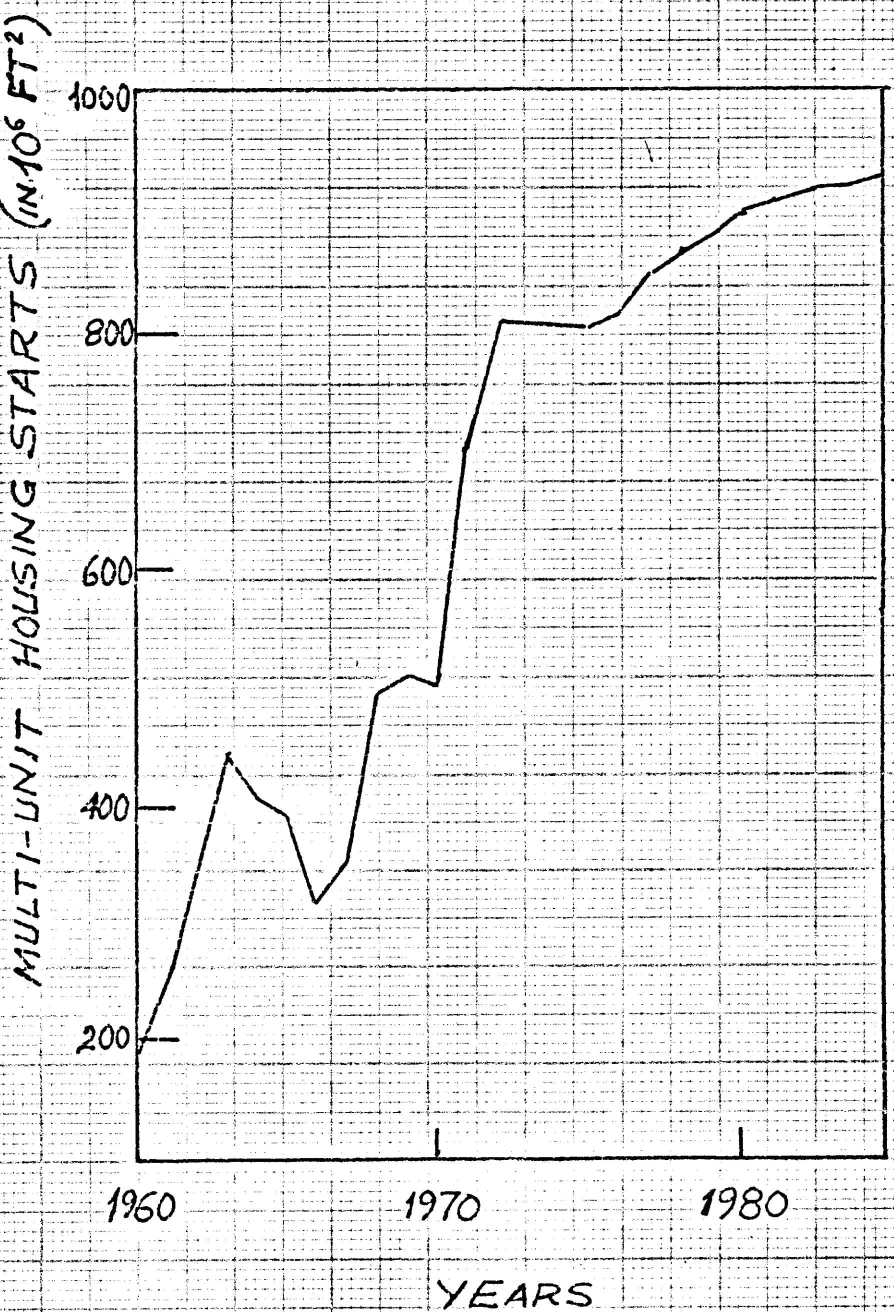
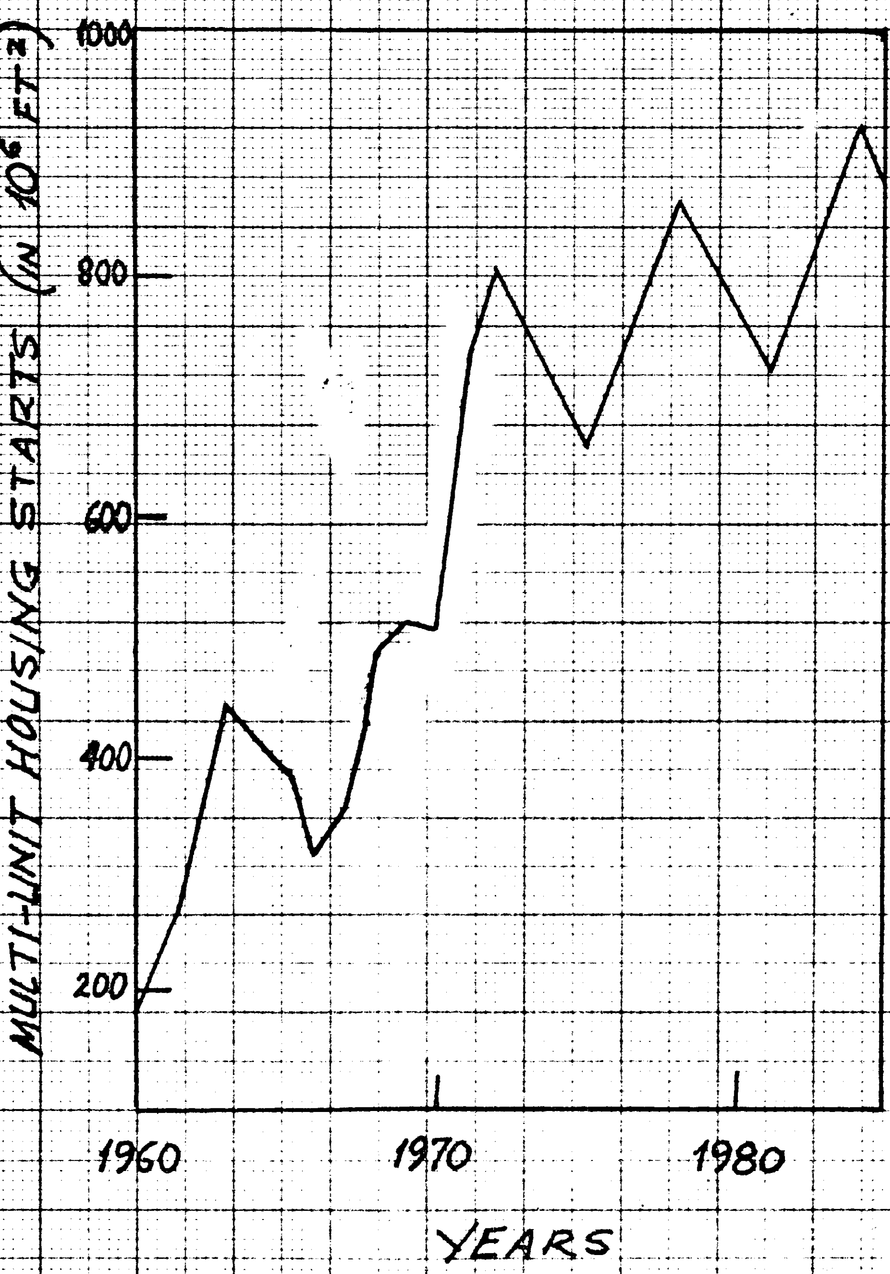

MULTI-UNIT HOUSING STARTS (IN 10^6 FT^2)
1000
800
600
400
200
1960
1970
1980
YEARS

FIG. 22


MULTI-UNIT HOUSING STARTS (IN 10^6 FT^2)
1000
800
600
400
200
1960
1970
1980
YEARS

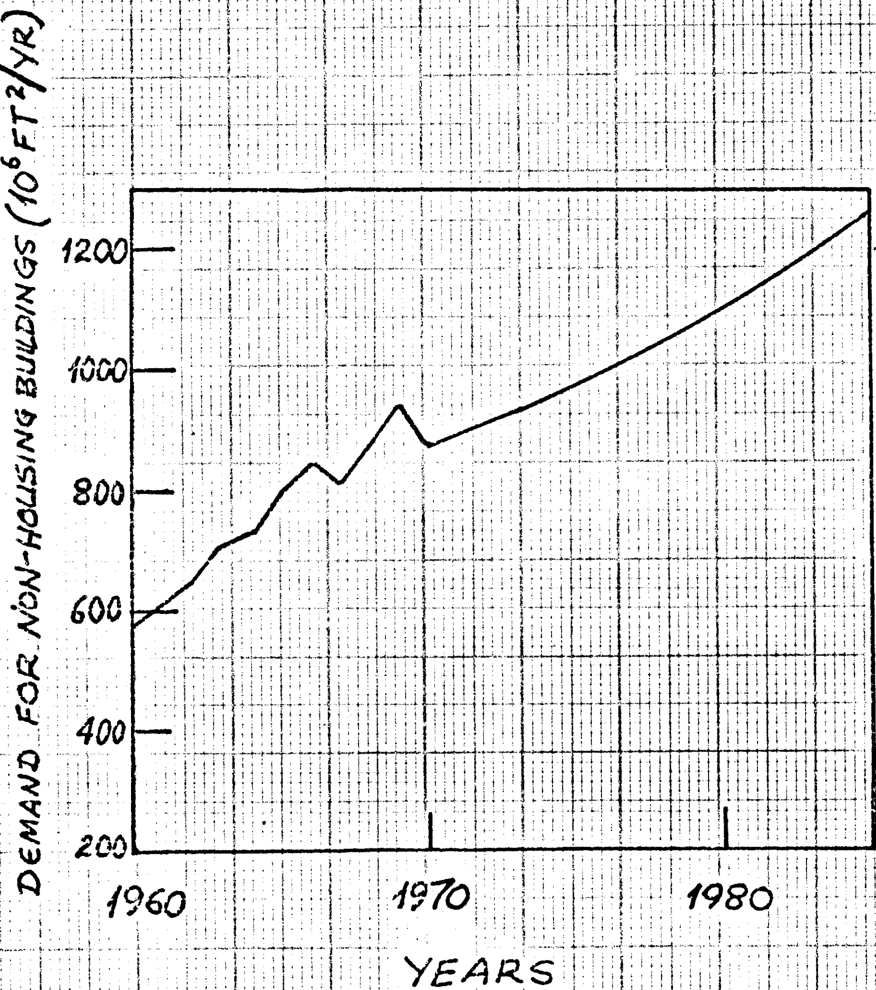
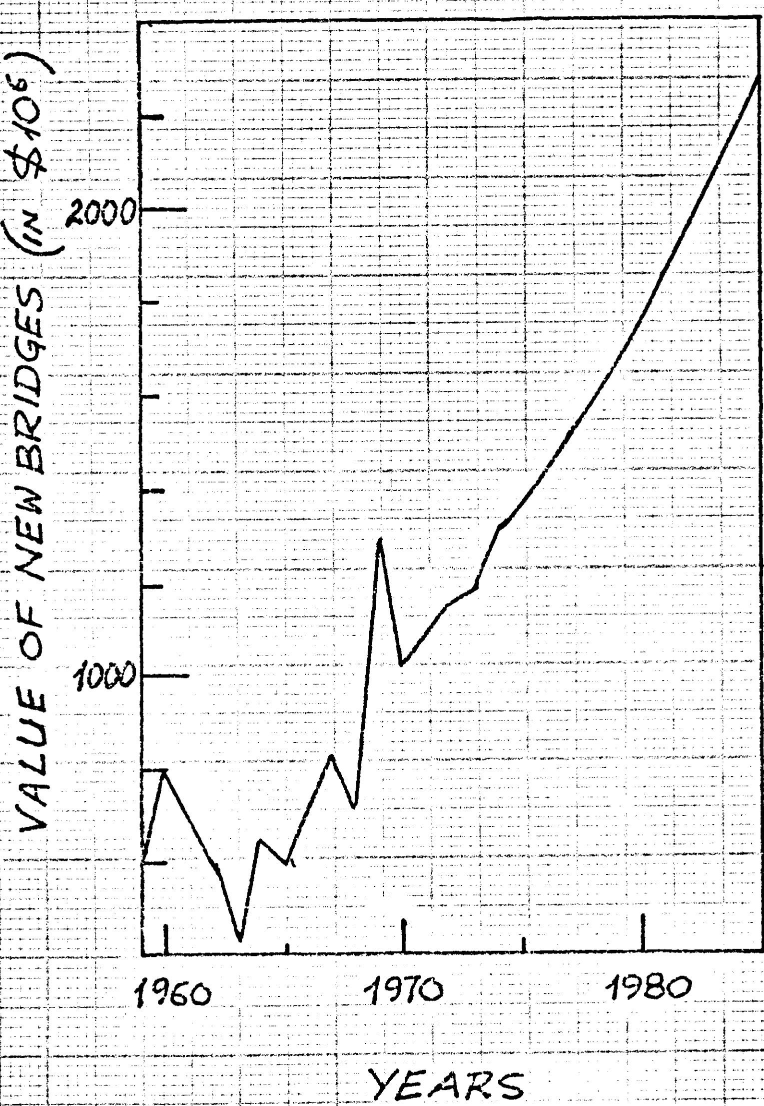

DEMAND FOR NON-HOUSING BUILDINGS (10^6 FT^2/YR)
1200
1000
800
600
400
200
1960
1970
1980
YEARS

FIG. 23

FIG. 24



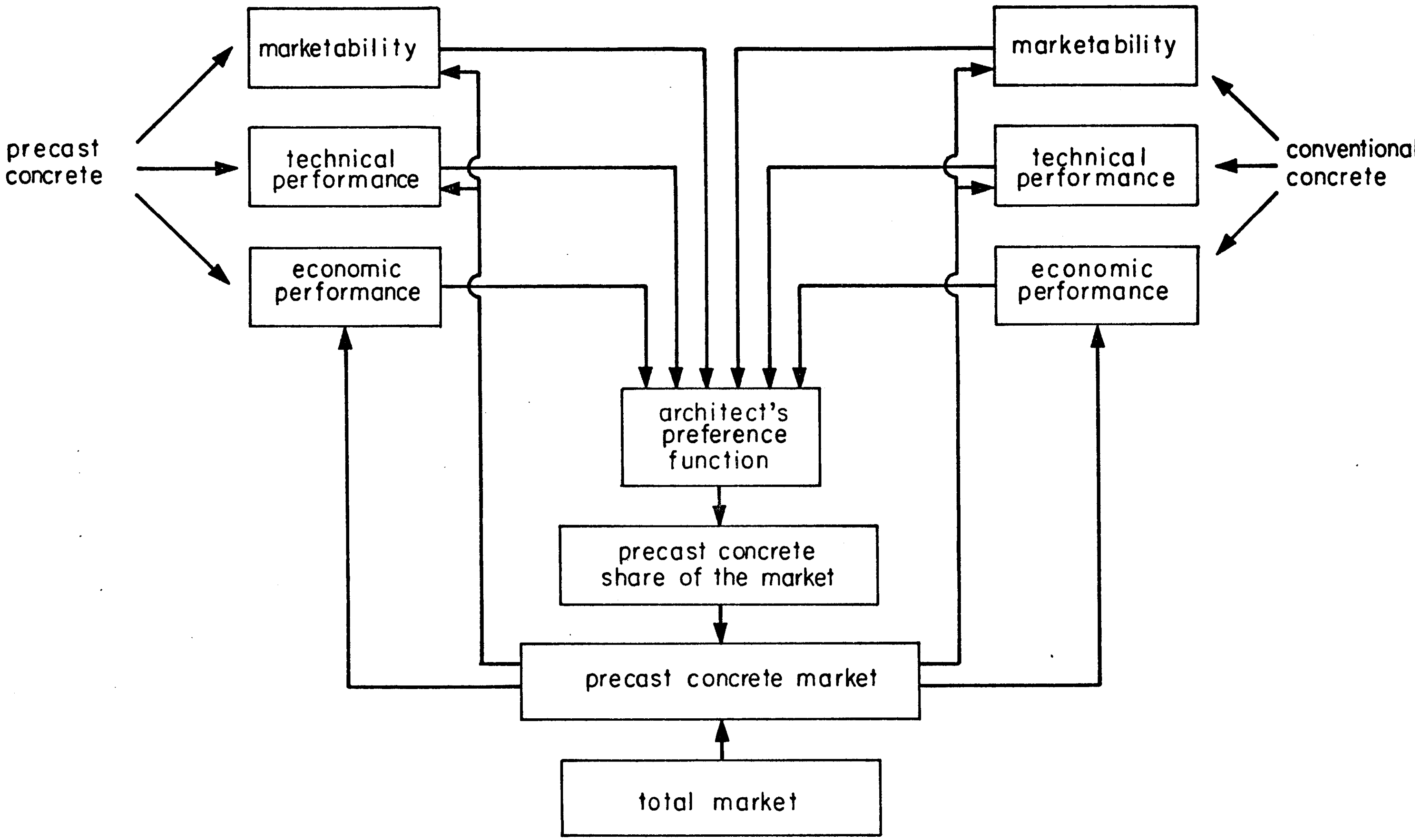
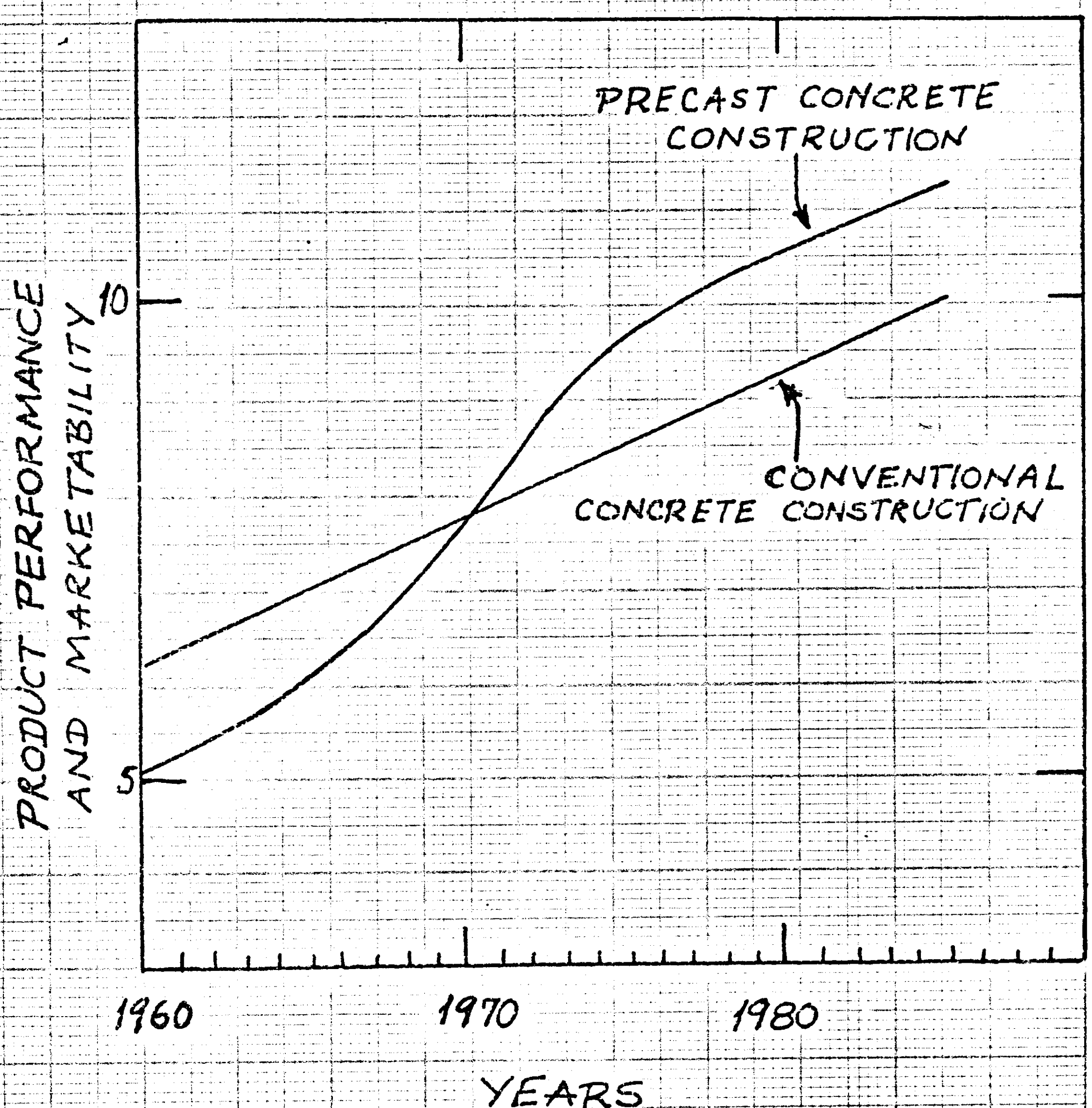


Fig. 25 Marketing of precast concrete

FIG. 26


PRECAST CONCRETE CONSTRUCTION
CONVENTIONAL CONCRETE CONSTRUCTION
PRODUCT PERFORMANCE AND MARKETABILITY
10
5
1960
1970
1980
YEARS

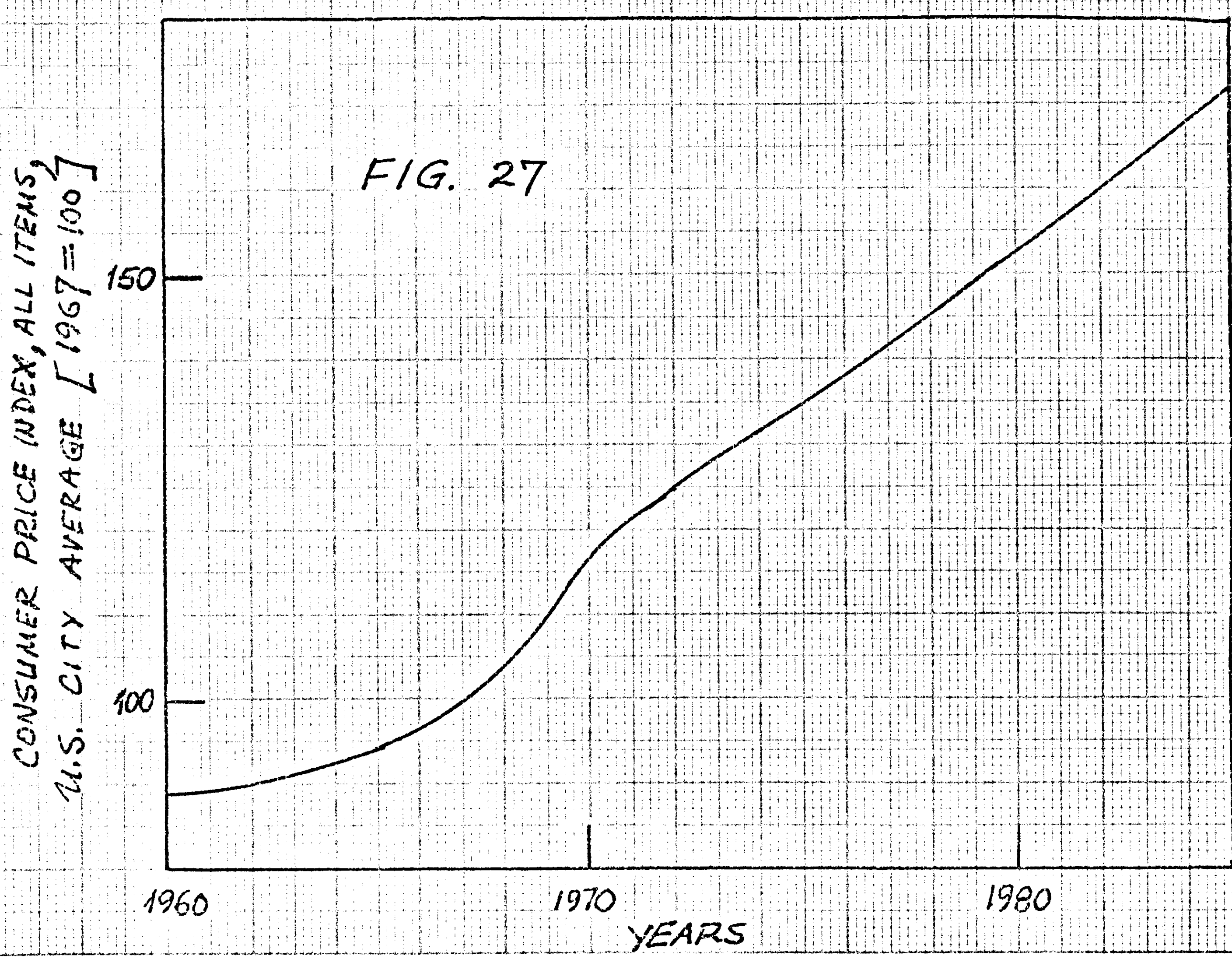


FIG. 27
CONSUMER PRICE INDEX, ALL ITEMS,
U.S. CITY AVERAGE [1967 = 100]
150
100
1960
1970
1980
YEARS

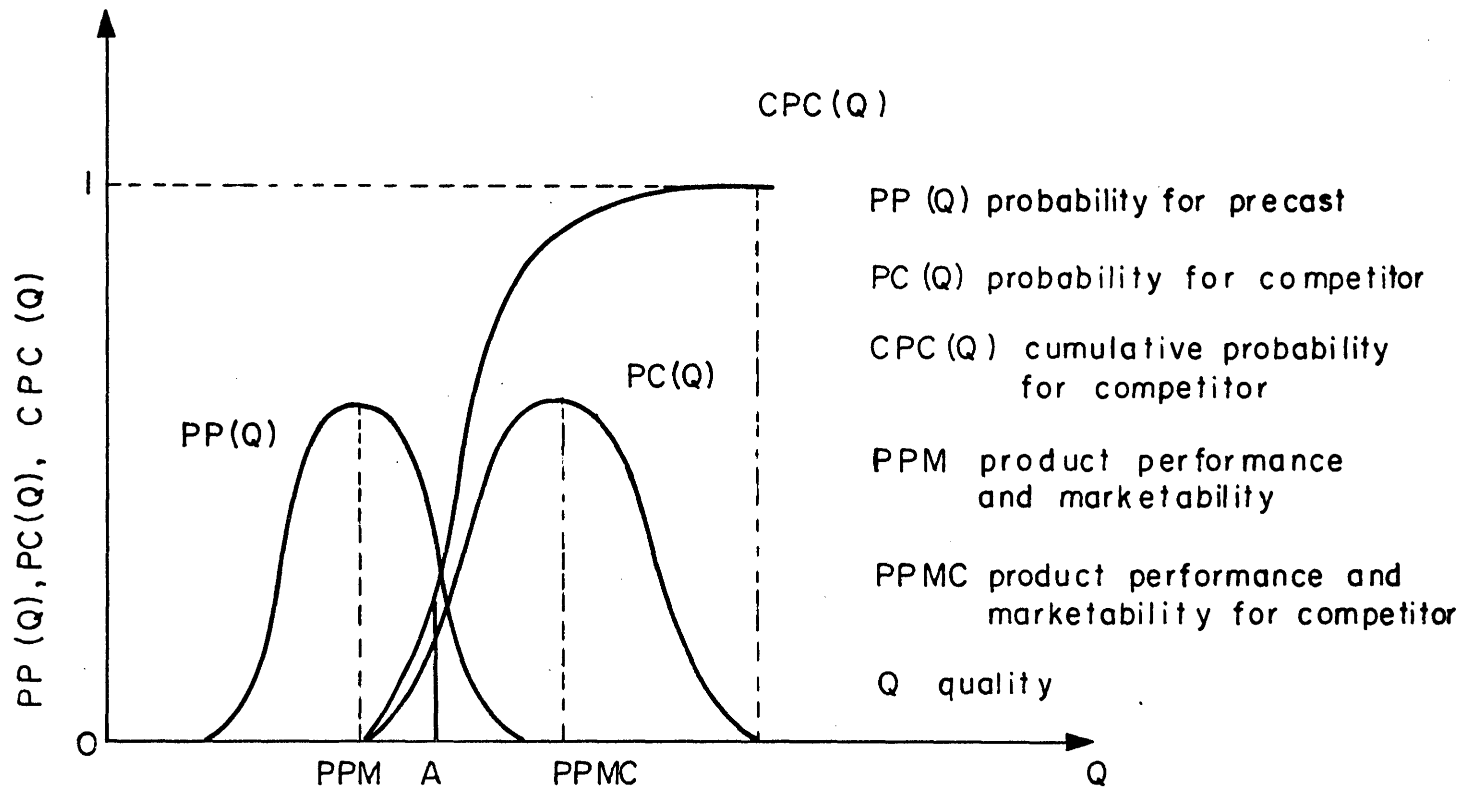
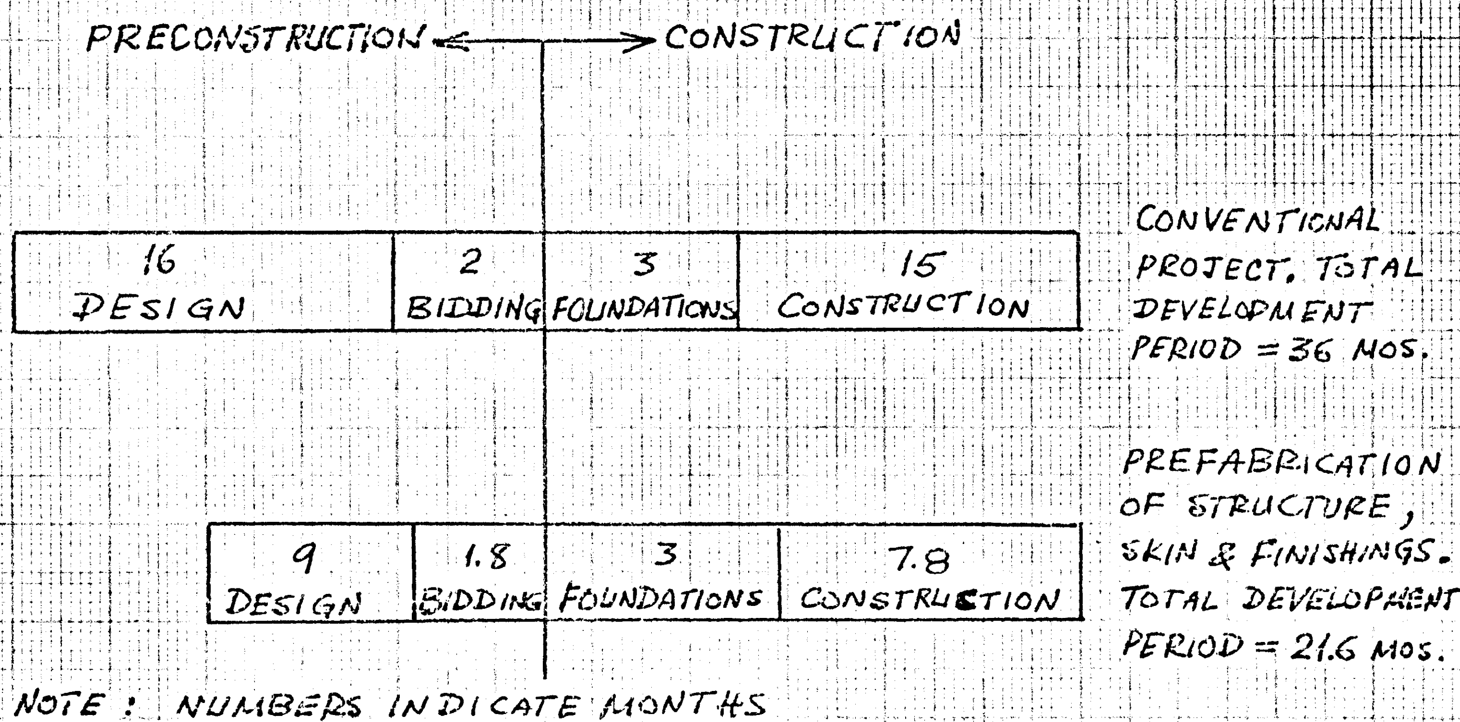


Fig. 28 Probability distribution for precast concrete and competitor.
Assumptions: The probabilities are normally distributed;
the standard deviation equals 1.

FIG. 29


PRECONSTRUCTION
CONSTRUCTION
16 DESIGN
2 BIDDING
3 FOUNDATIONS
15 CONSTRUCTION
CONVENTIONAL PROJECT. TOTAL DEVELOPMENT PERIOD = 36 MOS.
9 DESIGN
1.8 BIDDING
3 FOUNDATIONS
7.8 CONSTRUCTION
PREFABRICATION OF STRUCTURE, SKIN & FINISHINGS. TOTAL DEVELOPMENT PERIOD = 21.6 MOS.
NOTE: NUMBERS INDICATE MONTHS

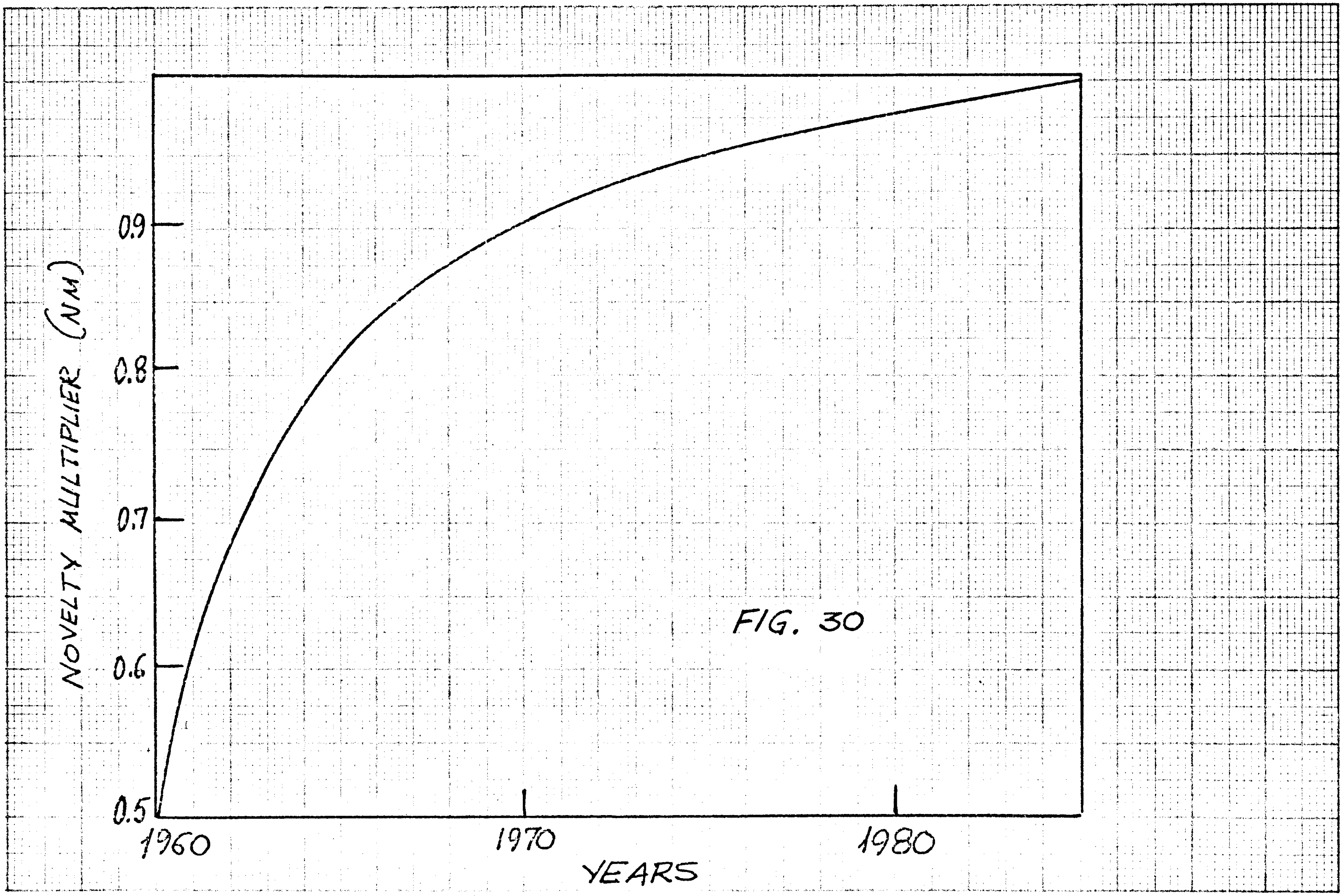


FIG. 30

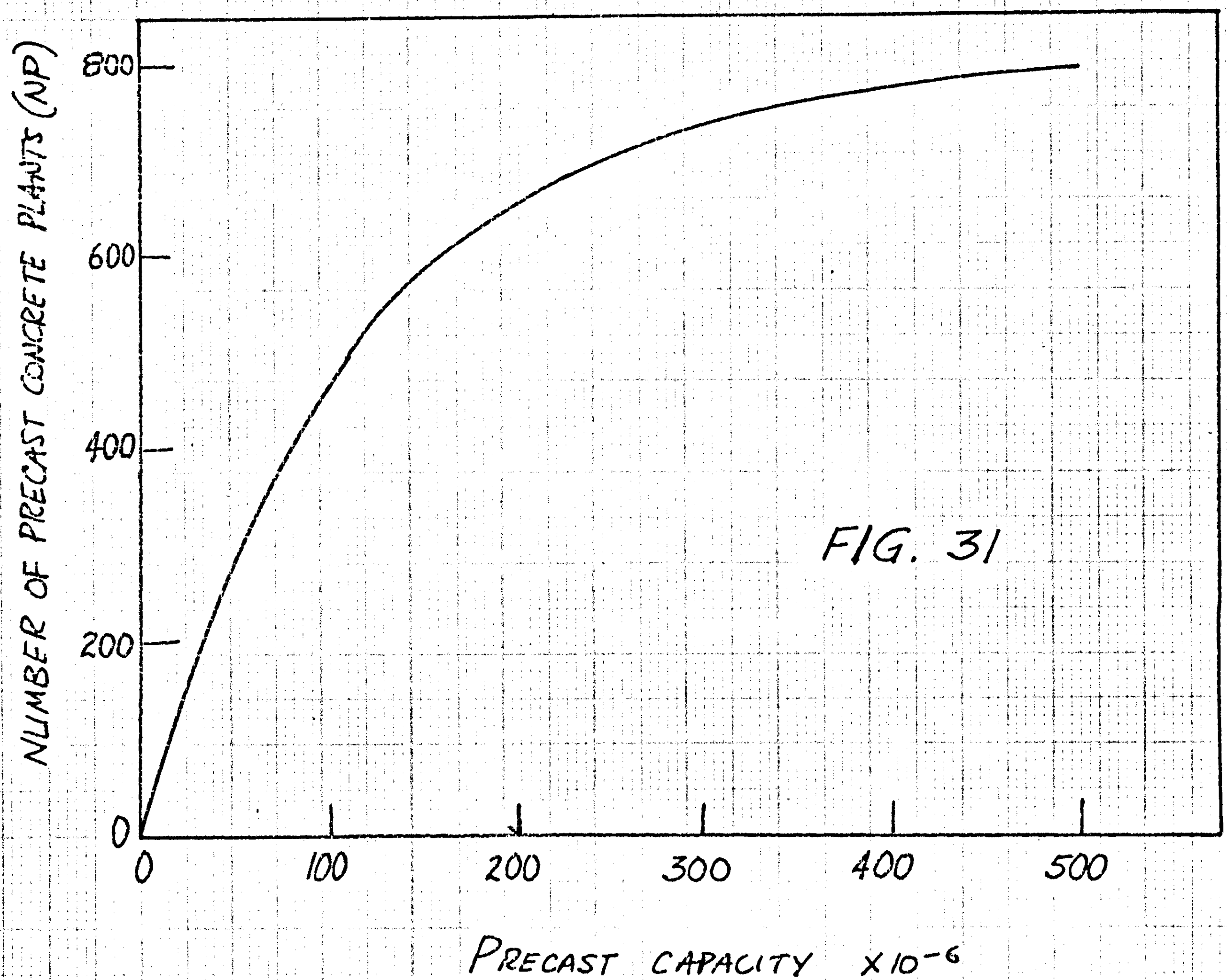
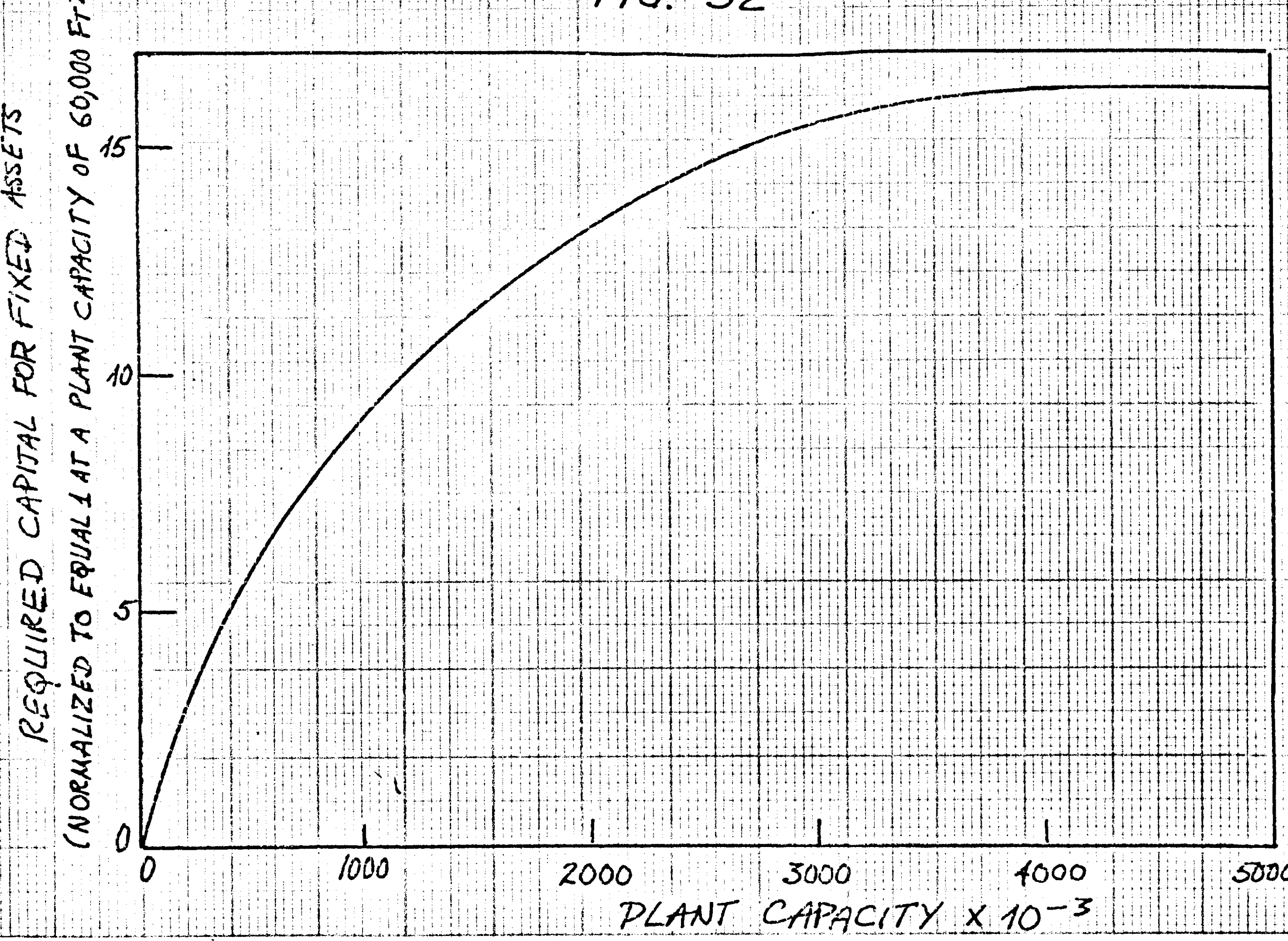

NUMBER OF PRECAST CONCRETE PLANTS (NP)
800
600
400
200
0
0
100
200
300
400
500
PRECAST CAPACITY X10^-6

FIG. 31

FIG. 32


REQUIRED CAPITAL FOR FIXED ASSETS
(NORMALIZED TO EQUAL 1 AT A PLANT CAPACITY OF 60,000 FT2)
0
5
10
15
0
1000
2000
3000
4000
5000
PLANT CAPACITY x 10^{-3}

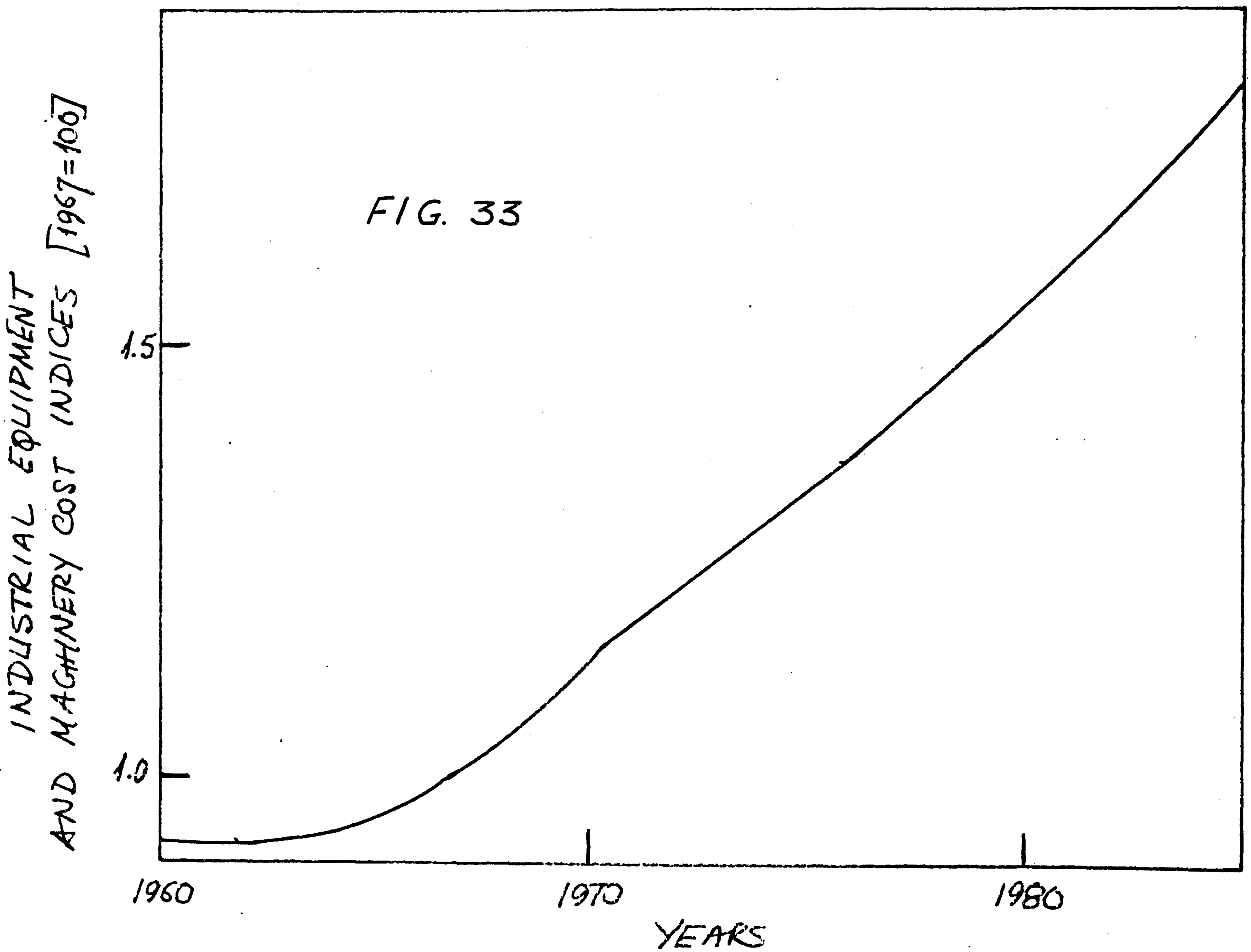
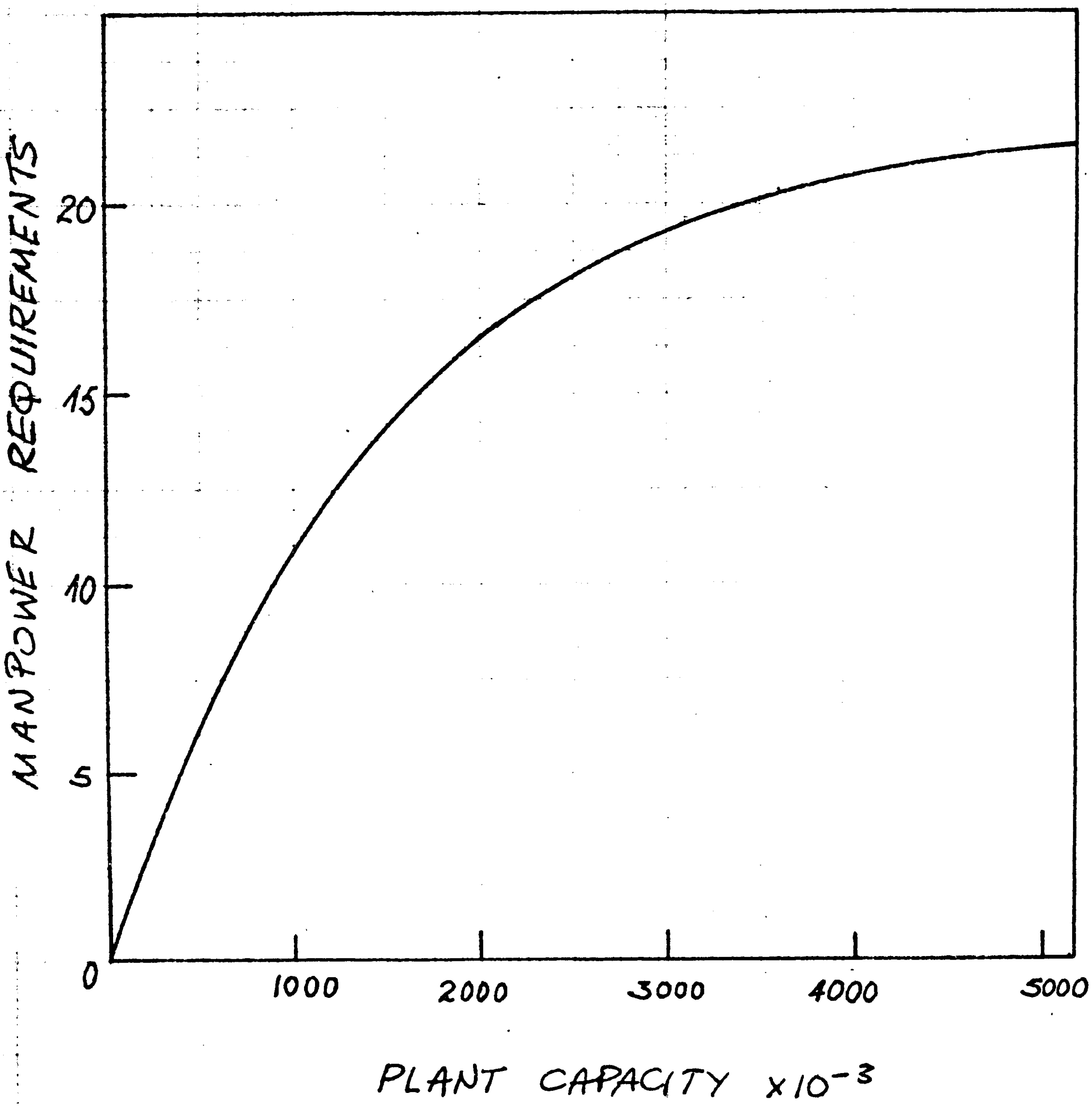

INDUSTRIAL EQUIPMENT
AND MACHINERY COST INDICES [1967=100]
1.5
1.0
1960
1970
1980
YEARS

FIG. 33

FIG. 34


MANPOWER REQUIREMENTS
0
5
10
15
20
1000
2000
3000
4000
5000
PLANT CAPACITY x10⁻³

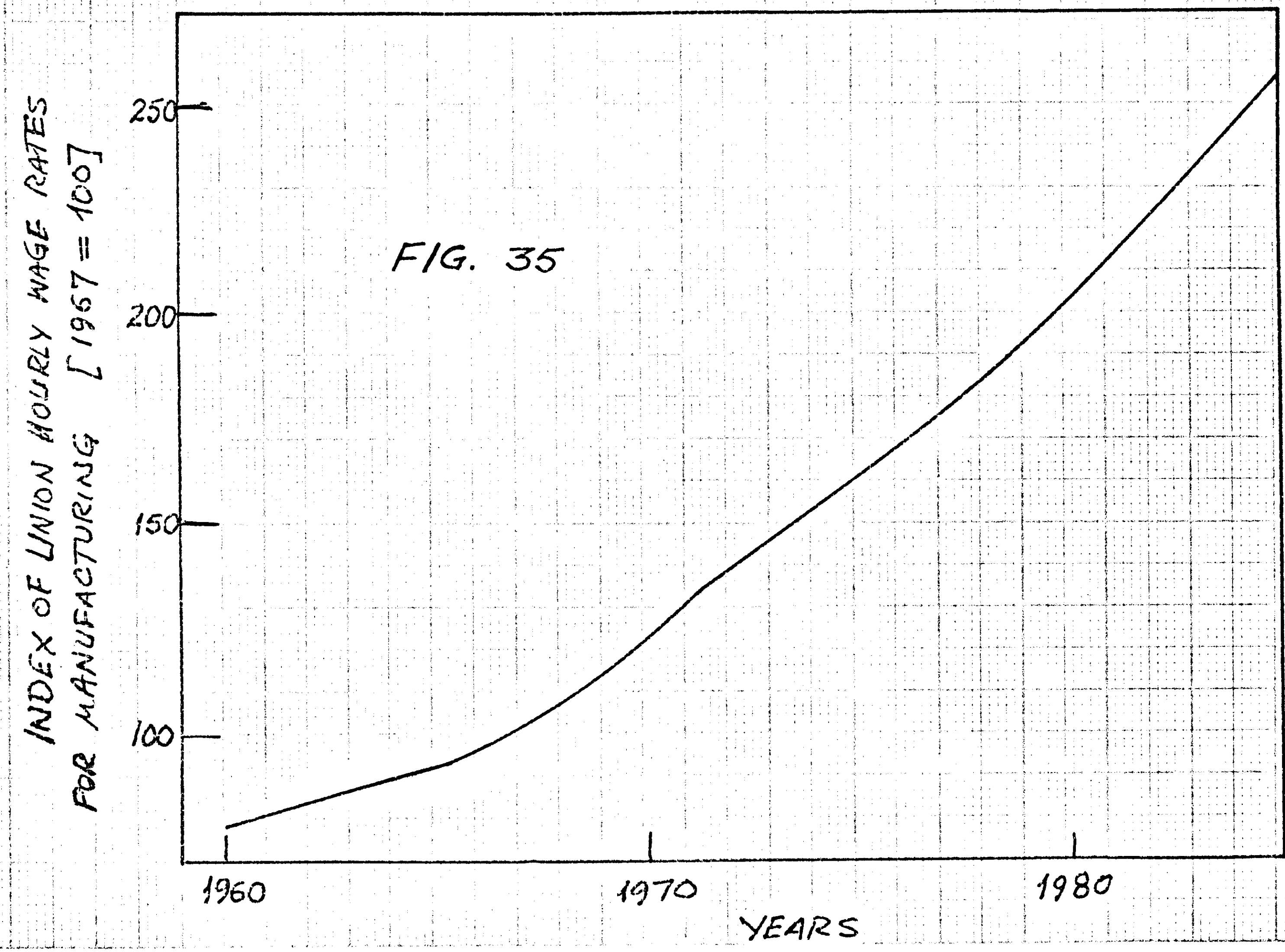
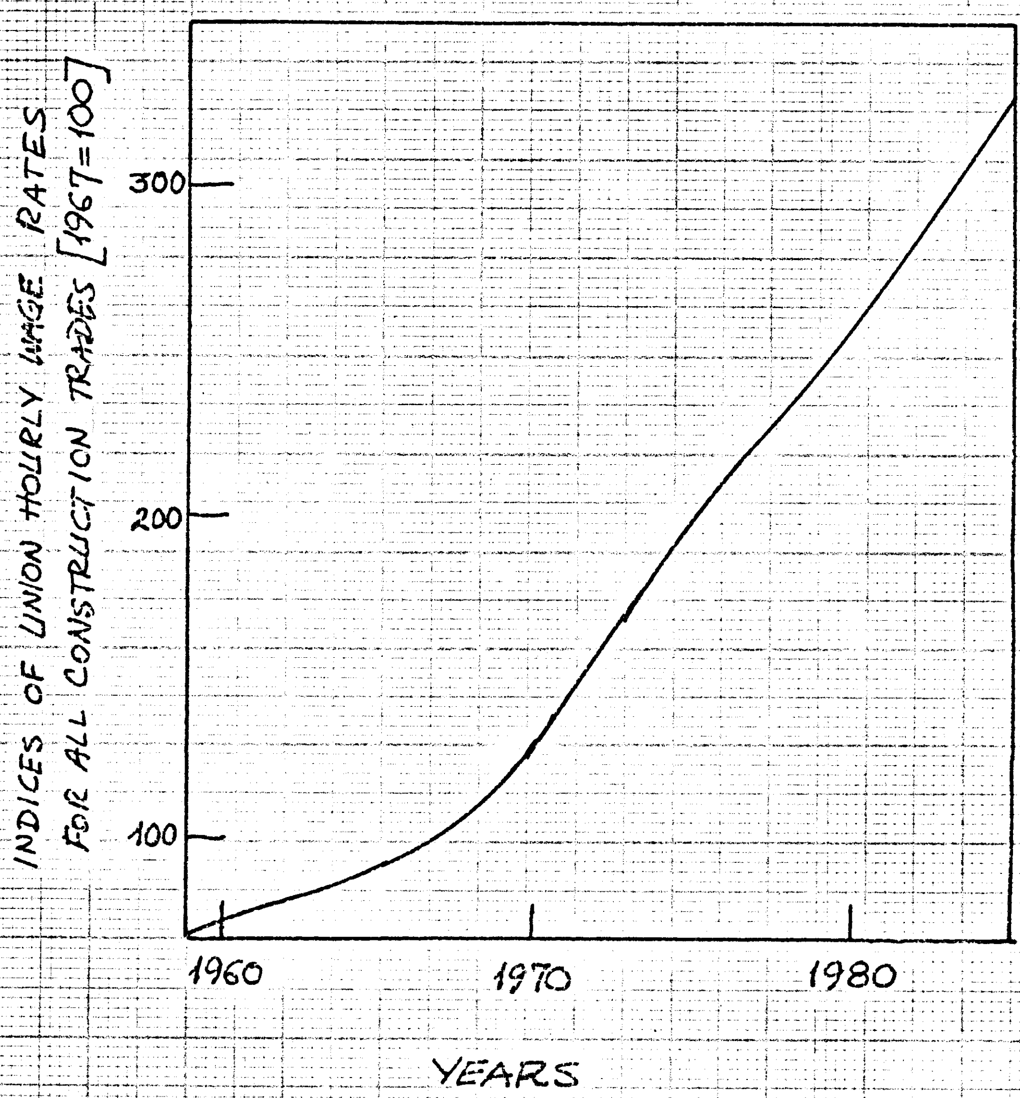

INDEX OF UNION HOURLY WAGE RATES
FOR MANUFACTURING [1957 = 100]
250
200
150
100
1960
1970
1980
YEARS

FIG. 35

FIG. 36


INDICES OF UNION HOURLY WAGE RATES
FOR ALL CONSTRUCTION TRADES [1967=100]
300
200
100
1960
1970
1980
YEARS

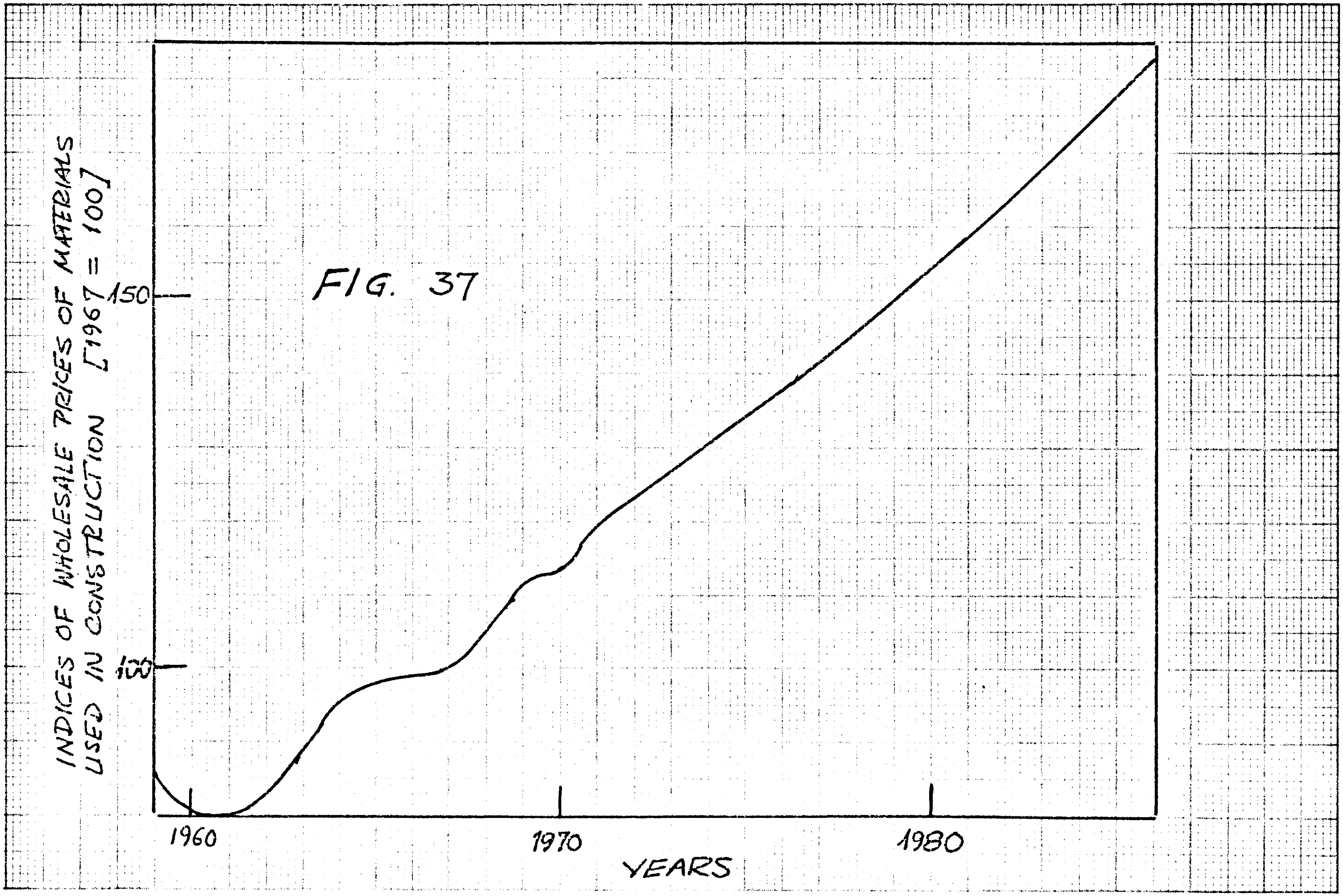


FIG. 37
INDICES OF WHOLESALE PRICES OF MATERIALS USED IN CONSTRUCTION [1967 = 100]
150
100
1960
1970
1980
YEARS

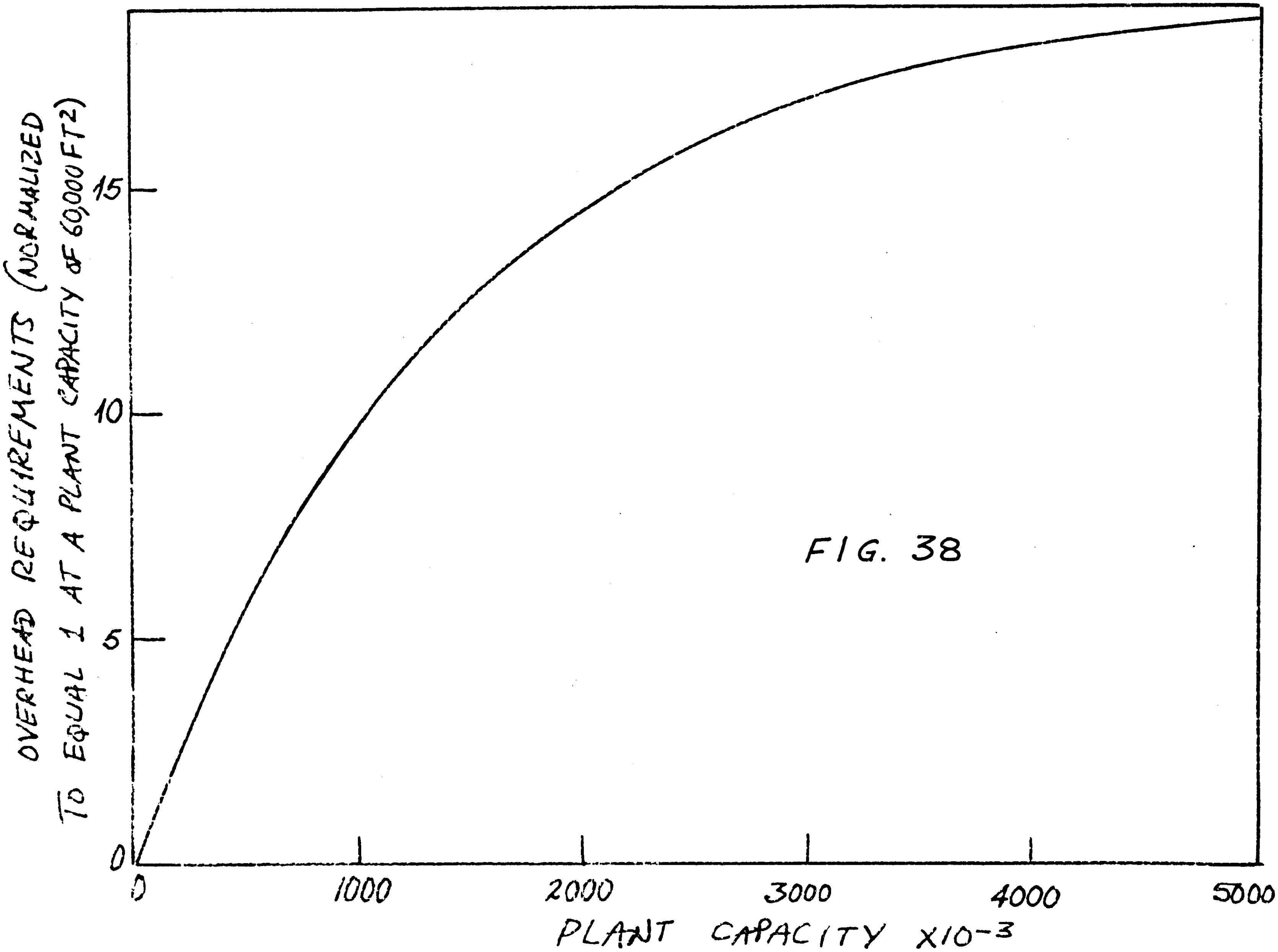
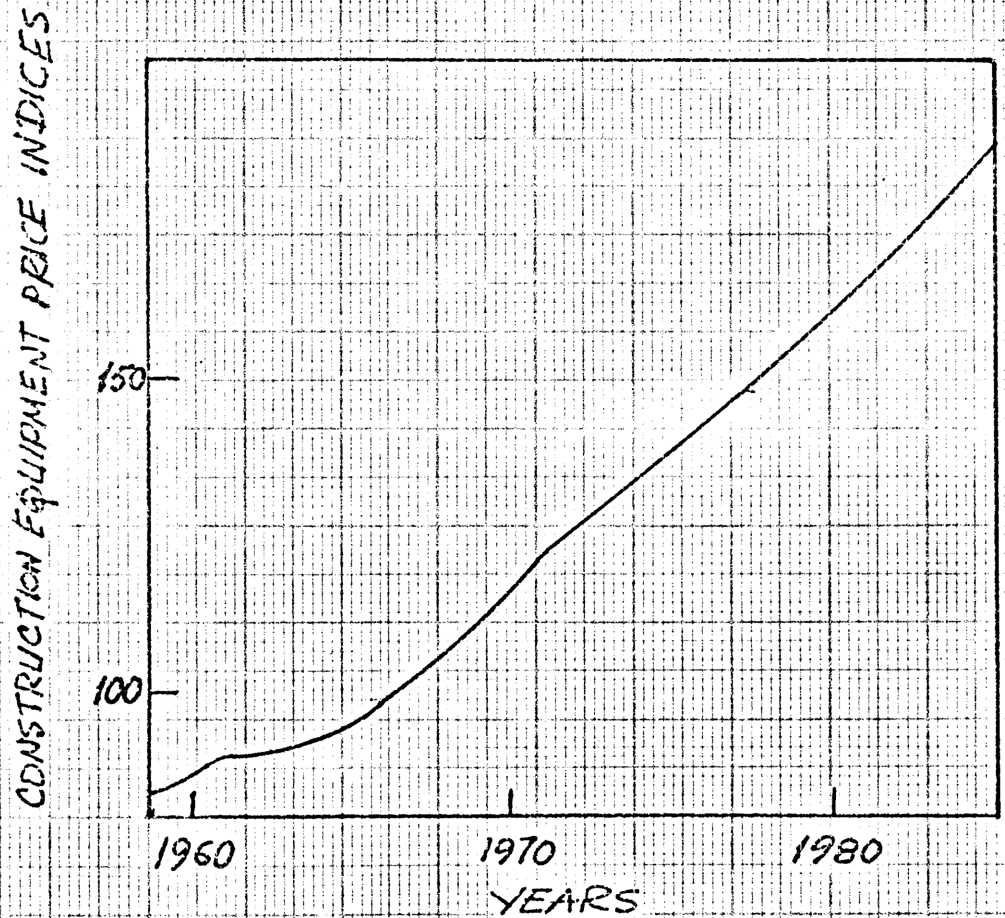

OVERHEAD REQUIREMENTS (NORMALIZED TO EQUAL 1 AT A PLANT CAPACITY OF 60,000 FT2)
0
5
10
15
0
1000
2000
3000
4000
5000
PLANT CAPACITY X10-3

FIG. 38

FIG. 39


CONSTRUCTION EQUIPMENT PRICE INDICES
150
100
1960
1970
1980
YEARS

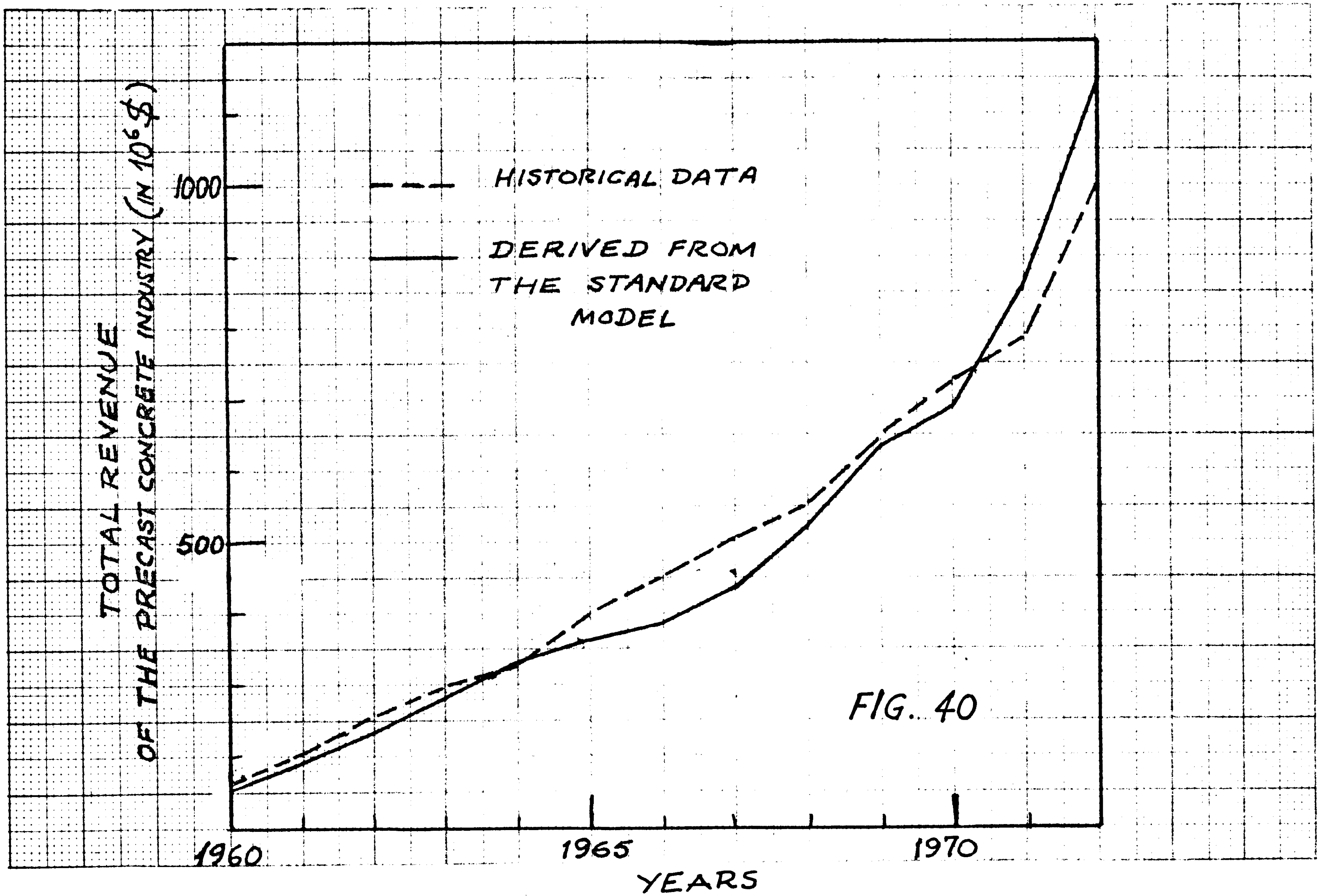

TOTAL REVENUE
OF THE PRECAST CONCRETE INDUSTRY (IN 10^6 $)
1000
500
HISTORICAL DATA
DERIVED FROM
THE STANDARD
MODEL
1960
1965
1970
YEARS

FIG. 40

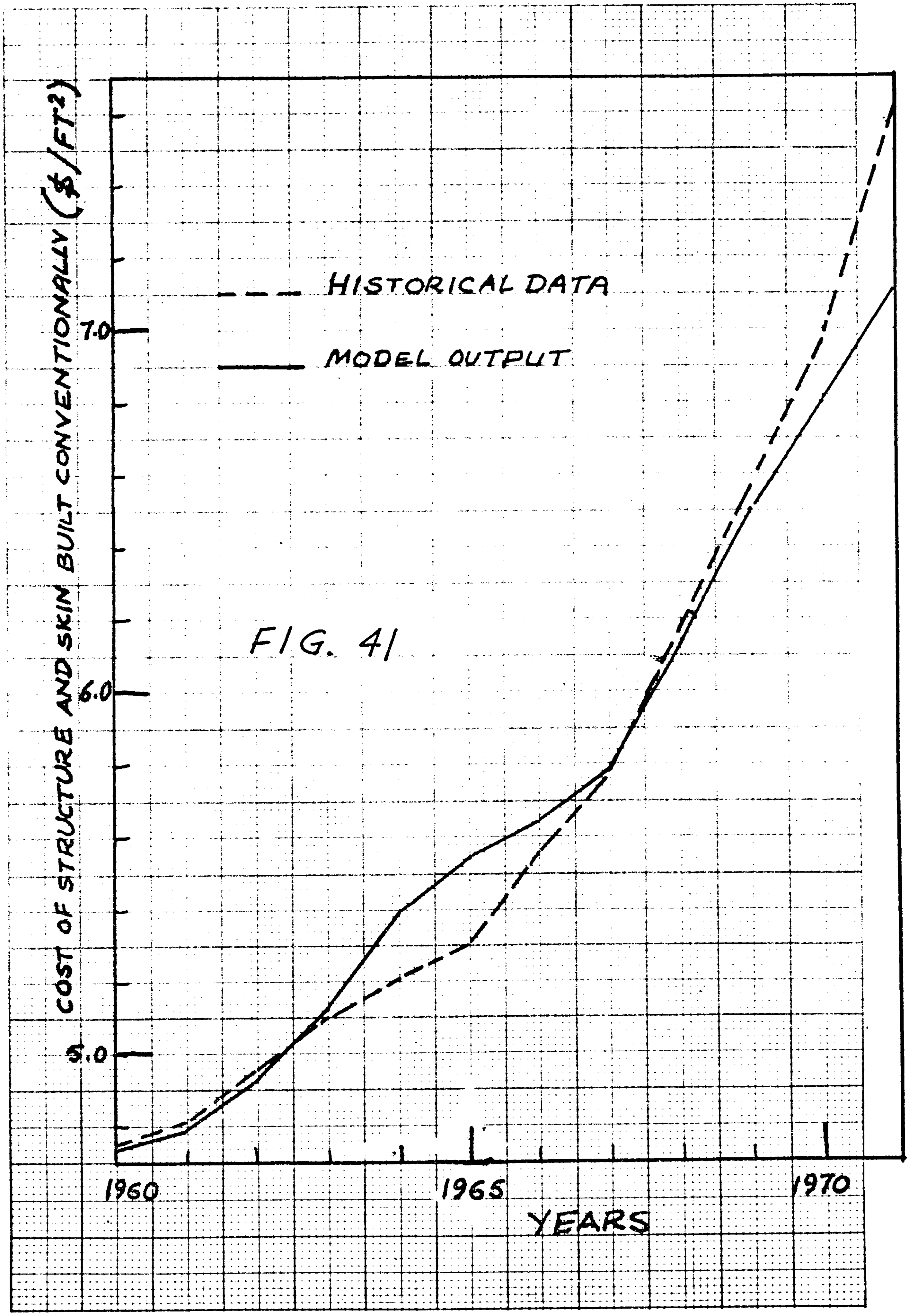
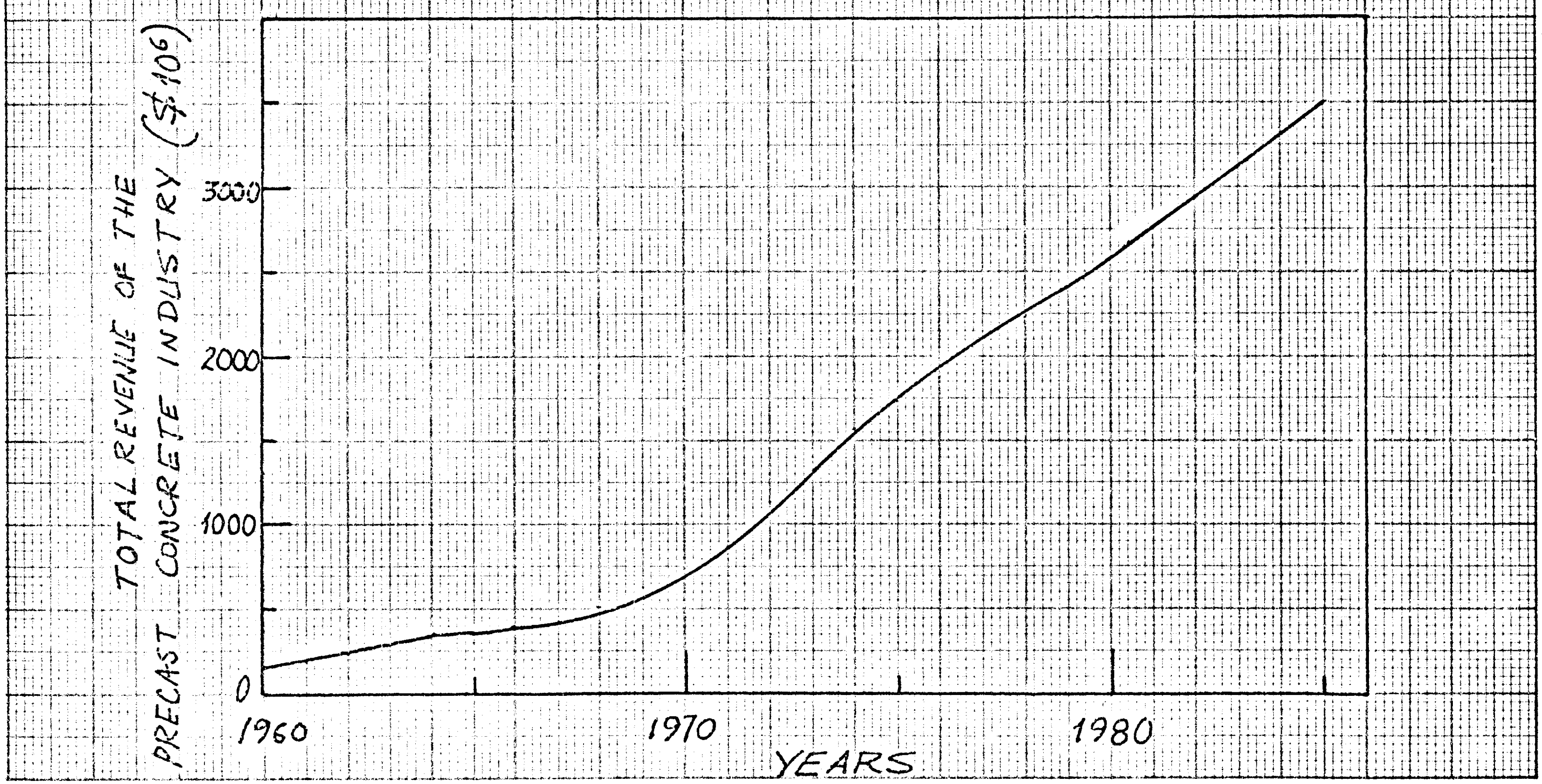

COST OF STRUCTURE AND SKIN BUILT CONVENTIONALLY ($/FT²)
7.0
6.0
5.0
HISTORICAL DATA
MODEL OUTPUT
1960
1965
1970
YEARS

FIG. 41

FIG. 42


TOTAL REVENUE OF THE PRECAST CONCRETE INDUSTRY ($·10^6)
3000
2000
1000
0
1960
1970
1980
YEARS

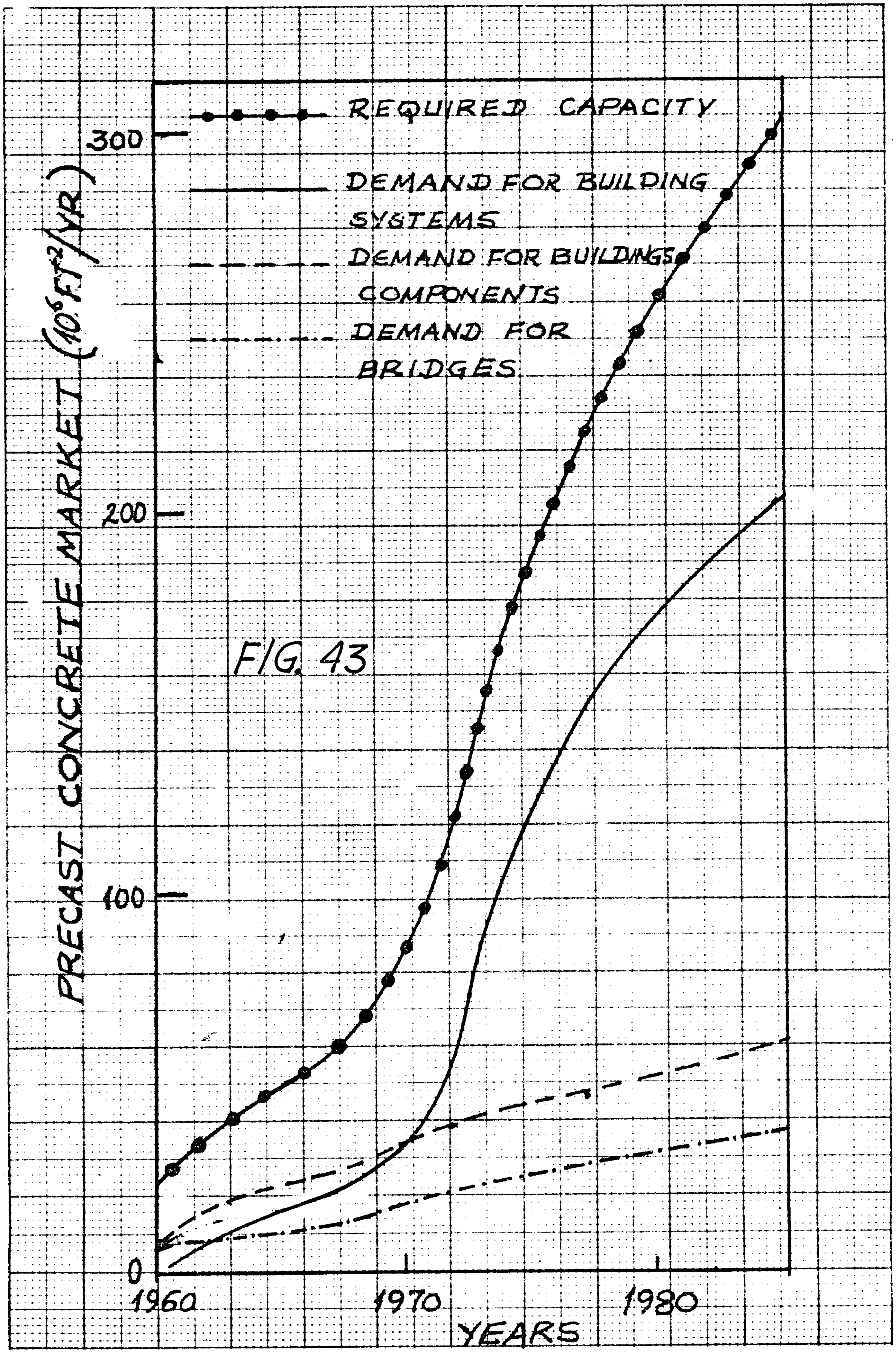

REQUIRED CAPACITY
DEMAND FOR BUILDING SYSTEMS
DEMAND FOR BUILDINGS COMPONENTS
DEMAND FOR BRIDGES
PRECAST CONCRETE MARKET (10^6 FT^2/YR)
300
200
100
0
1960
1970
1980
YEARS

FIG. 43

FIG. 44

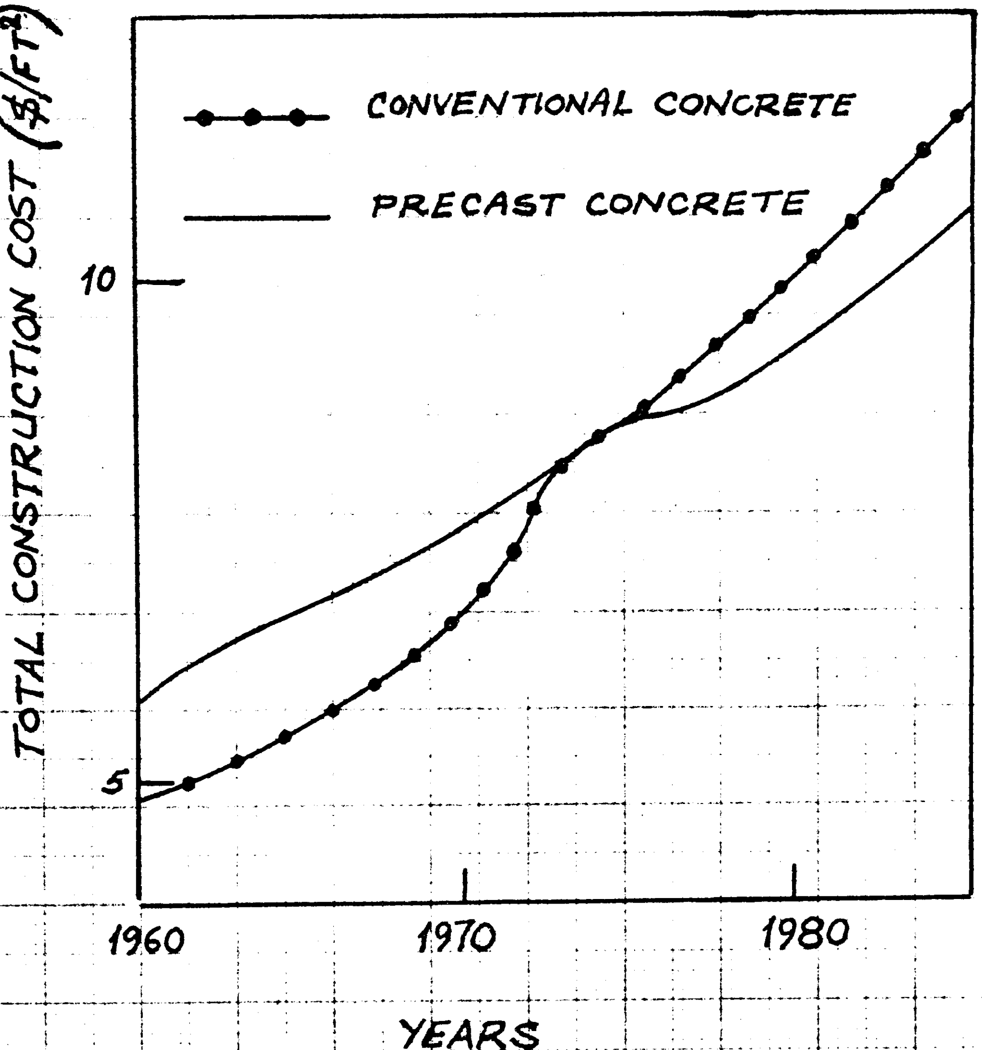

CONVENTIONAL CONCRETE
PRECAST CONCRETE
TOTAL CONSTRUCTION COST ($/FT²)
10
5
1960
1970
1980
YEARS

FIG. 45

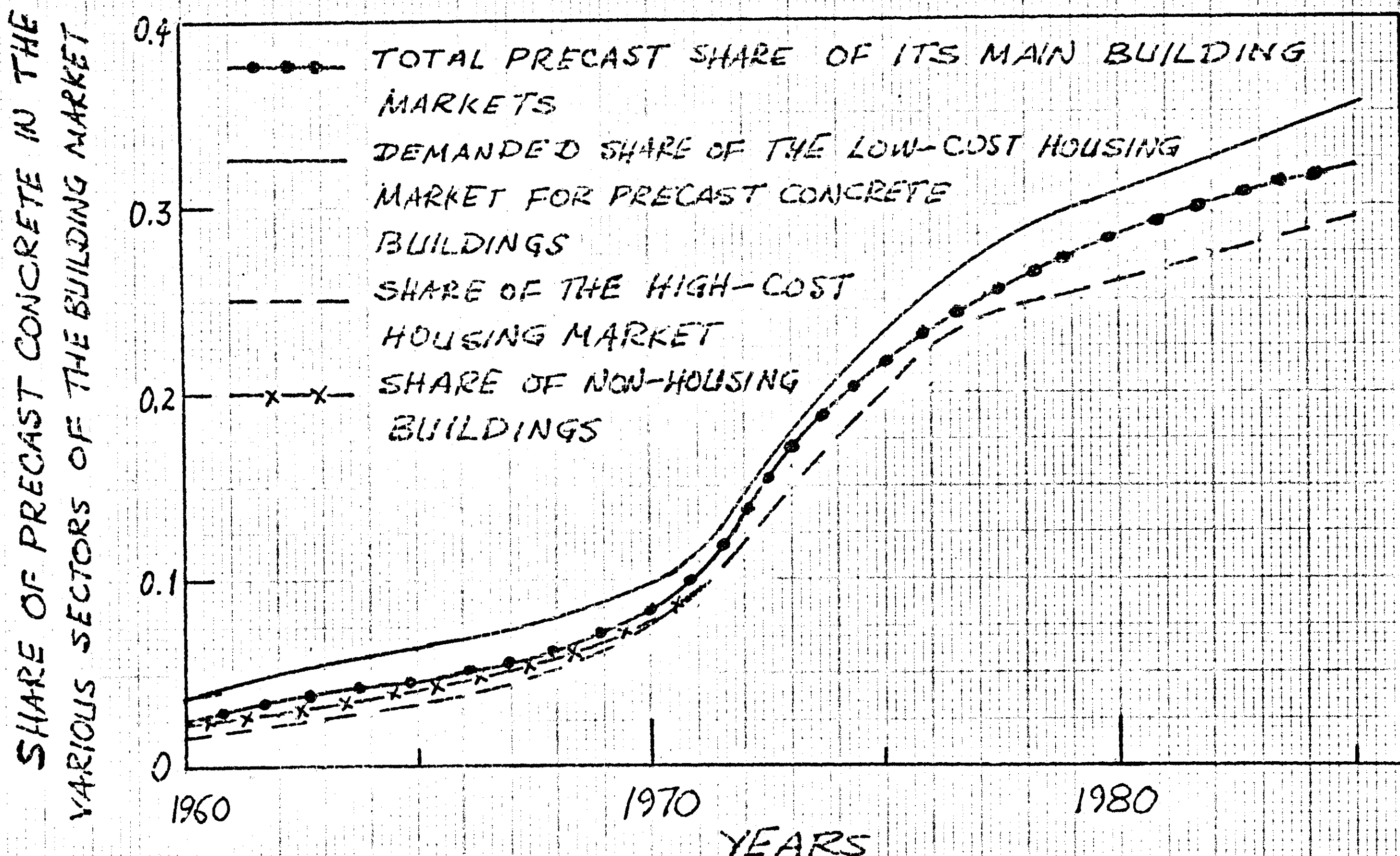

TOTAL PRECAST SHARE OF ITS MAIN BUILDING MARKETS
DEMANDED SHARE OF THE LOW-COST HOUSING MARKET FOR PRECAST CONCRETE BUILDINGS
SHARE OF THE HIGH-COST HOUSING MARKET
SHARE OF NON-HOUSING BUILDINGS
SHARE OF PRECAST CONCRETE IN THE VARIOUS SECTORS OF THE BUILDING MARKET
0.4
0.3
0.2
0.1
0
1960
1970
1980
YEARS

FIG. 46

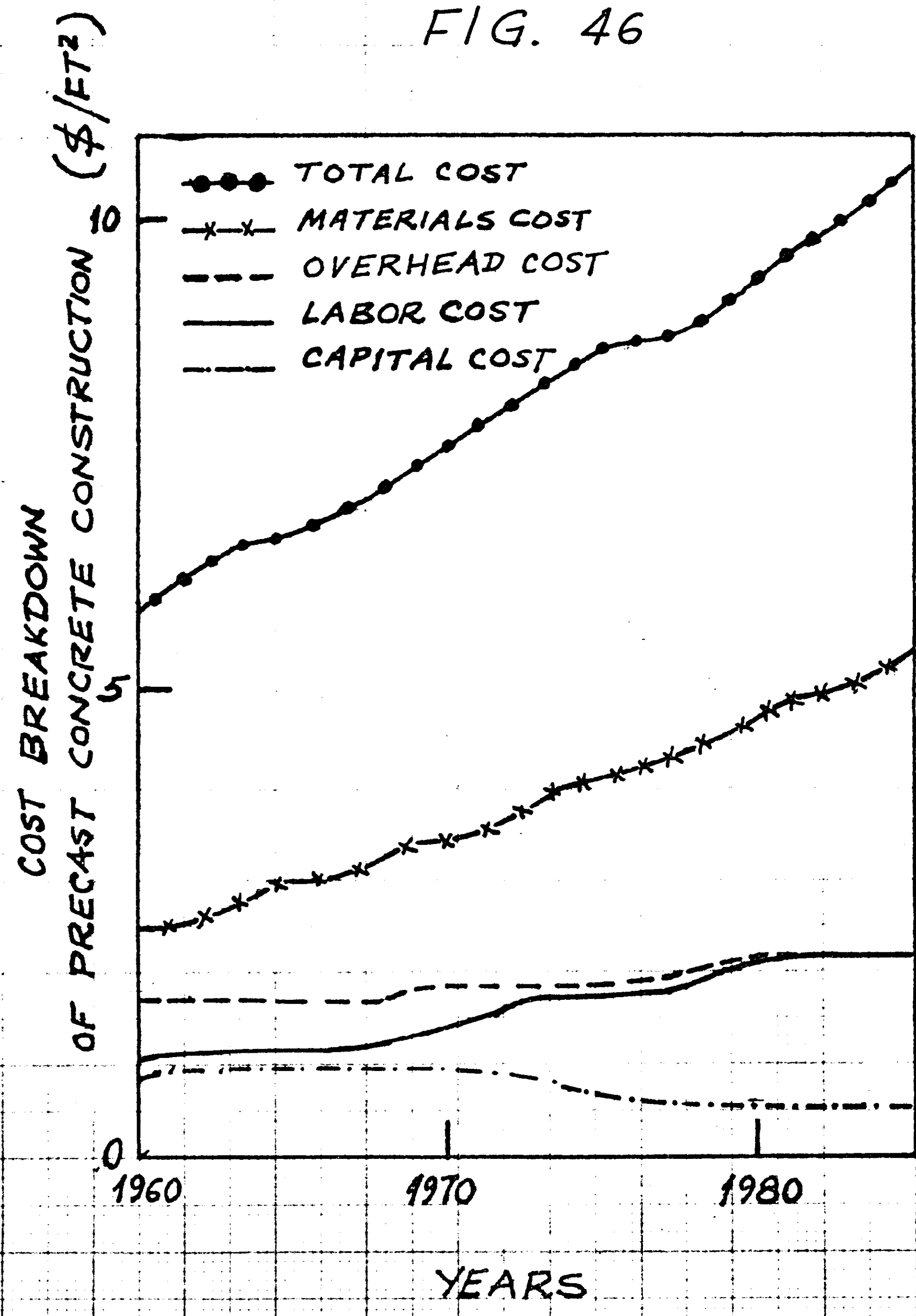

TOTAL COST
MATERIALS COST
OVERHEAD COST
LABOR COST
CAPITAL COST
COST BREAKDOWN OF PRECAST CONCRETE CONSTRUCTION ($/FT²)
10
5
0
1960
1970
1980
YEARS

FIG. 47

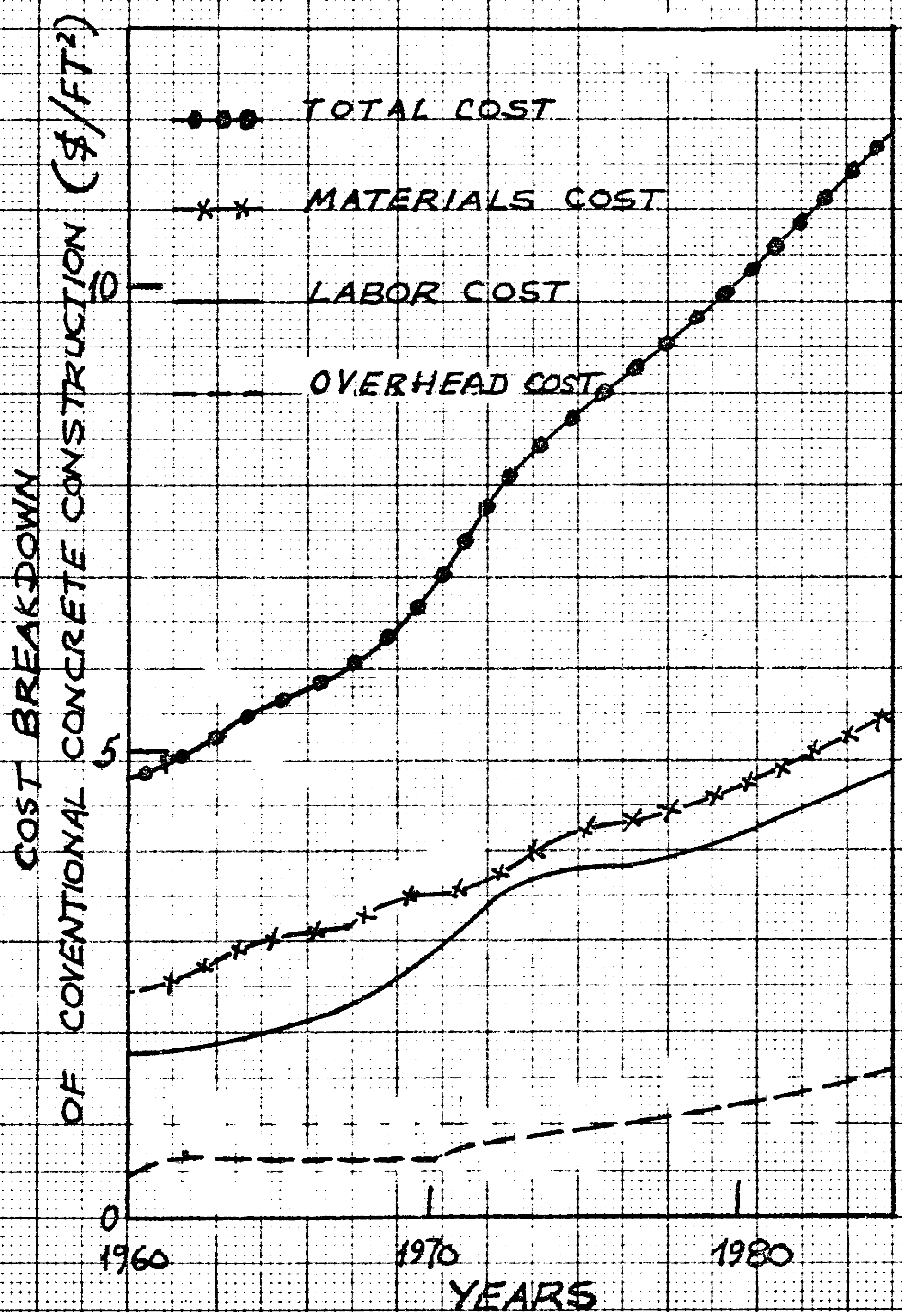

TOTAL COST
MATERIALS COST
LABOR COST
OVERHEAD COST
COST BREAKDOWN
OF COVENTIONAL CONCRETE CONSTRUCTION ($/FT²)
10
5
0
1960
1970
1980
YEARS

FIG. 48

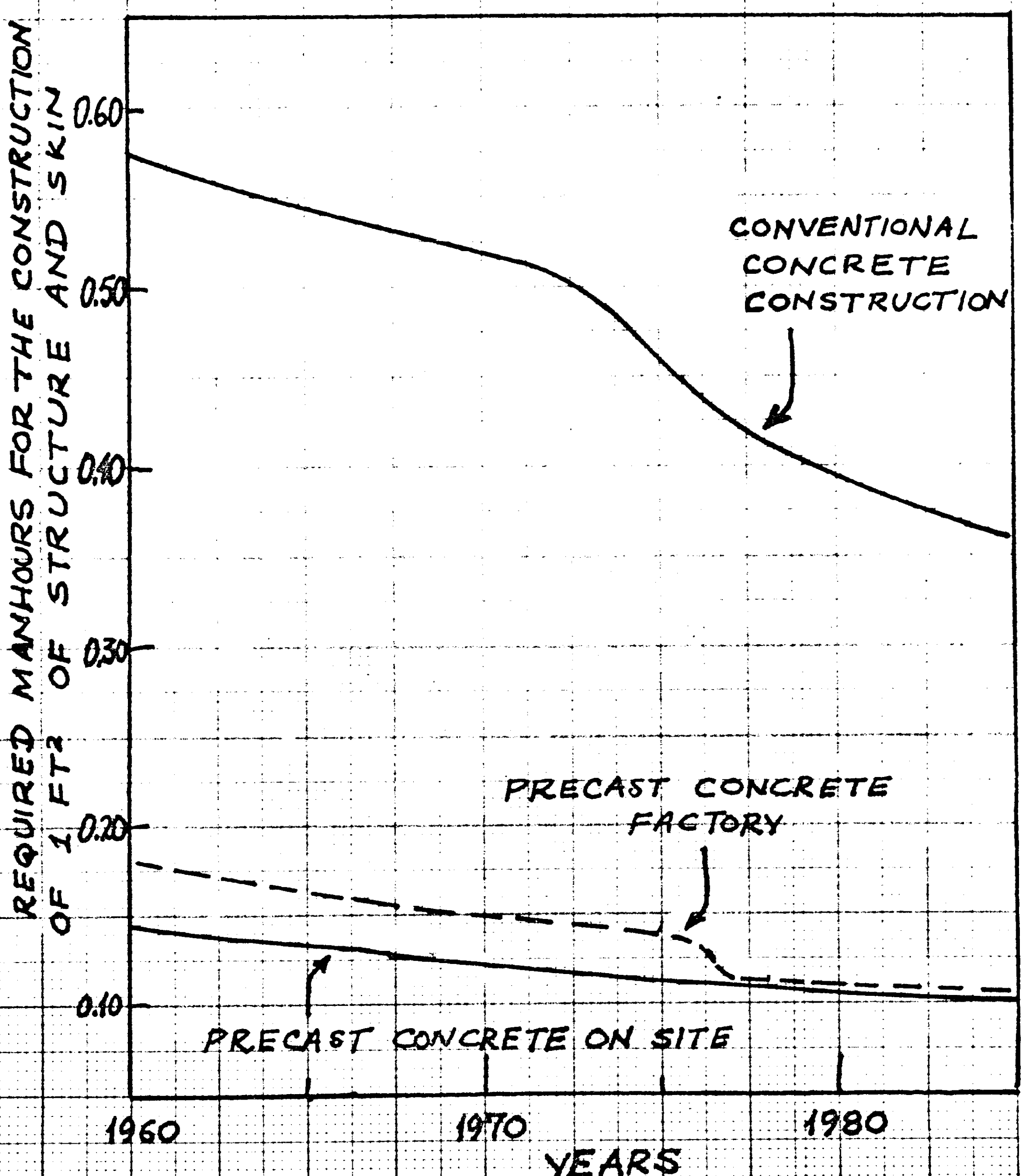

REQUIRED MANHOURS FOR THE CONSTRUCTION OF 1 FT2 OF STRUCTURE AND SKIN
0.60
0.50
0.40
0.30
0.20
0.10
CONVENTIONAL CONCRETE CONSTRUCTION
PRECAST CONCRETE FACTORY
PRECAST CONCRETE ON SITE
1960
1970
1980
YEARS

FIG. 49

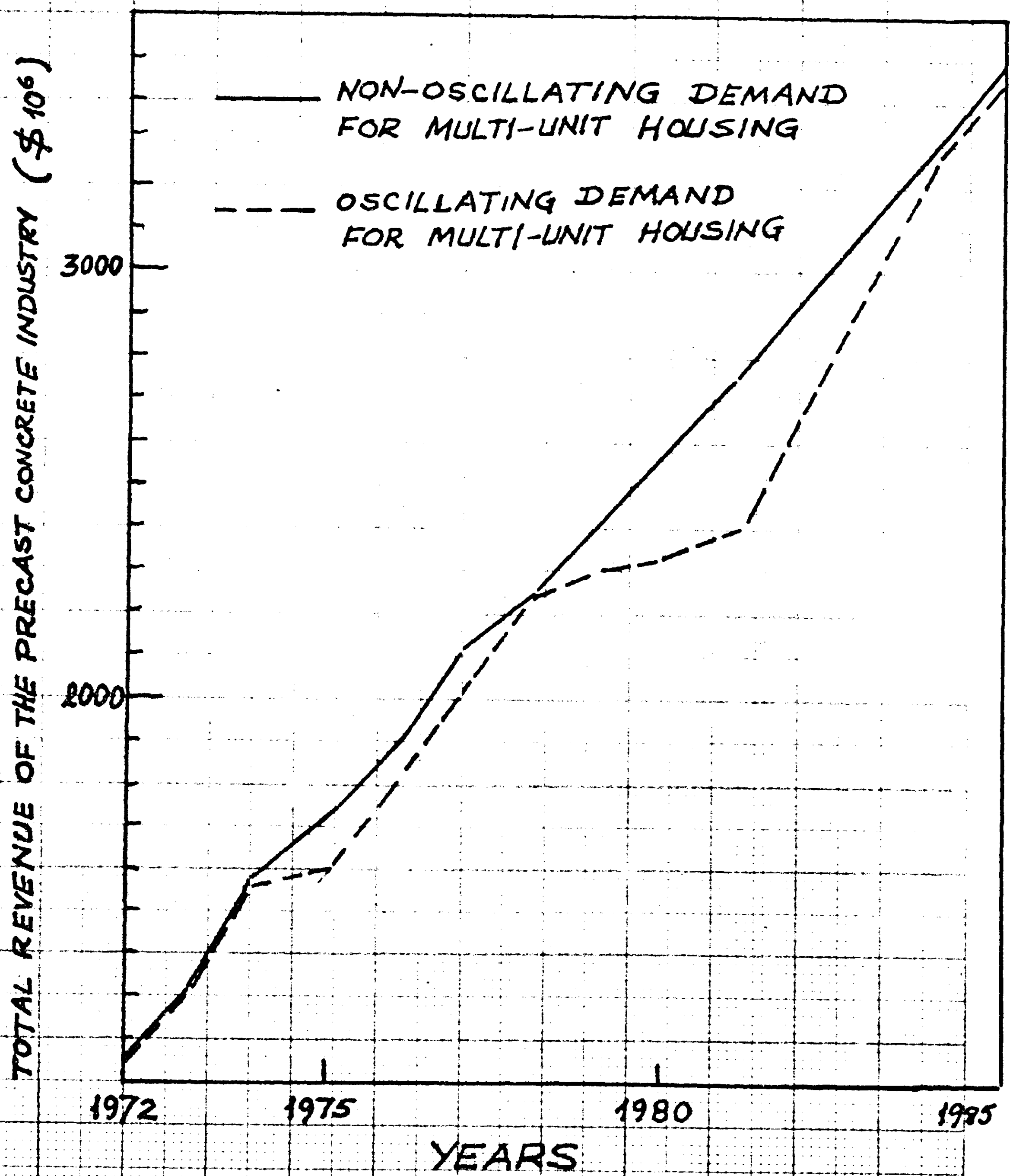
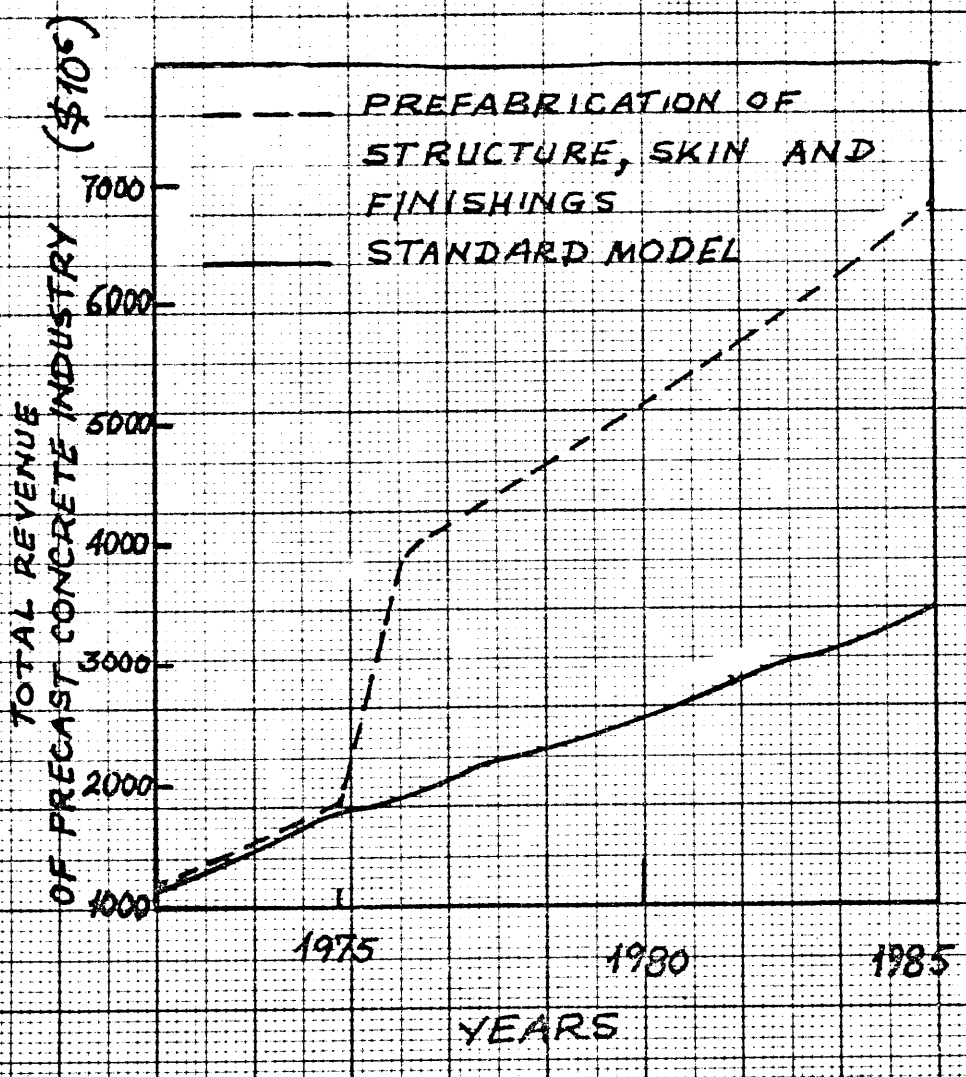
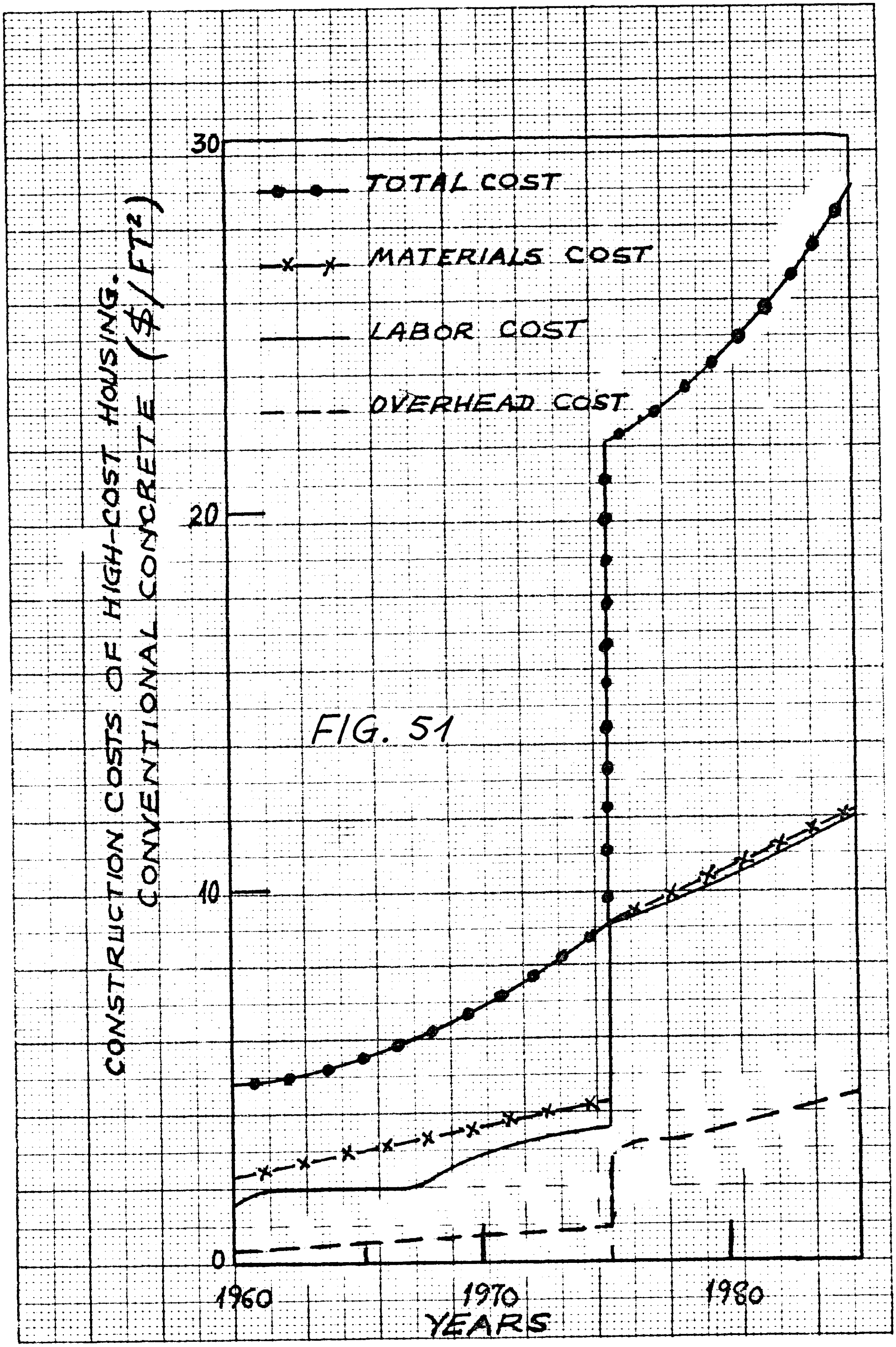

NON-OSCILLATING DEMAND FOR MULTI-UNIT HOUSING
OSCILLATING DEMAND FOR MULTI-UNIT HOUSING
TOTAL REVENUE OF THE PRECAST CONCRETE INDUSTRY ($10^6)
3000
2000
1972
1975
1980
1985
YEARS

FIG. 50


PREFABRICATION OF
STRUCTURE, SKIN AND
FINISHINGS
STANDARD MODEL
TOTAL REVENUE
OF PRECAST CONCRETE INDUSTRY ($10⁶)
7000
6000
5000
4000
3000
2000
1000
1975
1980
1985
YEARS


CONSTRUCTION COSTS OF HIGH-COST HOUSING.
CONVENTIONAL CONCRETE ($/FT²)
TOTAL COST
MATERIALS COST
LABOR COST
OVERHEAD COST
FIG. 51
30
20
10
0
1960
1970
1980
YEARS

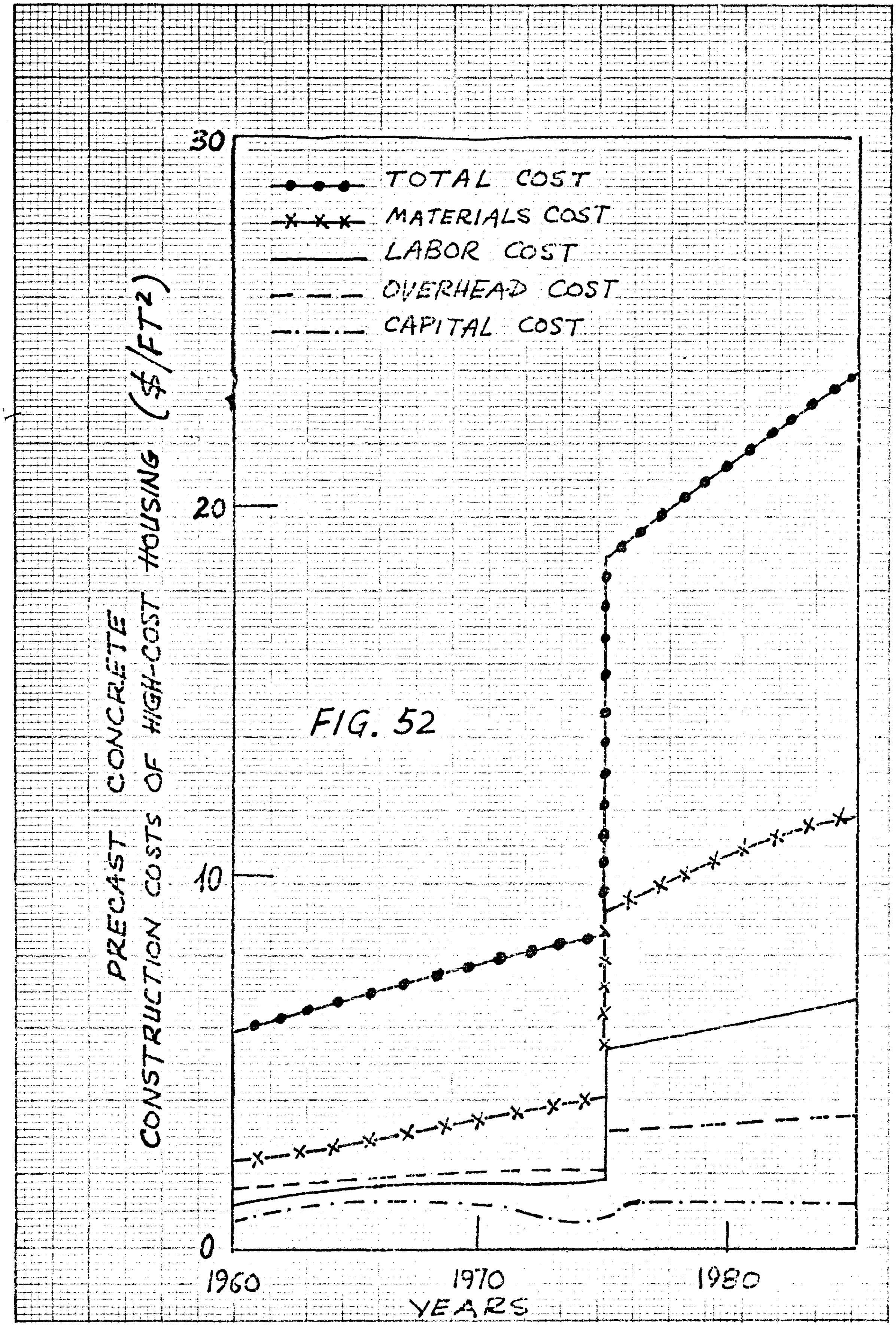

PRECAST CONCRETE
CONSTRUCTION COSTS OF HIGH-COST HOUSING ($/FT²)
TOTAL COST
MATERIALS COST
LABOR COST
OVERHEAD COST
CAPITAL COST
30
20
10
0
1960
1970
1980
YEARS

FIG. 52

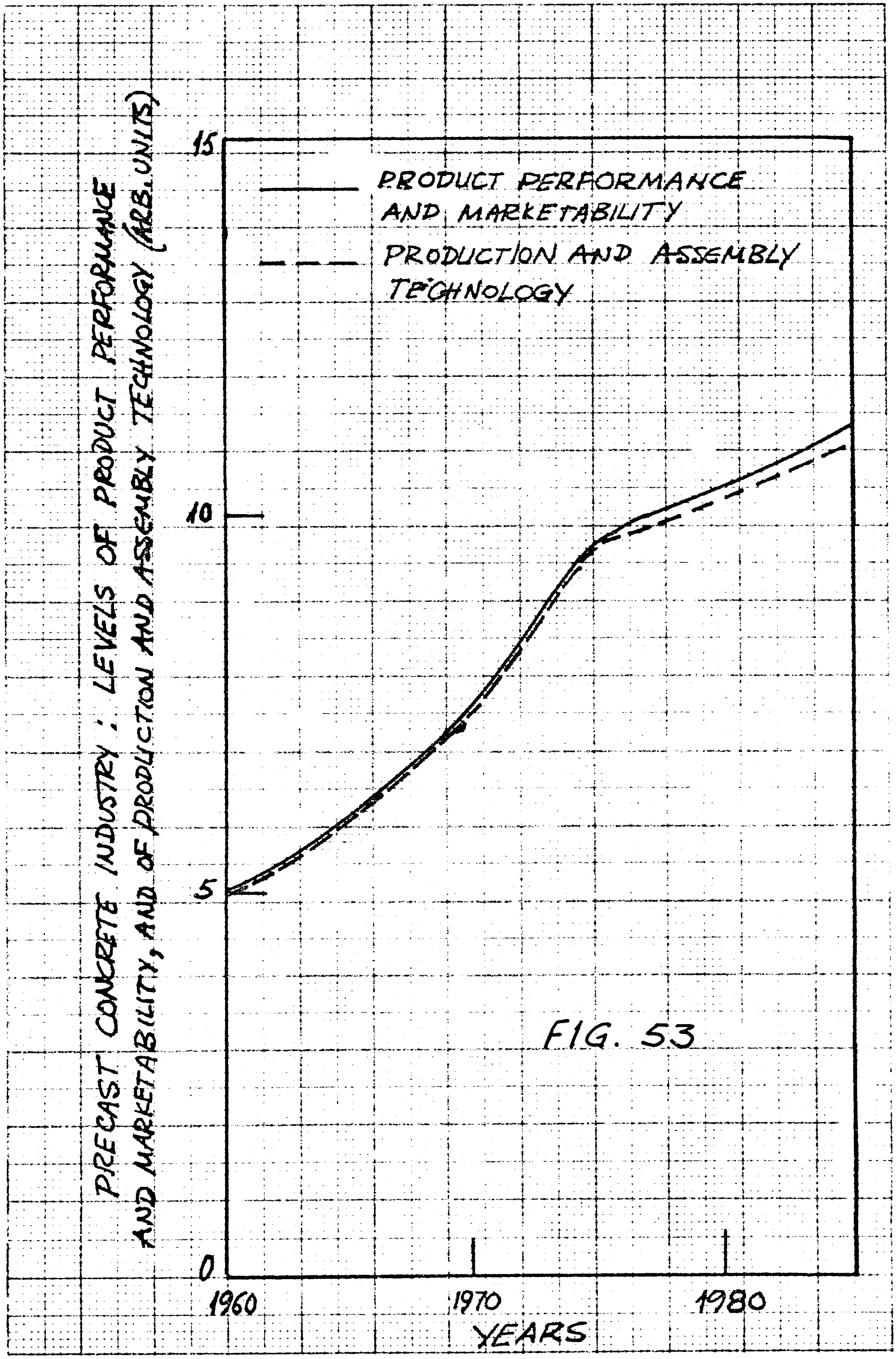

PRECAST CONCRETE INDUSTRY : LEVELS OF PRODUCT PERFORMANCE AND MARKETABILITY, AND OF PRODUCTION AND ASSEMBLY TECHNOLOGY (ARB. UNITS)
15
10
5
0
PRODUCT PERFORMANCE AND MARKETABILITY
PRODUCTION AND ASSEMBLY TECHNOLOGY
1960
1970
1980
YEARS

FIG. 53

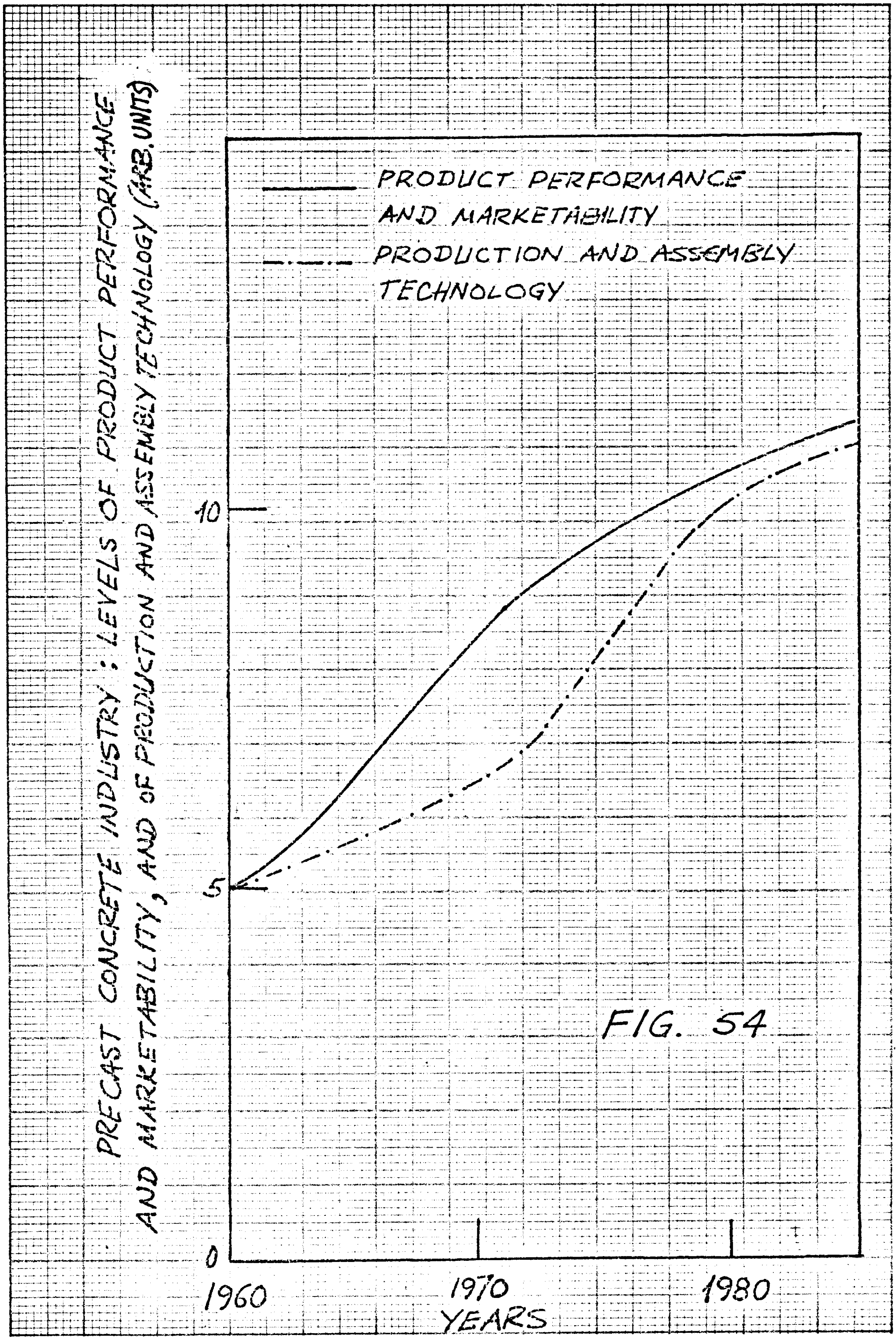

PRECAST CONCRETE INDUSTRY: LEVELS OF PRODUCT PERFORMANCE AND MARKETABILITY, AND OF PRODUCTION AND ASSEMBLY TECHNOLOGY (ARB. UNITS)
PRODUCT PERFORMANCE AND MARKETABILITY
PRODUCTION AND ASSEMBLY TECHNOLOGY
10
5
0
1960
1970
1980
YEARS

FIG. 54

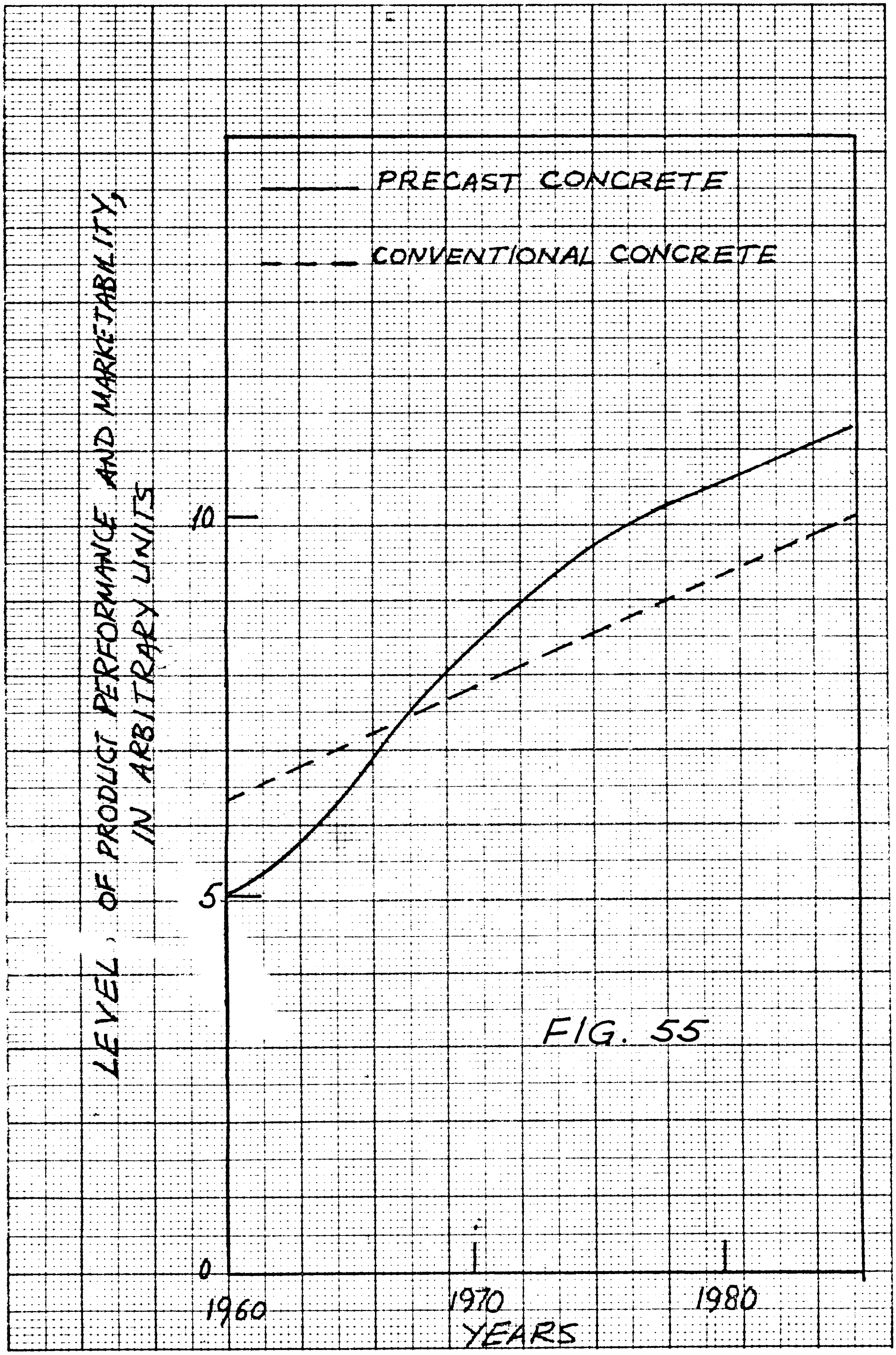

PRECAST CONCRETE
CONVENTIONAL CONCRETE
LEVEL OF PRODUCT PERFORMANCE AND MARKETABILITY, IN ARBITRARY UNITS
10
5
0
1960
1970
1980
YEARS

FIG. 55

APPENDIX A

1 COMPLETE COMPUTER PROGRAM OF THE MODEL (DYNAMO LANGUAGE)

```
* DYNAMICS OF THE PRECAST CONCRETE INDUSTRY
NOTE
NOTE TOTAL MARKET
NOTE
A MARKT1.K=EM.K*1E6*Ø.33*Ø.82*TABLE(THMARKT,TIME.K,1959,1985,1)
   MARKT1  MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE
           (SQ FT/YEAR)
   EM      EXPANSION MULTIPLIER(DIMENSIONLESS)
   THMARKT TABLE FOR THE MULTI-UNIT HOUSING MARKET
A EM.K=TABHL(TEM,PPS1.K,Ø.1,Ø.2,Ø.1)
T TEM=1/1.3
   EM      EXPANSION MULTIPLIER(DIMENSIONLESS)
   TEM     TABLE FOR EXPANSION MULTIPLIER
   PPS1    PERCEIVED PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM.LESS)
A MARKT2.K=1E6*Ø.33*Ø.18*TABLE(THMARKT,TIME.K,1959,1985,1)
T THMARKT=154.7/184/25Ø/342/444/415/393/312/346/486/51Ø/5Ø4/7Ø3/8Ø6/
X 8Ø5/8Ø4/8Ø3/815/845/864/881/9ØØ/9Ø6/915/92Ø/924/934
   MARKT2  MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST RANGE
           (SQ FT/YEAR)
   THMARKT TABLE FOR THE MULTI-UNIT HOUSING MARKET
A MARKT3.K=Ø.2E6*TABLE(TMARKT3,TIME.K,1959,1985,1)
T TMARKT3=558/581/61Ø/656/7Ø5/73Ø/8Ø1/846/812/872/949/871/887/9Ø5/929/
X 953/977/1ØØ2/1Ø27/1Ø54/1Ø8Ø/11Ø8/1138/1167/1198/123Ø/1262
   MARKT3  MARKET FOR CONCRETE NON-HOUSING BUILDINGS(SQ FT/YEAR)
   TMARKT3 TABLE FOR CONCRETE NON-HOUSING BUILDINGS
A BM.K=1E6*TABLE(TBM,TIME.K,196Ø,1985,1)
T TBM=794/651/6Ø1/427/636/593/72Ø/83Ø/7Ø8/98Ø/1Ø4Ø/1Ø9Ø/115Ø/1175/
X 13ØØ/1352/1433/1514/1595/1676/1757/1862/1968/2Ø73/2179/2284
   BM      BRIDGE MARKET($/YEAR)
```

```
   TBM      TABLE FOR THE BRIDGE MARKET
NOTE
NOTE PERCENT INDUSTRIALIZED COEFFICIENT
NOTE
A PIC.K=1+STEP(1,CPIT1)+STEP(1,CPIT2)
C CPIT1=1990
C CPIT2=1990
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
   CPIT1    CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
   CPIT2    CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
NOTE
NOTE FUNDS FOR RESEARCH AND DEVELOPMENT
NOTE
A FRAD.K=IF.K+GF.K+CF.K
   FRAD     FUNDS FOR RESEARCH AND DEVELOPMENT($/YEAR)
   IF       INDUSTRIAL FUNDS($/YEAR)
   GF       GOVERNMENTAL FUNDS($/YEAR)
   CF       CONSUMER FUNDS($/YEAR)
A IF.K=FM*SMOOTH(TR.K,1)
N IF=100E4
C FM=0.01
   IF       INDUSTRIAL FUNDS($/YEAR)
   FM       FRACTION OF THE MARKET(DIMENSIONLESS)
   TR       TOTAL REVENUE($/YEAR)
A GF.K=STEP(15E6,1970)+STEP(-15E6,1980)
   GF       GOVERNMENTAL FUNDS($/YEAR)
A CF.K=0.1*IF.K
   CF       CONSUMER FUNDS($/YEAR)
   IF       INDUSTRIAL FUNDS($/YEAR)
NOTE
NOTE PRODUCT PERFORMANCE AND MARKETABILITY
NOTE
```

```
L PPM.K=PPM.J+DT*CPPM.JK+RCPPM.J
N PPM=5
   PPM      PRODUCT PERFORMANCE AND MARKETABILITY (UNITS OF PERFORMANCE)
   CPPM     CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY
            (UNITS PERFORMANCE/YEAR)
   RCPPM    REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY (UNITS
            OF PERFORMANCE)
R CPPM.KL=ML*FCPPM.K*PPM.K*((MLV.K-PPM.K)/MLV.K)
C ML=1.5E-7
   CPPM     CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY
            (UNITS PERFORMANCE/YEAR)
   ML       MULTIPLIER(1/$)
   FCPPM    FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
   PPM      PRODUCT PERFORMANCE AND MARKETABILITY (UNITS OF PERFORMANCE)
   MLV      MATURATION LEVEL(UNITS OF PERFORMANCE)
A FCPPM.K=DLINF3((1-F.K)*FRAD.K*DEFL.K,TICPPM)
C TICPPM=3
   FCPPM    FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
   F        FRACTION(DIMENSIONLESS)
   FRAD     FUNDS FOR RESEARCH AND DEVELOPMENT($/YEAR)
   DEFL     DEFLATOR(DIMENSIONLESS)
   TICPPM   TIME TO IMPLEMENT CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY
A F.K=0.5+STEP(S,T)
C S=0
C T=1990
   F        FRACTION(DIMENSIONLESS)
   S        STEP(DIMENSIONLESS)
   T        TIME (YEARS)
A DEFL.K=TABLE(TDEFL,TIME.K,1960,1985,5)
T TDEFL=1/0.94/0.76/0.66/0.53/0.52
   DEFL     DEFLATOR(DIMENSIONLESS)
   TDEFL    TABLE FOR DEFLATOR
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A MLV.K=7.5+Ø.15*(TIME.K-196Ø)
   MLV      MATURATION LEVEL(UNITS OF PERFORMANCE)
A RCPPM.K=PULSE(MRCPPM,RCPPMT,RCPPMI)
C MRCPPM=Ø
C RCPPMT=199Ø
C RCPPMI=5
   RCPPM    REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY (UNITS
            OF PERFORMANCE)
   MRCPPM   MAGNITUDE OF REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND
            MARKETABILITY(UNITS OF PERFORMANCE)
   RCPPMT   REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY TIME
            (YEARS)
   RCPPMI   REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY
            INTERVAL (YEARS)
NOTE
NOTE PRODUCT PERFORMANCE AND MARKETABILITY OF COMPETITOR
NOTE
A PPMC.K=6.25+Ø.15*(TIME.K-196Ø)
   PPMC     PRODUCT PERFORMANCE AND MARKETABILITY OF COMPETITOR (UNITS OF
            PERFORMANCE)
NOTE
NOTE PERCENT DIFFERENCE IN QUALITY BETWEEN PRECAST AND COMPETITOR
NOTE
C SDQ=1
   SDQ      STANDARD DEVIATION FOR QUALITY(UNITS OF PERFORMANCE)
A AUXQ.K=-1/(2*SDQ*SDQ)
   AUXQ     AUXILIARY FOR QUALITY(1/UNITS OF PERFORMANCE SQUARED)
   SDQ      STANDARD DEVIATION FOR QUALITY(UNITS OF PERFORMANCE)
A DMVQ.K=PPMC.K-PPM.K
   DMVQ     DIFFERENCE IN MEAN VALUES OF QUALITY(UNITS PERFORMANCE)
   PPMC     PRODUCT PERFORMANCE AND MARKETABILITY OF COMPETITOR (UNITS OF
            PERFORMANCE)
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   PPM       PRODUCT PERFORMANCE AND MARKETABILITY (UNITS OF PERFORMANCE)
NOTE PROBABILITIES FOR QUALITY
A PQ1.K=Ø.ØØØ2*EXP(AUXQ.K*(DMVQ.K-3.5)(DMVQ.K-3.5))
A PQ2.K=Ø.ØØ62*EXP(AUXQ.K*(DMVQ.K-2.5)(DMVQ.K-2.5))
A PQ3.K=Ø.Ø668*EXP(AUXQ.K*(DMVQ.K-1.5)(DMVQ.K-1.5))
A PQ4.K=Ø.3Ø85*EXP(AUXQ.K*(DMVQ.K-Ø.5)(DMVQ.K-Ø.5))
A PQ5.K=Ø.6915*EXP(AUXQ.K*(DMVQ.K+Ø.5)(DMVQ.K+Ø.5))
A PQ6.K=Ø.9332*EXP(AUXQ.K*(DMVQ.K+1.5)(DMVQ.K+1.5))
A PQ7.K=Ø.9938*EXP(AUXQ.K*(DMVQ.K+2.5)(DMVQ.K+2.5))
A PQ8.K=Ø.9998*EXP(AUXQ.K*(DMVQ.K+3.5)(DMVQ.K+3.5))
A PQ9.K=1*EXP(AUXQ.K*(DMVQ.K+4.5)(DMVQ.K+4.5))
A PQ1Ø.K=1*EXP(AUXQ.K*(DMVQ.K+5.5)(DMVQ.K+5.5))
A PPBQ.K=(Ø.398/SDQ)(PQ1.K+PQ2.K+PQ3.K+PQ4.K+PQ5.K+PQ6.K+PQ7.K+PQ8.K
X +PQ9.K+PQ1Ø.K)
   PPBQ      PROBABILITY THAT PRECAST HAS BETTER QUALITY (DIM.LESS)
   SDQ       STANDARD DEVIATION FOR QUALITY(UNITS OF PERFORMANCE)
A PDQ.K=(Ø.398/SDQ)(((Ø.185*PQ1.K)/(-3.685+PPMC.K))+((Ø.193*PQ2.K)/
X (-2.693+PPMC.K))+((Ø.428*PQ3.K)/(-1.928+PPMC.K))+((Ø.6391*PQ4.K)/
X (-1.1391+PPMC.K))+((1.ØØ818*PQ5.K)/(-Ø.5Ø818+PPMC.K))+((1.6379*PQ6.K)
X /(-Ø.1379+PPMC.K))+((2.51683*PQ7.K)/(-Ø.Ø1683+PPMC.K))+((3.5*PQ8.K
X +4.5*PQ9.K+5.5*PQ1Ø.K)/(PPMC.K)))
   PDQ       PERCENT DIFFERENCE IN QUALITY (DIMENSIONLESS)
   SDQ       STANDARD DEVIATION FOR QUALITY (UNITS OF PERFORMANCE)
   PPMC      PRODUCT PERFORMANCE AND MARKETABILITY OF COMPETITOR (UNITS OF
             PERFORMANCE)
A PPDQ.K=DLINF3(PDQ.K,DPQ)
C DPQ=2
   PPDQ      PERCIEVED PERCENT DIFFERENCE IN QUALITY (DIM.LESS)
   PDQ       PERCENT DIFFERENCE IN QUALITY (DIMENSIONLESS)
   DPQ       DELAY IN PERCEIVING QUALITY(YEARS)
NOTE
NOTE PRODUCTION AND ASSEMBLY TECHNOLOGY
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NOTE
L PAT.K=PAT.J+DT*CPAT.JK+RCPAT.J
N PAT=5
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS OF TECHNOLOGY)
   CPAT     CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS TECHNOLOGY/YEAR)
   RCPAT    REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS
            OF TECHNOLOGY)
R CPAT.KL=M*FCPAT.K*PAT.K*((MLV.K-PAT.K)/MLV.K)
C M=1.5E-7
   CPAT     CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS TECHNOLOGY/YEAR)
   M        MULTIPLIER(1/$)
   FCPAT    FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS OF TECHNOLOGY)
   MLV      MATURATION LEVEL (UNITS OF TECHNOLOGY)
A FCPAT.K=DLINF3(F.K*FRAD.K*DEFL.K,TICPAT)
C TICPAT=3
   FCPAT    FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
   F        FRACTION(DIMENSIONLESS)
   FRAD     FUNDS FOR RESEARCH AND DEVELOPMENT($/YEAR)
   DEFL     DEFLATOR(DIMENSIONLESS)
   TICPAT   TIME TO IMPLEMENT CHANGES IN PRODUCTION AND ASSEMBLY TECHNOLOGY
            (YEARS)
A RCPAT.K=PULSE(MRCPAT,RCPATT,RCPATI)
C MRCPAT=0
C RCPATT=1990
C RCPATI=5
   RCPAT    REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS
            OF TECHNOLOGY)
   MRCPAT   MAGNITUDE OF REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY
            TECHNOLOGY(UNITS OF TECHNOLOGY)
   RCPATT   REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY TIME
            (YEARS)
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   RCPATI  REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY INTERVAL
           (YEARS)
NOTE
NOTE SAVINGS
NOTE
C SDC=1
   SDC     STANDARD DEVIATION FOR COSTS($/SQ FT)
A AUXC.K=-1/(2*SDC*SDC)
   AUXC    AUXILIARY FOR COSTS(1/(SQ FT)X(SQ FT))
   SDC     STANDARD DEVIATION FOR COSTS($/SQ FT)
A DMV1.K=TCC1.K-TPC1.K
   DMV1    DIFFERENCE IN MEAN VALUE OF COSTS IN THE LOW-COST HOUSING
           MARKET($/SQ FT)
   TCC1    TOTAL COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/
           SQ.FT.)
   TPC1    TOTAL PRECAST COST IN THE LOW COST HOUSING MARKET($/SQ FT)
NOTE PROBABILITIES FOR COST. LOW-COST HOUSING MARKET
A P11.K=0.0002*EXP(AUXC.K*(DMV1.K+3.5)(DMV1.K+3.5))
A P12.K=0.0062*EXP(AUXC.K*(DMV1.K+2.5)(DMV1.K+2.5))
A P13.K=0.0668*EXP(AUXC.K*(DMV1.K+1.5)(DMV1.K+1.5))
A P14.K=0.3085*EXP(AUXC.K*(DMV1.K+0.5)(DMV1.K+0.5))
A P15.K=0.6915*EXP(AUXC.K*(DMV1.K-0.5)(DMV1.K-0.5))
A P16.K=0.9332*EXP(AUXC.K*(DMV1.K-1.5)(DMV1.K-1.5))
A P17.K=0.9938*EXP(AUXC.K*(DMV1.K-2.5)(DMV1.K-2.5))
A P18.K=0.9998*EXP(AUXC.K*(DMV1.K-3.5)(DMV1.K-3.5))
A P19.K=1*EXP(AUXC.K*(DMV1.K-4.5)(DMV1.K-4.5))
A P110.K=1*EXP(AUXC.K*(DMV1.K-5.5)(DMV1.K-5.5))
A PPLC1.K=(0.398/SDC)(P11.K+P12.K+P13.K+P14.K+P15.K+P16.K+P17.K+P18.K
X +P19.K+P110.K)
   PPLC1   PROBABILITY THAT PRECAST HAS LOWER COST IN THE LOW-COST HOUSING
           MARKET (DIM.LESS)
   SDC     STANDARD DEVIATION FOR COSTS($/SQ FT)
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A PDCPSF1.K=(0.398/SDC)(((0.185*P11.K)/(TCC1.K+3.685))+((0.193*P12.K)
X /(TCC1.K+2.693))+((0.428*P13.K)/(TCC1.K+1.928))+((0.6931*P14.K)
X /(TCC1.K+1.1391))+((1.00818*P15.K)/(TCC1.K+0.50818))+((1.6379*P16.K)
X /(TCC1.K+0.1379))+((2.51683*P17.K)/(TCC1.K+0.01683))+((3.5*P18.K
X +4.5*P19.K+5.5*P110.K)/(TCC1.K)))
   PDCPSF1 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE LOW-COST
           HOUSING MARKET (DIMENSIONLESS)
   SDC     STANDARD DEVIATION FOR COSTS ($/SQ.FT.).
   TCC1    TOTAL COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/
           SQ.FT.)
A PSAVGS1.K=PDCPSF1.K*0.7*PCC1.K+SDSDT.K
   PSAVGS1 PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM.LESS)
   PDCPSF1 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE LOW-COST
           HOUSING MARKET (DIMENSIONLESS)
   PCC1    PERCENT OF CONSTRUCTION COST IN THE LOW-COST HOUSING MARKET(DIM.LESS)
   SDSDT   SAVINGS DUE TO SHORTENED DEVELOPMENT TIME(DIMENSIONLESS)
A PCC1.K=TABLE(TPCC1,PIC.K,1,3,1)
T TPCC1=0.37/0.62/0.90
   PCC1    PERCENT OF CONSTRUCTION COST IN THE LOW-COST HOUSING MARKET(DIM.LESS)
   TPCC1   TABLE FOR PERCENT OF CONSTRUCTION COST IN THE LOW COST HOUSING
   PIC     PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
A SDSDT.K=TABLE(TSDSDT,PIC.K,1,3,1)
T TSDSDT=0.03/0.06/0.09
   SDSDT   SAVINGS DUE TO SHORTENED DEVELOPMENT TIME(DIMENSIONLESS)
   TSDSDT  TABLE FOR SAVINGS DUE TO SHORTENED DEVELOPMENT TIME
   PIC     PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
A PPS1.K=DLINF3(PSAVGS1.K,DPS)
N PPS1=0
C DPS=1
   PPS1    PERCEIVED PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM.LESS)
   PSAVGS1 PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM.LESS)
   DPS     DELAY IN PERCEIVING SAVINGS(YEARS)
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A DMV2.K=TCC2.K-TPC2.K
   DMV2     DIFFERENCE IN MEAN VALUE OF COSTS IN THE HIGH-COST HOUSING
            MARKET($/SQ FT)
   TCC2     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/
            SQ.FT.)
   TPC2     TOTAL PRECAST COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
NOTE PROBABILITIES FOR COST.HIGH-COST HOUSING MARKET
A P21.K=0.0002*EXP(AUXC.K*(DMV2.K+3.5)(DMV2.K+3.5))
A P22.K=0.0062*EXP(AUXC.K*(DMV2.K+2.5)(DMV2.K+2.5))
A P23.K=0.0668*EXP(AUXC.K*(DMV2.K+1.5)(DMV2.K+1.5))
A P24.K=0.3085*EXP(AUXC.K*(DMV2.K+0.5)(DMV2.K+0.5))
A P25.K=0.6915*EXP(AUXC.K*(DMV2.K-0.5)(DMV2.K-0.5))
A P26.K=0.9332*EXP(AUXC.K*(DMV2.K-1.5)(DMV2.K-1.5))
A P27.K=0.9938*EXP(AUXC.K*(DMV2.K-2.5)(DMV2.K-2.5))
A P28.K=0.9998*EXP(AUXC.K*(DMV2.K-3.5)(DMV2.K-3.5))
A P29.K=1*EXP(AUXC.K*(DMV2.K-4.5)(DMV2.K-4.5))
A P210.K=1*EXP(AUXC.K*(DMV2.K-5.5)(DMV2.K-5.5))
A PPLC2.K=(0.398/SDC)(P21.K+P22.K+P23.K+P24.K+P25.K+P26.K+P27.K+P28.K+
X P29.K+P210.K)
   PPLC2    PROBABILITY THAT PRECAST HAS LOWER COST IN THE HIGH-COST HOUSING
            MARKET (DIM.LESS)
   SDC      STANDARD DEVIATION FOR COSTS ($/SQ.FT.)
A PDCPSF2.K=(0.398/SDC)(((0.185*P21.K)/(TCC2.K+3.685))+((0.193*P22.K)
X /(TCC2.K+2.693))+((0.428*P23.K)/(TCC2.K+1.928))+((0.6931*P24.K)
X /(TCC2.K+1.1391))+((1.00818*P25.K)/(TCC2.K+0.50818))+((1.6379*P26.K)
X /(TCC2.K+0.1379))+((2.51683*P27.K)/(TCC2.K+0.01683))+((3.5*P28.K
X +4.5*P29.K+5.5*P210.K)/(TCC2.K)))
   PDCPSF2  PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE HIGH-COST
            HOUSING MARKET (DIMENSIONLESS)
   SDC      STANDARD DEVIATION FOR COSTS ($/SQ.FT.)
   TCC2     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/
            SQUARE FEET)
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A PSAVGS2.K=PDCPSF2.K*Ø.7*PCC2.K+SDSDT.K
   PSAVGS2 PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PDCPSF2 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE HIGH-COST
           HOUSING MARKET (DIMENSIONLESS)
   PCC2    PERCENT OF CONSTRUCTION COST IN THE HIGH-COST HOUSING MARKET
           (DIMENSIONLESS)
   SDSDT   SAVINGS DUE TO SHORTENED DEVELOPMENT TIME(DIMENSIONLESS)
A PCC2.K=TABLE(TPCC2,PIC.K,1,3,1)
T TPCC2=Ø.25/Ø.62/Ø.90
   PCC2    PERCENT OF CONSTRUCTION COST IN THE HIGH-COST HOUSING MARKET
           (DIMENSIONLESS)
   TPCC2   TABLE FOR PERCENT OF CONSTRUCTION COST IN THE HIGH COST HOUSING
           MARKET
   PIC     PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
A PPS2.K=DLINF3(PSAVGS2.K,DPS)
N PPS2=Ø
   PPS2    PERCEIVED PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PSAVGS2 PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM.LESS)
   DPS     DELAY IN PERCEIVING SAVINGS(YEARS)
A DMV3.K=TCC3.K-TPC3.K
   DMV3    DIFFERENCE IN MEAN VALUE OF COSTS IN THE NON-HOUSING BUILDING
           MARKET($/SQ FT)
   TCC3    TOTAL COST IN CONVENTIONAL CONSTRUCTION IN NON-HOUSING BUILDING ($/
           SQUARE FEET)
   TPC3    TOTAL PRECAST COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
NOTE PROBABILITIES FOR COST, NON-HOUSING BUILDING MARKET
A P31.K=Ø.ØØØ2*EXP(AUXC.K*(DMV3.K+3.5)(DMV3.K+3.5))
A P32.K=Ø.ØØ62*EXP(AUXC.K*(DMV3.K+2.5)(DMV3.K+2.5))
A P33.K=Ø.Ø668*EXP(AUXC.K*(DMV3.K+1.5)(DMV3.K+1.5))
A P34.K=Ø.3Ø85*EXP(AUXC.K*(DMV3.K+Ø.5)(DMV3.K+Ø.5))
A P35.K=Ø.6915*EXP(AUXC.K*(DMV3.K-Ø.5)(DMV3.K-Ø.5))
A P36.K=Ø.9332*EXP(AUXC.K*(DMV3.K-1.5)(DMV3.K-1.5))
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A P37.K=Ø.9938*EXP(AUXC.K*(DMV3.K-2.5)(DMV3.K-2.5))
A P38.K=Ø.9998*EXP(AUXC.K*(DMV3.K-3.5)(DMV3.K-3.5))
A P39.K=1*EXP(AUXC.K*(DMV3.K-4.5)(DMV3.K-4.5))
A P31Ø.K=1*EXP(AUXC.K*(DMV3.K-5.5)(DMV3.K-5.5))
A PPLC3.K=(Ø.398/SDC)(P31.K+P32.K+P33.K+P34.K+P35.K+P36.K+P37.K+P38.K
X +P39.K+P31Ø.K)
   PPLC3    PROBABILITY THAT PRECAST HAS LOWER COST IN THE NON-HOUSING BUILDING
            MARKET (DIM.LESS)
   SDC      STANDARD DEVIATION FOR COSTS ($/SQ.FT.)
A PDCPSF3.K=(Ø.398/SDC)(((Ø.185*P31.K)/(TCC3.K+3.685))+((Ø.193*P32.K)
X /(TCC3.K+2.693))+((Ø.428*P33.K)/(TCC3.K+1.928))+((Ø.6931*P34.K)
X /(TCC3.K+1.1391))+((1.ØØ818*P35.K)/(TCC3.K+Ø.5Ø818))+((1.6379*P36.K)
X /(TCC3.K+Ø.1379))+((2.51683*P37.K)/(TCC3.K+Ø.Ø1683))+((3.5*P38.K
X +4.5*P39.K+5.5*P31Ø.K)/(TCC3.K)))
   PDCPSF3  PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE NON-HOUSING
            BUILDING MARKET (DIMENSIONLESS)
   SDC      STANDARD DEVIATION FOR COSTS ($/SQ.FT.)
   TCC3     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN NON-HOUSING BUILDING ($/
            SQUARE FEET)
A PSAVGS3.K=PDCPSF3.K*Ø.7*PCC3.K+SDSDT.K
   PSAVGS3  PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET (DIM.LESS)
   PDCPSF3  PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE NON-HOUSING
            BUILDING MARKET (DIMENSIONLESS)
   PCC3     PERCENT OF CONSTRUCTION COST IN THE NON-HOUSING BUILDING MARKET
            (DIMENSIONLESS)
   SDSDT    SAVINGS DUE TO SHORTENED DEVELOPMENT TIME (DIM.LESS)
A PCC3.K=TABLE(TPCC3,PIC.K,1,3,1)
T TPCC3=Ø.27/Ø.58/Ø.9Ø
   PCC3     PERCENT OF CONSTRUCTION COST IN THE NON-HOUSING BUILDING MARKET
            (DIMENSIONLESS)
   TPCC3    TABLE FOR PERCENT OF CONSTRUCTION COST IN THE NON-HOUSING
            BUILDING MARKET
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   PIC      PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
A PPS3.K=DLINF3(PSAVGS3.K,DPS)
N PPS3=0
   PPS3     PERCEIVED PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET
            (DIMENSIONLESS)
   PSAVGS3  PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET (DIM.LESS)
   DPS      DELAY IN PERCEIVING SAVINGS(YEARS)
NOTE
NOTE ARCHITECT'S PREFERENCE FUNCTION
NOTE
A PF1.K=FIFGE(PF1B.K,PF1A.K,PPDQ.K,0.1)
A PF1B.K=TABHL(TPF1B,PPS1.K,0,0.2,0.1)
T TPF1B=0.6/0.75/0.9
A PF1A.K=TABHL(TPF1A,PPS1.K,0,0.2,0.1)
T TPF1A=0.55/0.7/0.85
   PF1      PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)
   PF1B     PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)
   PF1A     PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)
   PPDQ     PERCIEVED PERCENT DIFFERENCE IN QUALITY (DIM.LESS)
   PPS1     PERCEIVED PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM.LESS)
A PF2.K=FIFGE(PF2B.K,PF2A.K,PPDQ.K,0.1)
A PF2B.K=TABHL(TPF2B,PPS2.K,0,0.2,0.1)
T TPF2B=0.7/0.75/0.8
A PF2A.K=TABHL(TPF2A,PPS2.K,0,0.2,0.1)
T TPF2A=0.6/0.65/0.7
   PF2      PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PF2B     PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PF2A     PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PPDQ     PERCIEVED PERCENT DIFFERENCE IN QUALITY (DIM.LESS)
   PPS2     PERCEIVED PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM.LESS)
A PF3.K=FIFGE(PF3B.K,PF3A.K,PPDQ.K,0.1)
A PF3B.K=TABHL(TPF3B,PPS3.K,0,0.2,0.1)
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T TPF3B=Ø•65/Ø•75/Ø•85
A PF3A•K=TABHL(TPF3A,PPS3•K,Ø,Ø•2,Ø•1)
T TPF3A=Ø•575/Ø•675/Ø•775
   PF3      PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM•LESS)
   PF3B     PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM•LESS)
   PF3A     PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM•LESS)
   PPDQ     PERCEIVED PERCENT DIFFERENCE IN QUALITY (DIM•LESS)
   PPS3     PERCEIVED PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET
            (DIMENSIONLESS)
NOTE
NOTE DEMANDED PRECAST MARKET
NOTE
L DSM1•K=(PF1•J*PPBQ•J*PPLC1•J+Ø•1*PPLC1•J*(1-PPBQ•J))*Ø•6*NM•J*PP•J+
X Ø•05*MLTP•J
N DSM1=Ø•03641
   DSM1     DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
   PF1      PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM•LESS)
   PPBQ     PROBABILITY THAT PRECAST HAS BETTER QUALITY (DIM•LESS)
   PPLC1    PROBABILITY THAT PRECAST HAS LOWER COST IN THE LOW-COST HOUSING
            MARKET (DIM•LESS)
   NM       NOVELTY MULTIPLIER(DIMENSIONLESS)
   PP       PUBLIC POLICY (DIM•LESS)
   MLTP     MULTIPLIER(DIMENSIONLESS)
A NM•K=TABHL(TNM,TIME•K,1960,1985,1)
T TNM=Ø•5/Ø•61/Ø•68/Ø•735/Ø•775/Ø•815/Ø•84/Ø•86/Ø•875/Ø•89/Ø•905/Ø•915/
X Ø•925/Ø•935/Ø•945/Ø•95/Ø•955/Ø•96/Ø•965/Ø•97/Ø•975/Ø•98/Ø•985/Ø•99
X /Ø•995/1
   NM       NOVELTY MULTIPLIER(DIMENSIONLESS)
   TNM      TABLE FOR NOVELTY MULTIPLIER
A PP•K=1+STEP(Ø•1,1973)
   PP       PUBLIC POLICY (DIM•LESS)
A MLTP•K=SLM•K*PATM•K*NM•K
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   MLTP     MULTIPLIER(DIMENSIONLESS)
   SLM      SCARCITY OF LABOR MULTIPLIER(DIMENSIONLESS)
   PATM     PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER (DIMENSIONLESS)
   NM       NOVELTY MULTIPLIER(DIMENSIONLESS)
A SLM.K=TABHL(TSLM,LWC.K/LWF.K,1.2,2,Ø.8)
T TSLM=1/1.1
   SLM      SCARCITY OF LABOR MULTIPLIER(DIMENSIONLESS)
   TSLM     TABLE FOR SCARCITY OF LABOR MULTIPLIER
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
   LWF      LABOR WAGES IN THE FACTORY($/HOUR)
A PATM.K=TABHL(TPATM,PAT.K,5,11.25,6.25)
T TPATM=Ø.976/1.Ø7
   PATM     PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER (DIMENSIONLESS)
   TPATM    TABLE FOR PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS OF TECHNOLOGY)
L DSM2.K=(PF2.J*PPBQ.J*PPLC2.J+Ø.1*PPBQ.J*(1-PPLC2.J))*Ø.6*NM.J+
X Ø.Ø1*MLTP.J
N DSM2=Ø.Ø1633
   DSM2     DEMANDED SHARE OF THE MARKET FOR HIGH-COST HOUSING(DIMENSIONLESS)
   PF2      PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)
   PPBQ     PROBABILITY THAT PRECAST HAS BETTER QUALITY (DIM.LESS)
   PPLC2    PROBABILITY THAT PRECAST HAS LOWER COST IN THE HIGH-COST HOUSING
            MARKET (DIM.LESS)
   NM       NOVELTY MULTIPLIER (DIM.LESS)
   MLTP     MULTIPLIER(DIMENSIONLESS)
L DSM3.K=(PF3.J*PPBQ.J*PPLC3.J+Ø.Ø5*PPLC3.J*(1-PPBQ.J)+Ø.Ø5*PPBQ.J*
X (1-PPLC3.J))*Ø.6*NM.J+Ø.Ø2*MLTP.J
N DSM3=Ø.Ø2135
   DSM3     DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS (DIM.LESS)
   PF3      PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM.LESS)
   PPBQ     PROBABILITY THAT PRECAST HAS BETTER QUALITY (DIM.LESS)
   PPLC3    PROBABILITY THAT PRECAST HAS LOWER COST IN THE NON-HOUSING BUILDING
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            MARKET (DIM.LESS)
   NM       NOVELTY MULTIPLIER (DIM.LESS)
   MLTP     MULTIPLIER (DIM.LESS)
A DBS.K=1.275*(DSM1.K*MARKT1.K+DSM2.K*MARKT2.K)+DSM3.K*MARKT3.K
   DBS      DEMANDED BUILDING SYSTEMS(SQ FT/YEAR)
   DSM1     DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
   MARKT1   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE
            (SQ FT/YEAR)
   DSM2     DEMANDED SHARE OF THE MARKET FOR HIGH-COST HOUSING(DIMENSIONLESS)
   MARKT2   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST RANGE
            (SQ FT/YEAR)
   DSM3     DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS (DIM.LESS)
   MARKT3   MARKET FOR CONCRETE NON-HOUSING BUILDINGS(SQ FT/YEAR)
A DPCBM.K=((MARKT1.K/Ø.33)+(MARKT2.K/Ø.33)+(MARKT3.K/Ø.2))*DSBMPC.K
   DPCBM    DEMAND FOR PRECAST COMPONENTS IN THE BUILDING MARKET(SQ FT/YEAR)
   MARKT1   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE
            (SQ FT/YEAR)
   MARKT2   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST RANGE
            (SQ FT/YEAR)
   MARKT3   MARKET FOR CONCRETE NON-HOUSING BUILDINGS(SQ FT/YEAR)
   DSBMPC   DEMANDED SHARE OF THE BUILDING MARKET FOR PRECAST COMPONENTS
            (DIMENSIONLESS)
A DSBMPC.K=Ø.Ø2325*MLTP.K
   DSBMPC   DEMANDED SHARE OF THE BUILDING MARKET FOR PRECAST COMPONENTS
            (DIMENSIONLESS)
   MLTP     MULTIPLIER (DIM.LESS)
A DNBPM.K=BM.K*DSBM.K*CC.K
   DNBPM    DEMAND FOR NON-BUILDING PRECAST MARKET(SQ FT)
   BM       BRIDGE MARKET($/YEAR)
   DSBM     DEMANDED SHARE OF THE BRIDGE MARKET(DIMENSIONLESS)
   CC       CONVERSION COEFFICIENT(1/$/SQ FT)
A DSBM.K=Ø.138*MLTP.K
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   DSBM     DEMANDED SHARE OF THE BRIDGE MARKET(DIMENSIONLESS)
   MLTP     MULTIPLIER (DIM.LESS)
L CC.K=1/TCC.J
N CC=Ø.17
   CC       CONVERSION COEFFICIENT(1/$/SQ FT)
   TCC      TABLE FOR COST ($/SQUARE FEET)
A RC.K=DBS.K+DPCBM.K+DNBPM.K
   RC       REQUIRED CAPACITY (SQUARE FEET/YEAR)
   DBS      DEMANDED BUILDING SYSTEMS(SQ FT/YEAR)
   DPCBM    DEMAND FOR PRECAST COMPONENTS IN THE BUILDING MARKET(SQ FT/YEAR)
   DNBPM    DEMAND FOR NON-BUILDING PRECAST MARKET(SQ FT)
NOTE
NOTE FORECASTING SYSTEM
NOTE
A SD.K=SDJ.K*(1-SCN.K)+SCN.K*RC.K
   SD       SMOOTHED DEMAND(SQ FT/YEAR)
   SDJ      SMOOTHED DEMAND PREVIOUSLY($/SQ FT)
   SCN      SMOOTHING CONSTANT(DIMENSIONLESS)
   RC       REQUIRED CAPACITY (SQUARE FEET/YEAR)
L SDJ.K=SD.J
N SDJ=22.66E6
   SDJ      SMOOTHED DEMAND PREVIOUSLY($/SQ FT)
A TREND.K=SCN.K*(SD.K-SDJ.K)+(1-SCN.K)*TRENDJ.K
   TREND    TREND(SQ FT/YEAR)
   SCN      SMOOTHING CONSTANT(DIMENSIONLESS)
   SD       SMOOTHED DEMAND(SQ FT/YEAR)
   SDJ      SMOOTHED DEMAND PREVIOUSLY($/SQ FT)
   TRENDJ   TREND PREVIOUSLY(SQ FT/YEAR)
L TRENDJ.K=TREND.J
N TRENDJ=65E3
   TRENDJ   TREND PREVIOUSLY(SQ FT/YEAR)
A FORD.K=SD.K+((1-SCN.K)/SCN.K)*TREND.K
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    FORD     FORECASTED DEMAND(SQ FT/YEAR)
    SD       SMOOTHED DEMAND(SQ FT/YEAR)
    SCN      SMOOTHING CONSTANT(DIMENSIONLESS)
    TREND    TREND(SQ FT/YEAR)
A DPC.K=MAX(Ø,FORD.K+3ØØ*TREND.K)
    DPC      DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
    FORD     FORECASTED DEMAND(SQ FT/YEAR)
    TREND    TREND(SQ FT/YEAR)
L DPC1.K=DPC1.J+DT*PULSE(1/DT,196Ø,1)
N DPC1=37.6E6
    DPC1     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
L DPC2.K=DPC2.J+DT*PULSE(1/DT,196Ø,1)*(DPC1.J-DPC2.J)
N DPC2=3Ø.2E6
    DPC2     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
    DPC1     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
L DPC3.K=DPC3.J+DT*PULSE(1/DT,196Ø,1)*(DPC2.J-DPC3.J)
N DPC3=23E6
    DPC3     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
    DPC2     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
A AX.K=AXJ.K+PULSE(1,196Ø,1)*(FORD.K-AXJ.K)
    AX       AUXILIARY (SQ.FT./YEAR)
    FORD     FORECASTED DEMAND(SQ FT/YEAR)
    AXJ      AUXILIARY PREVIOUSLY(SQ FT/YEAR)
L AXJ.K=AX.J
N AXJ=23E6
    AXJ      AUXILIARY PREVIOUSLY(SQ FT/YEAR)
    AX       AUXILIARY (SQ.FT./YEAR)
A ER.K=AX.K-DPC3.K
    ER       ERROR(SQ FT/YEAR)
    AX       AUXILIARY (SQ.FT./YEAR)
    DPC3     DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
A SER.K=SERJ.K+DT*ER.K
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   SER      SUM OF ERRORS(SQ FT)
   SERJ     SUM OF ERRORS PREVIOUSLY(SQ FT)
   ER       ERROR(SQ FT/YEAR)
L SERJ.K=SER.J
N SERJ=0.001E6
   SERJ     SUM OF ERRORS PREVIOUSLY(SQ FT)
   SER      SUM OF ERRORS(SQ FT)
A ASE.K=ASEJ.K+DT*FIFGE(ER.K,-ER.K,ER.K,0)
   ASE      ABSOLUTE SUM OF ERRORS(SQUARE FEET)
   ASEJ     ABSOLUTE SUM OF ERRORS PREVIOUSLY(SQUARE FEET)
   ER       ERROR(SQ FT/YEAR)
L ASEJ.K=ASE.J
N ASEJ=0.01E6
   ASEJ     ABSOLUTE SUM OF ERRORS PREVIOUSLY(SQUARE FEET)
   ASE      ABSOLUTE SUM OF ERRORS(SQUARE FEET)
L SCN.K=FIFGE(SER.J/ASE.J,-SER.J/ASE.J,SER.J,0)
N SCN=0.1
   SCN      SMOOTHING CONSTANT(DIMENSIONLESS)
   SER      SUM OF ERRORS(SQ FT)
   ASE      ABSOLUTE SUM OF ERRORS (SQ.FT.)
NOTE
NOTE PRODUCTION CAPACITY OF THE PRECAST CONCRETE INDUSTRY
NOTE
L PC.K=PC.J+DT*(CPC.JK-PCDR.JK)
N PC=32.2E6
   PC       PRODUCTION CAPACITY (SQUARE FEET/YEAR)
   CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   PCDR     PRODUCTION CAPACITY DEPRECIATION RATE (SQUARE FEET/YEAR/YEAR)
R CPC.KL=FIFGE(CPCA.K,CPCB.K,PC.K-1.4*RC.K,0)
   CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   CPCA     CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   CPCB     CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
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   PC       PRODUCTION CAPACITY (SQUARE FEET/YEAR)
   RC       REQUIRED CAPACITY (SQUARE FEET/YEAR)
A CPCA.K=MAX((1.4*RC.K+PC.K*((1-ALPC*MM.K)/(ALPC*MM.K))),0)
   CPCA     CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   RC       REQUIRED CAPACITY (SQUARE FEET/YEAR)
   PC       PRODUCTION CAPACITY (SQUARE FEET/YEAR)
   ALPC     AVERAGE LIFETIME OF PLANT CAPACITY(YEARS)
   MM       MAINTENANCE MULTIPLIER(DIMENSIONLESS)
A CPCB.K=MAX((1.4*DPC.K+3*(PC.K/(ALPC*MM.K))-PC.K)/3,0)
   CPCB     CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   DPC      DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
   PC       PRODUCTION CAPACITY (SQ.FT./YEAR)
   ALPC     AVERAGE LIFETIME OF PLANT CAPACITY(YEARS)
   MM       MAINTENANCE MULTIPLIER(DIMENSIONLESS)
R PCDR.KL=PC.K/(ALPC*MM.K)
C ALPC=16
   PCDR     PRODUCTION CAPACITY DEPRECIATION RATE (SQUARE FEET/YEAR/YEAR)
   PC       PRODUCTION CAPACITY (SQ.FT./YEAR)
   ALPC     AVERAGE LIFETIME OF PLANT CAPACITY(YEARS)
   MM       MAINTENANCE MULTIPLIER(DIMENSIONLESS)
A MM.K=FIFGE(1,0.6,1.4*DPC.K-PC.K,0)
   MM       MAINTENANCE MULTIPLIER (DIM.LESS)
   DPC      DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
   PC       PRODUCTION CAPACITY (SQ.FT./YEAR)
NOTE
NOTE ACTUAL PRECAST MARKET
NOTE
A PMARKT.K=MIN(PC.K,RC.K)
   PMARKT   PRECAST MARKET (SQUARE FEET/YEAR)
   PC       PRODUCTION CAPACITY (SQ.FT./YEAR)
   RC       REQUIRED CAPACITY  (SQ.FT./YEAR)
NOTE
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NOTE PER PLANT CAPACITY , PRODUCTION
NOTE
A PPC.K=PC.K/NP.K
   PPC       PER PLANT CAPACITY (SQUARE FEET/YEAR)
   PC        PRODUCTION CAPACITY (SQ.FT./YEAR)
   NP        NUMBER OF PLANTS(DIMENSIONLESS)
A NP.K=TABHL(TNP,PC.K,0,500E6,25E6)
T TNP=0/160/280/380/460/540/580/620/660/680/700/720/740/750/760/770/
X 780/785/790/795/800
   NP        NUMBER OF PLANTS(DIMENSIONLESS)
   TNP       TABLE FOR NUMBER OF PLANTS
   PC      PRODUCTION CAPACITY (SQ.FT./YEAR)
A PPP.K=PMARKT.K/NP.K
   PPP       PER PLANT PRODUCTION (SQUARE FEET/YEAR)
   PMARKT    PRECAST MARKET (SQUARE FEET/YEAR)
   NP        NUMBER OF PLANTS(DIMENSIONLESS)
A PPP1.K=(1.275*DSM1.K*MARKT1.K*PPP.K)/RC.K
   PPP1      PER PLANT PRODUCTION OF LOW-COST HOUSING (SQUARE FEET/YEAR)
   DSM1      DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
   MARKT1    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
             (SQ.FT./YEAR)
   PPP       PER PLANT PRODUCTION (SQ.FT./YEAR)
   RC        REQUIRED CAPACITY  (SQ.FT./YEAR)
A PPP2.K=(1.275*DSM2.K*MARKT2.K*PPP.K)/RC.K
   PPP2      PER PLANT PRODUCTION OF HIGH COST HOUSING (SQUARE FEET/YEAR)
   DSM2      DEMANDED SHARE OF THE MARKET FOR HIGH-COST HOUSING(DIMENSIONLESS)
   MARKT2    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
             (SQ.FT./YEAR)
   PPP       PER PLANT PRODUCTION (SQUARE FEET/YEAR)
   RC        REQUIRED CAPACITY  (SQ.FT./YEAR)
A PPP3.K=(DSM3.K*MARKT3.K*PPP.K)/RC.K
   PPP3      PER PLANT PRODUCTION OF NON-HOUSING BUILDINGS (SQUARE FEET/YEAR)
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   DSM3     DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS (DIM.LESS)
   MARKT3   MARKET FOR CONCRETE NON-HOUSING BUILDINGS (SQ.FT./YEAR)
   PPP      PER PLANT PRODUCTION (SQ.FT./YEAR)
   RC       REQUIRED CAPACITY (SQ.FT./YEAR)
NOTE
NOTE TOTAL REVENUE
NOTE
A TR.K=FIFGE(PC.K/RC.K,1,RC.K-PC.K,Ø)*(DBS.K*APC.K+
X DPCBM.K*TCC.K+DNBPM.K/CC.K)*1.1Ø
   TR       TOTAL REVENUE($/YEAR)
   PC     PRODUCTION CAPACITY (SQ.FT./YEAR)
   RC       REQUIRED CAPACITY (SQ.FT./YEAR)
   DBS      DEMANDED BUILDING SYSTEMS(SQ FT/YEAR)
   APC      AVERAGE PRECAST COST($/SQ FT)
   DPCBM    DEMAND FOR PRECAST COMPONENTS IN THE BUILDING MARKET(SQ FT/YEAR)
   TCC      TABLE FOR COST ($/SQUARE FEET)
   DNBPM    DEMAND FOR NON-BUILDING PRECAST MARKET(SQ FT)
   CC       CONVERSION COEFFICIENT(1/$/SQ FT)
NOTE
NOTE THE SHARE OF MAIN BUILDING MARKETS BELONGING TO PRECAST CONCRETE
NOTE
A PSM.K=FIFGE((PC.K/RC.K),1,(RC.K-PC.K),Ø)*
X ((DSM1.K*MARKT1.K+DSM2.K*MARKT2.K+DSM3.K*MARKT3.K)/(MARKT1.K+MARKT2.K
X +MARKT3.K))
   PSM      PRECAST'S SHARE OF ITS MAIN BUILDING MARKETS (DIM.LESS)
   PC     PRODUCTION CAPACITY (SQ.FT./YEAR)
   RC       REQUIRED CAPACITY (SQ.FT./YEAR)
   DSM1     DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
   MARKT1   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
            (SQ.FT./YEAR)
   DSM2     DEMANDED SHARE OF THE MARKET FOR HIGH COST HOUSING(DIMENSIONLESS)
   MARKT2   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
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              (SQ.FT./YEAR)
    DSM3      DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS
    MARKT3    MARKET FOR CONCRETE NON-HOUSING BUILDINGS (SQ.FT./YEAR)
NOTE
NOTE ECONOMIC PERFORMANCE
NOTE
NOTE RISK
NOTE
A RISK.K=FIFGE(RISKH.K,RISKNH.K,(1.275*DSM1.K*MARKT1.K+1.275*DSM2.K*
X MARKT2.K)-(DSM3.K*MARKT3.K),0)
    RISK      RISK (UNITS OF RISK)
    RISKH     RISK AS DETERMINED BY THE HOUSING MARKET (UNITS OF RISK)
    RISKNH    RISK AS DETERMINED BY THE NON-HOUSING BUILDING MARKET (UNITS OF RISK)
    DSM1      DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
    MARKT1    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
              (SQ.FT./YEAR)
    DSM2      DEMANDED SHARE OF THE MARKET FOR HIGH COST HOUSING(DIMENSIONLESS)
    MARKT2    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
              (SQ.FT./YEAR)
    DSM3      DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS
    MARKT3    MARKET FOR CONCRETE NON-HOUSING BUILDINGS (SQ.FT./YEAR)
A RISKH.K=FIFGE(RISK1.K,RISK4.K,C.K,10)
    RISKH     RISK AS DETERMINED BY THE HOUSING MARKET (UNITS OF RISK)
    RISK1     RISK (UNITS OF RISK)
    RISK4     RISK (UNITS OF RISK)
    C         COUNTER(DIMENSIONLESS)
A C.K=(CJ.K+DT*1)*A.K
    C         COUNTER(DIMENSIONLESS)
    CJ        COUNTER PREVIOUSLY(DIMENSIONLESS)
    A         AUXILIARY(DIMENSIONLESS)
L CJ.K=C.J
N CJ=0
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     CJ        COUNTER PREVIOUSLY(DIMENSIONLESS)
     C         COUNTER(DIMENSIONLESS)
A  A.K=FIFGE(1,Ø,MARKT1.K+MARKT2.K-104E6,Ø)
     A         AUXILIARY(DIMENSIONLESS)
     MARKT1    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
               (SQ.FT./YEAR)
     MARKT2    MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
               (SQ.FT./YEAR)
A  RISK1.K=TABHL(TRISK1,PGHM.K,-Ø.2,Ø.2,Ø.4)
T  TRISK1=1.5/Ø
     RISK1     RISK (UNITS OF RISK)
     TRISK1    TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
     PGHM      PERCIEVED GROWTH OF THE HOUSING MARKET (DIM.LESS)
A  RISK4.K=FIFGE(RISK2.K,RISK3.K,C.K,5)
A  RISK2.K=TABHL(TRISK2,PGHM.K,-Ø.3,Ø.3,Ø.6)
T  TRISK2=2.5/1.5
A  RISK3.K=TABHL(TRISK3,PGHM.K,-Ø.4,Ø.4,Ø.8)
T  TRISK3=5/2.5
     RISK4     RISK (UNITS OF RISK)
     RISK2     RISK (UNITS OF RISK)
     RISK3     RISK (UNITS OF RISK)
     C         COUNTER(DIMENSIONLESS)
     TRISK2    TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
     PGHM      PERCIEVED GROWTH OF THE HOUSING MARKET (DIM.LESS)
     TRISK3    TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
A  RISKNH.K=TABHL(TRISK1,PGNHBM.K,-Ø.2,Ø.2,Ø.4)
     RISKNH    RISK AS DETERMINED BY THE NON-HOUSING BUILDING MARKET (UNITS OF RISK)
     TRISK1    TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
     PGNHBM    PERCEIVED GROWTH IN THE NON-HOUSING BUILDING MARKET (DIM.LESS)
A  MARKT1J.K=EM.K*1E6*Ø.33*Ø.82*TABLE(THMARKT,TIME.K-1,1959,1985,1)
     MARKT1J   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE
               LAST YEAR(SQ FT)
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   EM       EXPANSION MULTIPLIER(DIMENSIONLESS)
   THMARKT  TABLE FOR THE MULTI-UNIT HOUSING MARKET
A MARKT2J.K=1E6*0.33*0.18*TABLE(THMARKT,TIME.K-1,1959,1985,1)
   MARKT2J  MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST
            RANGE LAST YEAR(SQ FT)
   THMARKT  TABLE FOR MULTI-UNIT HOUSING MARKET
A GHM.K=(MARKT1.K+MARKT2.K-MARKT1J.K-MARKT2J.K)/(MARKT1J.K+MARKT2J.K)
   GHM      GROWTH IN THE HOUSING MARKET(DIMENSIONLESS)
   MARKT1   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
            (SQ.FT./YEAR)
   MARKT2   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
            (SQ.FT./YEAR)
   MARKT1J  MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE
            LAST YEAR(SQ FT)
   MARKT2J  MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST
            RANGE LAST YEAR(SQ FT)
A PGHM.K=SMOOTH(GHM.K,5)
   PGHM     PERCIEVED GROWTH OF THE HOUSING MARKET (DIM.LESS)
   GHM      GROWTH IN THE HOUSING MARKET(DIMENSIONLESS)
A MARKT3J.K=0.2E6*TABLE(TMARKT3,TIME.K-1,1959,1985,1)
   MARKT3J  MARKET FOR CONCRETE NON-HOUSING BUILDINGS LAST YEAR(SQ FT)
   TMARKT3  TABLE FOR CONCRETE NON-HOUSING BUILDINGS
A GNHBM.K=(MARKT3.K-MARKT3J.K)/MARKT3J.K
   GNHBM    GROWTH IN THE NON-HOUSING BUILDINGS MARKET(DIMENSIONLESS)
   MARKT3   MARKET FOR CONCRETE NON-HOUSING BUILDINGS (SQ.FT./YEAR)
   MARKT3J  MARKET FOR CONCRETE NON-HOUSING BUILDINGS LAST YEAR(SQ FT)
A PGNHBM.K=SMOOTH(GNHBM.K,5)
   PGNHBM   PERCEIVED GROWTH IN THE NON-HOUSING BUILDING MARKET (DIM.LESS)
   GNHBM    GROWTH IN THE NON-HOUSING BUILDINGS MARKET(DIMENSIONLESS)
NOTE
NOTE COST OF CAPITAL
NOTE
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A INTRST.K=TABHL(TINTRST,RISK.K,0,5,5)
T TINTRST=0.06/0.25
   INTRST   INTEREST(1/YEAR)
   TINTRST TABLE FOR INTEREST
   RISK     RISK (UNITS OF RISK)
A DEPRT.K=TABHL(TDEPRT,RISK.K,0,5,5)
T TDEPRT=16/3
   DEPRT    DEPRECIATION TIME(YEARS)
   TDEPRT   TABLE FOR DEPRECIATION TIME
   RISK     RISK (UNITS OF RISK)
A RFA.K=PIM.K*PATMC.K*PPMMC.K*FIFGE(CB.K,CA.K,PPC.K,1040000)*
X ((CPC.JK*DT)/NP.K)
   RFA      REQUIRED FIXED ASSETS ($/YEAR)
   PIM      PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
   PATMC    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR CAPITAL (DIM.LESS)
   PPMMC    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR CAPITAL
   CB       CAPITAL($/SQ FT)
   CA       CAPITAL($/SQ FT)
   PPC      PER PLANT CAPACITY (SQUARE FEET/YEAR)
   CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   NP       NUMBER OF PLANTS(DIMENSIONLESS)
A PIM.K=TABLE(TPIM,PIC.K,1,3,1)
T TPIM=1/1.4/1.6
   PIM      PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
   TPIM     TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)
A PATMC.K=TABLE(TPATMC,PAT.K,5,11.25,1.25)
T TPATMC=1/0.88/0.793/0.719/0.657/0.6
   PATMC    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR CAPITAL (DIM.LESS)
   TPATMC   TABLE FOR THE PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS OF TECHNOLOGY)
A PPMMC.K=TABLE(TPPMMC,PPM.K,5,11.25,1.25)
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T TPPMMC=1/1.13/1.26/1.39/1.52/1.65
   PPMMC    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR CAPITAL
   TPPMMC   TABLE FOR THE PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER
            FOR CAPITAL
   PPM    PRODUCT PERFORMANCE AND MARKETABILITY(UNITS OF PERFORMANCE)
A CA.K=((940000/6)*IECI.K*TABLE(TCA,PPC.K,0,6E5,6E4))/PPC.K
T TCA=0/1/1.76/2.5/3.2/3.93/4.45/5/5.5/6/6.52
   CA       CAPITAL($/SQ FT)
   IECI     INDUSTRIAL EQUIPMENT COST INDEX(DIMENSIONLESS)
   TCA      TABLE FOR CAPITAL
   PPC      PER PLANT CAPACITY (SQUARE FEET/YEAR)
A CB.K=((940000/6)*IECI.K*TABLE(TCB,PPC.K,6E5,51E5,5E5))/PPC.K
T TCB=6.52/9.65/11.92/13.56/14.75/15.612/16.233/16.278/16.311/16.34
   CB       CAPITAL($/SQ FT)
   TCB      TABLE FOR CAPITAL
   PPC      PER PLANT CAPACITY(SQ FT/YEAR)
A IECI.K=TABLE(TIECI,TIME.K,1960,1985,1)
T TIECI=0.92/0.92/0.925/0.93/0.94/0.95/0.98/1/1.04/1.09/1.15/1.185/
X 1.22/1.26/1.30/1.34/1.38/1.42/1.46/1.505/1.55/1.60/1.65/1.70/1.75/1.80
   IECI     INDUSTRIAL EQUIPMENT COST INDEX(DIMENSIONLESS)
   TIECI    TABLE FOR INDUSTRIAL EQUIPMENT COST INDEX
A CRFAPSF.K=(AX2.K*RFA.K*PC.K*((1/DEPRT.K)+INTRST.K))/((CPC.JK+AX1.K)
X *DT*PPP.K)
   CRFAPSF    COST OF REQUIRED FIXED ASSETS PER SQUARE FOOT($/SQ FT)
   AX2        AUXILIARY(DIMENSIONLESS)
   RFA      REQUIRED FIXED ASSETS ($/YEAR)
   PC     PRODUCTION CAPACITY (SQ.FT./YEAR)
   DEPRT    DEPRECIATION TIME(YEARS)
   INTRST   INTEREST(1/YEAR)
   CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
   AX1      AUXILIARY(DIMENSIONLESS)
   PPP      PER PLANT PRODUCTION (SQUARE FEET/YEAR)
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A AX1.K=FIFZE(1,Ø,CPC.JK)
    AX1      AUXILIARY(DIMENSIONLESS)
    CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
A AX2.K=FIFZE(Ø,1,CPC.JK)
    AX2        AUXILIARY(DIMENSIONLESS)
    CPC      CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
A CVLCMC.K=TABHL(TCVLCMC,CRFAPSF.K/ALC.K,Ø.3,1,Ø.7)
T TCVLCMC=1.5/1
    CVLCMC   CAPITAL VERSUS LABOR COST MULTIPLIER FOR CAPITAL(DIMENSIONLESS)
    TCVLCMC  TABLE FOR CAPITAL VERSUS LABOR COST MULTIPLIER FOR CAPITAL
    CRFAPSF    COST OF REQUIRED FIXED ASSETS PER SQUARE FOOT($/SQ FT)
    ALC      AVERAGE LABOR COST($/SQUARE FOOT)
A CIFA.K=RFA.K*CVLCMC.K
    CIFA     CAPITAL INVESTED IN FIXED ASSETS($/YEAR)
    RFA      REQUIRED FIXED ASSETS ($/YEAR)
    CVLCMC   CAPITAL VERSUS LABOR COST MULTIPLIER FOR CAPITAL(DIMENSIONLESS)
A TCIFA.K=TCIFAJ.K+CIFA.K+PULSE(PIM.K-1,CPIT1,3Ø)*TCIFAJ.K+
X PULSE(PIM.K-1.4,CPIT2,3Ø)*TCIFAJ.K
    TCIFA    TOTAL CAPITAL INVESTED IN FIXED ASSETS ($/YEAR)
    TCIFAJ   TOTAL CAPITAL INVESTED IN FIXED ASSETS PREVIOUSLY ($/YEAR)
    PIM      PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
    CPIT1    CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
    CPIT2    CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
L TCIFAJ.K=TCIFA.J-DT*(TCIFA.J/DEPRT.J)
N TCIFAJ=3ØØØØØ
    TCIFAJ   TOTAL CAPITAL INVESTED IN FIXED ASSETS PREVIOUSLY ($/YEAR)
    TCIFA    TOTAL CAPITAL INVESTED IN FIXED ASSETS ($/YEAR)
    DEPRT    DEPRECIATION TIME(YEARS)
A CAPCA.K=(TCIFA.K/DEPRT.K)+TCIFA.K*INTRST.K+Ø.Ø3*PAPC.K*PPP.K*INTRST.K
    CAPCA      CAPITAL COST ANNUALLY($/YEAR)
    DEPRT    DEPRECIATION TIME(YEARS)
    TCIFA    TOTAL CAPITAL INVESTED IN FIXED ASSETS ($/YEAR)
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   INTRST   INTEREST(1/YEAR)
   PAPC     PERCIEVED AVERAGE PRECAST COST ($/SQUARE FEET)
   PPP      PER PLANT PRODUCTION (SQ.FT./YEAR)
A CAPC1.K=CAPCA.K*(RLF1.K/TLRF.K)
   CAPC1    CAPITAL COST IN THE LOW COST HOUSING MARKET($/SQ FT)
   CAPCA      CAPITAL COST ANNUALLY($/YEAR)
   RLF1     REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
A CAPC2.K=CAPCA.K*(RLF2.K/TLRF.K)
   CAPC2    CAPITAL COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
   CAPCA      CAPITAL COST ANNUALLY($/YEAR)
   RLF2     REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
A CAPC3.K=CAPCA.K*(RLF3.K/TLRF.K)
   CAPC3    CAPITAL COST IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
   CAPCA    CAPITAL COST ANNUALLY($/YEAR)
   RLF3     REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
A CAPCC.K=CAPCA.K*(FLM.K/TLRF.K)
   CAPCC      CAPITAL COST FOR COMPONENTS($/YEAR)
   CAPCA    CAPITAL COST ANNUALLY($/YEAR)
   FLM      FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
NOTE
NOTE COST OF LABOR
NOTE
A PATML.K=TABLE(TPATML,PAT.K,5,11.25,1.25)
T TPATML=1/0.88/0.793/0.719/0.657/0.6
   PATML    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTILPIER FOR LABOR (DIM.LESS)
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS OF TECHNOLOGY)
   TPATML   TABLE FOR PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR
            LABOR
            LABOR
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A PPMML.K=TABLE(TPPMML,PPM.K,5,11.25,1.25)
T TPPMML=1/1.13/1.26/1.39/1.52/1.65
   PPMML    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR LABOR (DIM.LESS)
   TPPMML   TABLE FOR PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR
            LABOR
   PPM    PRODUCT PERFORMANCE AND MARKETABILITY(UNITS OF PERFORMANCE)
A CVLCML.K=FIFZE(CVLCMLJ.K,TABHL(TCVLCML,CRFAPSF.K/ALC.K,Ø.3,1,Ø.7),
X CRFAPSF.K)
T TCVLCML=Ø.5/1
   CVLCML     CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR(DIMENSIONLESS)
   CVLCMIJ  CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR PREVIOUSLY
   TCVLCML  TABLE FOR CAPITAL VERSUS LABOR COST MULTIPLIFR FOR LABOR
   CRFAPSF    COST OF REQUIRED FIXED ASSETS PER SQUARE FOOT($/SQ FT)
   ALC      AVERAGE LABOR COST($/SQUARE FOOT)
L CVLCMLJ.K=CVLCML.J
N CVLCMLJ=1
   CVLCMIJ  CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR PREVIOUSLY
   CVLCML     CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR(DIMENSIONLESS)
A PML.K=1/EXP(Ø.015*(TIME.K-196Ø))
   PML      PRODUCTIVITY MULTIPLIER FOR LABOR (DIM.LESS)
A LM.K=PML.K*PATML.K*PPMML.K
   LM       LABOR MULTIPLIER(DIMENSIONLESS)
   PML      PRODUCTIVITY MULTIPLIER FOR LABOR (DIM.LESS)
   PATML    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTILPIER FOR LABOR (DIM.LESS)
   PPMML    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR LABOR (DIM.LESS)
A FLM.K=LM.K*CVLCML.K*FIFGE(LB.K,LA.K,PPC.K,1.Ø4E6)
   FLM      FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
   LM       LABOR MULTIPLIER(DIMENSIONLESS)
   CVLCML     CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR(DIMENSIONLESS)
   LB       LABOR(MANHOURS/SQ FT)
   LA       LABOR(MANHOURS/SQ FT)
   PPC      PER PLANT CAPACITY(SQ FT/YEAR)
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A LA.K=(64680/(6.5*PPP.K))*TABLE(TLA,PPC.K,Ø,600000,60000)
T TLA=Ø/1/1.6/2.3/3/3.87/4.4/5.1/5.9/6.5/7.4
   LA        LABOR(MANHOURS/SQ FT)
   PPP       PER PLANT PRODUCTION (SQ.FT./YEAR)
   TLA       TABLE FOR LABOR
   PPC       PER PLANT CAPACITY(SQ FT/YEAR)
A LB.K=(64680/(6.5*PPP.K))*TABLE(TLB,PPC.K,6E5,51E5,5E5)
T TLB=7.4/11.64/14.71/16.93/18.53/19.69/20.39/20.9/21.27/21.54
   LB        LABOR(MANHOURS/SQ FT)
   PPP       PER PLANT PRODUCTION(SQ FT/YEAR)
   TLB       TABLE FOR LABOR
   PPC       PER PLANT CAPACITY(SQ FT/YEAR)
A RLF1.K=FLM.K*TABLE(TRLF1,PIC.K,1,3,1)
T TRLF1=1/1.2/1.3
   RLF1      REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
   FLM       FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
   TRLF1     TABLE FOR REQUIRED LABOR IN THE FACTORY FOR LOW COST HOUSING
   PIC       PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLS1.K=LM.K*TABLE(TRLS1,PIC.K,1,3,1)*Ø.144
T TRLS1=1/2.27/2.27
   PLS1      REQUIRED LABOR ON SITE FOR LOW-COST HOUSING (MANHOURS/SQUARE FEET)
   LM        LABOR MULTIPLIER(DIMENSIONLESS)
   TRLS1     TABLE FOR REQUIRED LABOR ON SITE FOR LOW COST HOUSING
   PIC       PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLF2.K=FLM.K*TABLE(TRLF2,PIC.K,1,3,1)
T TRLF2=1/1.68/1.82
   RLF2      REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
   FLM       FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
   TRLF2     TABLE FOR REQUIRED LABOR IN THE FACTORY FOR HIGH COST HOUSING
   PIC       PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLS2.K=LM.K*TABLE(TPLS2,PIC.K,1,3,1)*Ø.144
T TPLS2=1/3.78/3.78
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   PLS2     REQUIRED LABOR ON SITE FOR HIGH-COST HOUSING (MANHOURS/SQUARE FEET)
   LM       LABOR MULTIPLIER (DIM.LESS)
   TRLS2    TABLE FOR REQUIRED LABOR ON SITE FOR HIGH COST HOUSING
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLF3.K=FLM.K*TABLE(TRLF3,PIC.K,1,3,1)
T TRLF3=1/1.63/1.76
   RLF3     REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/
   FLM      FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
   TRLF3    TABLE FOR REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLS3.K=LM.K*TABLE(TRLS3,PIC.K,1,3,1)*0.144
T TRLS3=1/3.16/3.16
   RLS3     REQUIRED LABOR ON SITE FOR NON-HOUSING BUILDINGS (MANHOURS/SQ.FT.)
   LM       LABOR MULTIPLIER (DIM.LESS)
   TRLS3    TABLE FOR REQUIRED LABOR ON SITE FOR NON-HOUSING BUILDINGS
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A LRC.K=TABHL(TLRC,TIME.K,1960,1985,25)
T TLRC=1.3/1.1
   LRC      LABOR RESISTANCE COEFFICIENT(DIMENSIONLESS)
   TLRC     TABLE FOR LABOR RESISTANCE COEFFICIENT
A LWF.K=2.81*TABLE(TLWF,TIME.K,1960,1985,1)
T TLWF=0.786/0.815/0.845/0.87/0.9/0.915/0.95/1/1.07/1.142/1.221/
X 1.33/1.39/1.46/1.53/1.60/1.68/1.76/1.84/1.93/2.02/2.12/2.22/2.32
X /2.43/2.55
   LWF      LABOR WAGES IN THE FACTORY($/HOUR)
   TLWF     TABLE FOR LABOR WAGES IN THE FACTORY
A LC1.K=LRC.K*(RLF1.K*LWF.K+RLS1.K*LWC.K)
   LC1      LABOR COST IN THE LOW COST HOUSING MARKET($/SQ FT)
   LRC      LABOR RESISTANCE COEFFICIENT(DIMENSIONLESS)
   RLF1     REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
   LWF      LABOR WAGES IN THE FACTORY($/HOUR)
   RLS1     REQUIRED LABOR ON SITE FOR LOW-COST HOUSING (MANHOURS/SQUARE FEET)
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   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
A LC2.K=LRC.K*(RLF2.K*LWF.K+RLS2.K*LWC.K)
   LC2      LABOR COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
   LRC      LABOR RESISTANCE COEFFICIENT(DIMENSIONLESS)
   RLF2     REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
   LWF      LABOR WAGES IN THE FACTORY ($/HOUR)
   RLS2     REQUIRED LABOR ON SITE FOR HIGH-COST HOUSING (MANHOURS/SQUARE FEET)
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
A LC3.K=LRC.K*(RLF3.K*LWF.K+RLS3.K*LWC.K)
   LC3      LABOR COST IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
   LRC      LABOR RESISTANCE COEFFICIENT (DIM.LESS)
   RLF3     REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/
            SQUARE FEET)
   RLS3     REQUIRED LABOR ON SITE FOR NON-HOUSING BUILDINGS (MANHOURS/SQ.FT.)
A TLRF.K=RLF1.K*PPP1.K+RLF2.K*PPP2.K+RLF3.K*PPP3.K+(PPP.K-(PPP1.K+PPP2.K
X +PPP3.K))*FLM.K
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
   RLF1     REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
   PPP1     PER PLANT PRODUCTION OF LOW-COST HOUSING (SQUARE FEET/YEAR)
   RLF2     REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
   PPP2     PER PLANT PRODUCTION OF HIGH COST HOUSING (SQUARE FEET/YEAR)
   RLF3     REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/
   PPP3     PER PLANT PRODUCTION OF NON-HOUSING BUILDINGS (SQUARE FEET/YEAR)
   PPP      PER PLANT PRODUCTION(SQ FT/YEAR)
   FLM      FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
A ALC.K=SMOOTH((LWF.K*LRC.K*TLRF.K)/PPP.K,1)
N ALC=Ø.5
   ALC      AVERAGE LABOR COST($/SQUARE FOOT)
   LWF      LABOR WAGES IN THE FACTORY ($/HOUR)
   LRC      LABOR RESISTANCE COEFFICIENT (DIM.LESS)
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
   PPP      PER PLANT PRODUCTION(SQ FT/YEAR)
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A LCC.K=(FLM.K*LWF.K+LM.K*0.144*LWC.K)*LRC.K
   LCC      LABOR COST FOR COMPONENTS($/SQ FT)
   FLM      FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
   LWF      LABOR WAGES IN THE FACTORY ($/HOUR)
   LM       LABOR MULTIPLIER (DIM.LESS)
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
   LRC      LABOR RESISTANCE COEFFICIENT (DIM.LESS)
NOTE
NOTE COST OF MATERIALS
NOTE
A MATC.K=3.015*TABLE(TMATC,TIME.K,1960,1985,1)
T TMATC=0.811/0.806/0.838/0.89/0.956/0.981/0.988/1/1.056/1.119/1.125
X /1.119/1.223/1.265/1.30/1.338/1.375/1.415/1.455/1.495/1.54/1.585/
X 1.63/1.675/1.72/1.77
   MATC     MATERIALS COST($/SQ FT)
   TMATC    TABLE FOR MATERIAL COST
A MATCM.K=TABHL(TMATCM,PPP.K,1E6,5E6,4E6)
T TMATCM=1/0.8
   MATCM    MATERIALS COST MULTIPLIER(DIMENSIONLESS)
   TMATCM   TABLE FOR MATERIAL COST MULTIPLIER
   PPP      PER PLANT PRODUCTION(SQ FT/YEAR)
A MATC1.K=MATC.K*MATCM.K*TABLE(TPIML1,PIC.K,1,3,1)
T TPIML1=1/1.57/2.23
   MATC1    MATERIALS COST IN THE LOW COST HOUSING MARKET($/SQ FT)
   MATC     MATERIALS COST($/SQ FT)
   MATCM    MATERIALS COST MULTIPLIER(DIMENSIONLESS)
   TPIML1   TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE LOW COST
            HOUSING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A MATC2.K=MATC.K*MATCM.K*TABLE(TPIML2,PIC.K,1,3,1)
T TPIML2=1/2.25/3.22
   MATC2    MATERIALS COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
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    MATC     MATERIALS COST($/SQ FT)
    MATCM    MATERIALS COST MULTIPLIER(DIMENSIONLESS)
    TPIML2   TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE HIGH COST HOUSING
             MARKET
    PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A MATC3.K=MATC.K*MATCM.K*TABLE(TPIML3,PIC.K,1,3,1)
T TPIML3=1/1.98/3.Ø1
    MATC3    MATERIALS COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
    MATC     MATERIAL COST ($/SQ.FT.)
    MATCM    MATERIAL COST MULTIPLIER (DIM.LESS)
    TPIML3   TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE NON-HOUSING
             BUILDING MARKET
    PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A MATCC.K=MATC.K*MATCM.K
    MATCC    MATERIALS COST FOR COMPONENTS($/SQ FT)
    MATC     MATERIAL COST ($/SQ.FT.)
    MATCM    MATERIAL COST MULTIPLIER (DIM.LESS)
NOTE
NOTE OVERHEAD COSTS
NOTE
A FOOH.K=PATMO.K*PPMMO.K*PIML.K*FIFGE(FOOHB.K,FOOHA.K,PPC.K,6ØØE3)+
X IF.K/NP.K
    FOOH     FACTORY OPERATING OVERHEAD($)
    PATMO    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD (DIM.LESS)
    PPMMO    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR OVERHEAD
             (DIMENSIONLESS)
    PIML     PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
    FOOHB    FACTORY OPERATING OVERHEAD($)
    FOOHA    FACTORY OPERATING OVERHEAD($)
    PPC      PER PLANT CAPACITY(SQ FT/YEAR)
    IF       INDUSTRIAL FUNDS ($/YEAR)
    NP       NUMBER OF PLANTS(DIMENSIONLESS)
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A PATMO.K=TABLE(TPATMO,PAT.K,5,11.25,1.25)
T TPATMO=1/0.88/0.793/0.719/0.657/0.6
   PATMO    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD (DIM.LESS)
   TPATMO   TABLE FOR THE PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR
            OVERHEAD
   PAT      PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS OF TECHNOLOGY)
A PPMMO.K=TABLE(TPPMMO,PPM.K,5,11.25,1.25)
T TPPMMO=1/1.13/1.26/1.39/1.52/1.65
   PPMMO    PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR OVERHEAD
            (DIMENSIONLESS)
   TPPMMO   TABLE FOR PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR
            OVERHEAD
   PPM    PRODUCT PERFORMANCE AND MARKETABILITY(UNITS OF PERFORMANCE)
A FOOHA.K=TABLE(TFOOHA,PPC.K,0,600000,60000)*(357000/6.24)*IML.K
T TFOOHA=0/1/1.91/2.576/3.228/3.883/4.476/5.084/5.66/6.24/6.838
   FOOHA    FACTORY OPERATING OVERHEAD($)
   TFOOHA   TABLE FOR FACTORY OPERATING OVERHEAD
   PPC      PER PLANT CAPACITY(SQ FT/YEAR)
   IML      INFLATION MULTIPLIER(DIMENSIONLESS)
A IML.K=TABLE(TIML,TIME.K,1960,1985,1)
T TIML=0.887/0.896/0.906/0.917/0.929/0.945/0.972/1/1.042/1.098/1.163
X /1.21/1.257/1.288/1.32/1.351/1.388/1.42/1.453/1.49/1.525/1.562/
X 1.6/1.64/1.68/1.72
   IML      INFLATION MULTIPLIER(DIMENSIONLESS)
   TIML     TABLE FOR INFLATION MULTIPLIER
A FOOHB.K=TABLE(TFOOHB,PPC.K,6E5,51E5,5E5)*(357000/6.24)*IML.K
T TFOOHB=6.838/10.398/12.966/14.788/16.18/17.14/17.84/18.2/18.49/18.7
   FOOHB    FACTORY OPERATING OVERHEAD($)
   TFOOHB   TABLE FOR FACTORY OPERATING OVERHEAD
   PPC      PER PLANT CAPACITY (SQ.FT./YEAR)
   IML      INFLATION MULTIPLIER(DIMENSIONLESS)
A PIML.K=TABLE(TPIML,PIC.K,1,3,1)
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T TPIML=1/1.4/1.6
   PIML     PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
   TPIML    TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A TRANSPC.K=0.2456*PATMO.K*TABLE(TEPI,TIME.K,1960,1985,1)*PIML.K
   TRANSPC  TRANSPORTATION COST($/SQ FT)
   PATMO    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD
            (DIMENSIONLESS)
   TEPI     TABLE FOR EQUIPMENT PRICE INDEX
   PIML     PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)
A SO.K=0.2494*PATMO.K*TABLE(TEPI,TIME.K,1960,1985,1)*PIML.K
T TEPI=0.858/0.888/0.888/0.9/0.915/0.935/0.965/1/1.05/1.091/1.141/
X 1.216/1.254/1.294/1.333/1.374/1.417/1.46/1.5/1.55/1.6/1.65/
X 1.703/1.758/1.813/1.87
   SO       SITE OVERHEAD($/SQ FT)
   PATMO    PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD
            (DIMENSIONLESS)
   TEPI     TABLE FOR EQUIPMENT PRICE INDEX
   PIML     PERCENT INDUSTRIALIZED MULTIPLIER(DIMENSIONLESS)
A OC1.K=FOOH.K*(RLF1.K/TLRF.K)+TRANSPC.K+SO.K
   OC1      OVERHEAD COST IN THE LOW-COST HOUSING MARKET ($/SQUARE FEET)
   FOOH     FACTORY OPERATING OVERHEAD($)
   RLF1     REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
   TRANSPC  TRANSPORTATION COST($/SQ FT)
   SO       SITE OVERHEAD($/SQ FT)
A OC2.K=FOOH.K*(RLF2.K/TLRF.K)+TRANSPC.K+SO.K
   OC2      OVERHEAD COST IN THE HIGH-COST HOUSING MARKET ($/SQUARE FEET)
   FOOH     FACTORY OPERATING OVERHEAD($)
   RLF2     REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
   TLRF     TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
   TRANSPC  TRANSPORTATION COST($/SQ FT)
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    SO        SITE OVERHEAD($/SQ FT)
A  OC3.K=FOOH.K*(RLF3.K/TLRF.K)+TRANSPC.K+SO.K
    OC3       OVERHEAD COST IN THE NON-HOUSING BUILDING MARKET ($/SQUARE FEET)
    FOOH      FACTORY OPERATING OVERHEAD($)
    RLF3      REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/
    TLRF      TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
    TRANSPC   TRANSPORTATION COST ($/SQ.FT.)
    SO        SITE OVERHEAD($/SQ FT)
A  OCC.K=FOOH.K*(FLM.K/TLRF.K)+(TRANSPC.K+SO.K)/PIML.K
    OCC       OVERHEAD COST FOR COMPONENTS ($/SQUARE FEET)
    FOOH      FACTORY OPERATING OVERHEAD($)
    FLM       FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
    TLRF      TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
    TRANSPC   TRANSPORTATION COST ($/SQ.FT.)
    SO        SITE OVERHEAD ($/SQ.FT.)
    PIML      PERCENT INDUSTRIALIZED MULTIPLIER(DIMENSIONLESS)
NOTE
NOTE TOTAL PRECAST COST
NOTE
A  TPC1.K=CAPC1.K+LC1.K+MATC1.K+OC1.K
    TPC1      TOTAL PRECAST COST IN THE LOW COST HOUSING MARKET($/SQ FT)
    CAPC1     CAPITAL COST IN THE LOW COST HOUSING MARKET($/SQ FT)
    LC1       LABOR COST IN THE LOW COST HOUSING MARKET($/SQ FT)
    MATC1     MATERIALS COST IN THE LOW COST HOUSING MARKET($/SQ FT)
    OC1       OVERHEAD COST IN THE LOW-COST HOUSING MARKET ($/SQUARE FEET)
A  TPC2.K=CAPC2.K+LC2.K+MATC2.K+OC2.K
    TPC2      TOTAL PRECAST COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
    CAPC2     CAPITAL COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
    LC2       LABOR COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
    MATC2     MATERIALS COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
    OC2       OVERHEAD COST IN THE HIGH-COST HOUSING MARKET ($/SQUARE FEET)
A  TPC3.K=CAPC3.K+LC3.K+MATC3.K+OC3.K
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   TPC3     TOTAL PRECAST COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
   LC3      LABOR COST IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
   MATC3    MATERIALS COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
   OC3      OVERHEAD COST IN THE NON-HOUSING BUILDING MARKET ($/SQUARE FEET)
A APC.K=(1.275*TPC1.K*MARKT1.K*DSM1.K+1.275*TPC2.K*MARKT2.K*DSM2.K+
X TPC3.K*MARKT3.K*DSM3.K)/DBS.K
   APC      AVERAGE PRECAST COST($/SQ FT)
   TPC1     TOTAL PRECAST COST IN THE LOW COST HOUSING MARKET($/SQ FT)
   MARKT1   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW-COST RANGE
            (SQ.FT./YEAR)
   DSM1     DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
   TPC2     TOTAL PRECAST COST IN THE HIGH-COST HOUSING MARKET ($/SQ.FT.)
   MARKT2   MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH-COST RANGE
            (SQ.FT./YEAR)
   DSM2     DEMANDED SHARE OF THE MARKET FOR HIGH COST HOUSING(DIMENSIONLESS)
   TPC3     TOTAL PRECAST COST IN THE NON-HOUSING BUILDING MARKET ($/SQ.FT.)
   MARKT3   MARKET FOR CONCRETE NON-HOUSING BUILDINGS (SQ.FT./YEAR)
   DSM3     DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS
   DBS      DEMANDED BUILDING SYSTEMS(SQ FT/YEAR)
A PAPC.K=SMOOTH(APC.K,1)
N PAPC=5.93
   PAPC     PERCIEVED AVERAGE PRECAST COST ($/SQUARE FEET)
   APC      AVERAGE PRECAST COST($/SQ FT)
A TCC.K=CAPCC.K+LCC.K+MATCC.K+OCC.K
   TCC      TABLE FOR COST ($/SQUARE FEET)
   CAPCC      CAPITAL COST FOR COMPONENTS($/YEAR)
   LCC      LABOR COST FOR COMPONENTS($/SQ FT)
   MATCC    MATERIALS COST FOR COMPONENTS($/SQ FT)
   OCC      OVERHEAD COST FOR COMPONENTS ($/SQUARE FEET)
NOTE
NOTE CONVENTIONAL CONCRETE INDUSTRY
NOTE
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NOTE COST OF LABOR
NOTE
A PMLC.K=1/EXP(0.01*(TIME.K-1960))
   PMLC     PRODUCTIVITY MULTIPLIER FOR LABOR IN CONVENTIONAL CONSTRUCTION
            (DIMENSIONLESS)
A MML.K=TABHL(TMML,SMOOTH(PSM.K,1),0.12,0.6,0.48)
N MML=1
T TMML=1/0.5
   MML      MECHANIZATION MULTIPLIER FOR LABOR(DIMENSIONLESS)
   TMML     TABLE FOR MECHANIZATION MULTIPLIER
   PSM      PRECAST'S SHARE OF ITS MAIN BUILDING MARKETS (DIM.LESS)
A RLC1.K=0.575*PMLC.K*MML.K*TABLE(TRLC1,PIC.K,1,3,1)
T TRLC1=1/1.82/2.72
   RLC1     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE LOW-COST HOUSING
            MARKET (MANHOURS/SQUARE FEET)
   PMLC     PRODUCTIVITY MULTIPLIER FOR LABOR IN CONVENTIONAL CONSTRUCTION
            (DIMENSIONLESS)
   MML      MECHANIZATION MULTIPLIER FOR LABOR(DIMENSIONLESS)
   TRLC1    TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE
            LOW COST HOUSING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLC2.K=0.575*PMLC.K*MML.K*TABLE(TRLC2,PIC.K,1,3,1)
T TRLC2=1/2.8/4.23
   RLC2     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE HIGH-COST HOUSING
            MARKET (MANHOURS/SQUARE FEET)
   PMLC     PRODUCTIVITY MULTIPLIER FOR LABOR IN CONVENTIONAL CONSTRUCTION
            (DIMENSIONLESS)
   MML      MECHANIZATION MULTIPLIER FOR LABOR(DIMENSIONLESS)
   TRLC2    TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION
            COST HOUSING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A RLC3.K=0.575*PMLC.K*MML.K*TABLE(TRLC3,PIC.K,1,3,1)
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T TRLC3=1/2.4/3.82
   RLC3     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDING MARKET (MANHOURS/SQUARE FEET)
   PMLC     PRODUCTIVITY MULTIPLIER FOR LABOR IN CONVENTIONAL CONSTRUCTION
            (DIMENSIONLESS)
   MML      MECHANIZATION MULTIPLIER FOR LABOR (DIM.LESS)
   TRLC3    TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE
            NON-HOUSING BUILDINGS MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A LWC.K=4.09*TABLE(TLWC,TIME.K,1960,1985,1)
T TLWC=0.754/0.784/0.813/0.842/0.873/0.909/0.947/1/1.066/1.154/
X 1.288/1.438/1.59/1.74/1.88/2.01/2.13/2.24/2.35/2.47/2.60/2.73/2.87
X /3.01/3.16/3.32
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
   TLWC     TABLE FOR LABOR WAGES IN CONVENTIONAL CONSTRUCTION
A LCC1.K=RLC1.K*LWC.K
   LCC1     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE LOW COST HOUSING
            MARKET($/SQ FT)
   RLC1     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE LOW-COST HOUSING
            MARKET (MANHOURS/SQUARE FEET)
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
A LCC2.K=RLC2.K*LWC.K
   LCC2     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE HIGH COST
            HOUSING MARKET($/SQ FT)
   RLC2     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE HIGH-COST HOUSING
            MARKET (MANHOURS/SQUARE FEET)
   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
A LCC3.K=RLC3.K*LWC.K
   LCC3     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDINGS MARKET($/SQ FT)
   RLC3     REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDING MARKET (MANHOURS/SQUARE FEET)
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   LWC      LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
NOTE
NOTE COST OF MATERIALS
NOTE
A MATCC1.K=MATC.K*TABLE(TPCM1,PIC.K,1,3,1)
T TPCM1=1/1.57/2.23
   MATCC1   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR LOW COST
            HOUSING($/SQ FT)
   MATC     MATERIAL COST ($/SQ.FT.)
   TPCM1    TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE LOW COST
            HOUSING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A MATCC2.K=MATC.K*TABLE(TPCM2,PIC.K,1,3,1)
T TPCM2=1/2.25/3.22
   MATCC2   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR HIGH COST
            HOUSING($/SQ FT)
   MATC     MATERIAL COST ($/SQ.FT.)
   TPCM2    TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE HIGH COST
            HOUSING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A MATCC3.K=MATC.K*TABLE(TPCM3,PIC.K,1,3,1)
T TPCM3=1/1.98/3.01
   MATCC3   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR NON-HOUSING
            BUILDINGS($/SQ FT)
   MATC     MATERIAL COST ($/SQ.FT.)
   TPCM3    TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE NON-HOUSIN
            BUILDING MARKET
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
NOTE
NOTE OVERHEAD COSTS
NOTE
A EOCC.K=0.12*TABLE(TEPI,TIME.K,1960,1985,1)*MME.K
```

```
   EQCC     EQUIPMENT COST IN CONVENTIONAL CONSTRUCTION($/SQ FT)
   TEPI     TABLE FOR EQUIPMENT PRICE INDEX
   MME      MECHANIZATION MULTIPLIER FOR EQUIPMENT(DIMENSIONLESS)
A MME.K=TABHL(TMME,SMOOTH(PSM.K,1),0.12,0.6,0.48)
N MME=1
T TMME=1/2
   MME      MECHANIZATION MULTIPLIER FOR EQUIPMENT(DIMENSIONLESS)
   TMME     TABLE FOR MECHANIZATION MULTIPLIER FOR EQUIPMENT
   PSM      PRECAST'S SHARE OF ITS MAIN BUILDING MARKETS (DIM.LESS)
A OCC1.K=4.85*EQCC.K*TABLE(TOCC1,PIC.K,1,3,1)
T TOCC1=1/1.68/2.43
   OC1      OVERHEAD COST IN THE LOW-COST HOUSING MARKET ($/SQUARE FEET)
   EQCC     EQUIPMENT COST IN CONVENTIONAL CONSTRUCTION($/SQ FT)
   TOCC1    TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION FOR
            LOW COST HOUSING
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A OCC2.K=4.85*EQCC.K*TABLE(TOCC2,PIC.K,1,3,1)
T TOCC2=1/2.48/3.60
   OCC2  OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/
            SQUARE FEET)
   EQCC     EQUIPMENT COST IN CONVENTIONAL CONSTRUCTION($/SQ FT)
   TOCC2    TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION FOR
            HIGH COST HOUSING
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
A OCC3.K=4.85*EQCC.K*TABLE(TOCC3,PIC.K,1,3,1)
T TOCC3=1/2.14/3.33
   OCC3     OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDING MARKET ($/SQUARE FEET)
   TOCC3    TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION  FOR
            NON-HOUSING BUILDINGS
   PIC      PERCENT INDUSTRIALIZED COEFFICIENT(DIMENSIONLESS)
NOTE
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```
NOTE TOTAL COST IN CONVENTIONAL CONSTRUCTION
NOTE
A TCC1.K=LCC1.K+MATCC1.K+OCC1.K
   TCC1     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/
            SQUARE FEET)
   LCC1     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE LOW COST HOUSING
            MARKET($/SQ FT)
   MATCC1   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR LOW COST
            HOUSING($/SQ FT)
   OCC1     OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/
            SQUARE FEET)
A TCC2.K=LCC2.K+MATCC2.K+OCC2.K
   TCC2     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/
            SQUARE FEET)
   LCC2     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE HIGH COST
            HOUSING MARKET($/SQ FT)
   MATCC2   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR HIGH COST
            HOUSING($/SQ FT)
   OCC2  OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/
            SQUARE FEET)
A TCC3.K=LCC3.K+MATCC3.K+OCC3.K
   TCC3     TOTAL COST IN CONVENTIONAL CONSTRUCTION IN NON-HOUSING BUILDING ($/
            SQUARE FEET)
   LCC3     LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDINGS MARKET($/SQ FT)
   MATCC3   MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR NON-HOUSING
            BUILDINGS($/SQ FT)
   OCC3     OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING
            BUILDING MARKET ($/SQUARE FEET)
NOTE
NOTE
NOTE CONTROL CARDS
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```
N TIME=1960
C DT=0.01
C LENGTH=1985
      END
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2 GLOSSARY OF TERMS IN COMPUTER PROGRAM

A	AUXILIARY(DIMENSIONLESS)
ALC	AVERAGE LABOR COST($/SQUARE FOOT)
ALPC	AVERAGE LIFETIME OF PLANT CAPACITY(YEARS)
APC	AVERAGE PRECAST COST($/SQ FT)
ASE	ABSOLUTE SUM OF ERRORS(SQUARE FEET)
ASE	ABSOLUTE SUM OF ERRORS(SQUARE FEET)
ASEJ	ABSOLUTE SUM OF ERRORS PREVIOUSLY(SQUARE FEET)
AX	AUXILIARY (SQ.FT./YEAR)
AXJ	AUXILIARY PREVIOUSLY(SQ FT/YEAR)
AUXC	AUXILIARY FOR COSTS(1/(SQ FT)X(SQ FT))
AUXQ	AUXILIARY FOR QUALITY(1/UNITS OF PERFORMANCE SQUARED)
AX1	AUXILIARY(DIMENSIONLESS)
AX2	AUXILIARY(DIMENSIONLESS)
BM	BRIDGE MARKET($/YEAR)
C	COUNTER(DIMENSIONLESS)
CA	CAPITAL($/SQ FT)
CAPC1	CAPITAL COST IN THE LOW COST HOUSING MARKET($/SQ FT)
CAPC2	CAPITAL COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
CAPC3	CAPITAL COST IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
CAPCA	CAPITAL COST ANNUALLY($/YEAR)
CAPCC	CAPITAL COST FOR COMPONENTS($/YEAR)
CB	CAPITAL($/SQ FT)
CC	CONVERSION COEFFICIENT(1/$/SQ FT)
CF	CONSUMER FUNDS($/YEAR)
CIFA	CAPITAL INVESTED IN FIXED ASSETS($/YEAR)
CJ	COUNTER PREVIOUSLY(DIMENSIONLESS)
CPAT	CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS TECHNOLOGY/YEAR)
CPC	CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
CPCA	CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)
CPCB	CHANGE IN PRODUCTION CAPACITY(SQ FT/YEAR/YEAR)

CPIT1	CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
CPIT2	CHANGE IN PERCENT INDUSTRIALIZED TIME (YEARS)
CPPM	CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY (UNITS PERFORMANCE/YEAR)
CRFAPSF	COST OF REQUIRED FIXED ASSETS PER SQUARE FOOT($/SQ FT)
CVLCMC	CAPITAL VERSUS LABOR COST MULTIPLIER FOR CAPITAL(DIMENSIONLESS)
CVLCML	CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR(DIMENSIONLESS)
CVLCMIJ	CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR PREVIOUSLY (DIMENSIONLESS)
DBS	DEMANDED BUILDING SYSTEMS(SQ FT/YEAR)
DEFL	DEFLATOR(DIMENSIONLESS)
DEPRT	DEPRECIATION TIME(YEARS)
DMV1	DIFFERENCE IN MEAN VALUE OF COSTS IN THE LOW-COST HOUSING MARKET($/SQ FT)
DMV2	DIFFERENCE IN MEAN VALUE OF COSTS IN THE HIGH-COST HOUSING MARKET($/SQ FT)
DMV3	DIFFERENCE IN MEAN VALUE OF COSTS IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
DMVQ	DIFFERENCE IN MEAN VALUES OF QUALITY(UNITS PERFORMANCE)
DNBPM	DEMAND FOR NON-BUILDING PRECAST MARKET(SQ FT)
DPC	DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
DPC1	DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
DPC2	DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
DPC3	DESIRED PRODUCTION CAPACITY(SQ FT/YEAR)
DPCBM	DEMAND FOR PRECAST COMPONENTS IN THE BUILDING MARKET(SQ FT/YEAR)
DPQ	DELAY IN PERCEIVING QUALITY(YEARS)
DPS	DELAY IN PERCEIVING SAVINGS(YEARS)
DSBM	DEMANDED SHARE OF THE BRIDGE MARKET(DIMENSIONLESS)
DSBMPC	DEMANDED SHARE OF THE BUILDING MARKET FOR PRECAST COMPONENTS (DIMENSIONLESS)
DSM1	DEMANDED SHARE OF THE MARKET FOR LOW COST HOUSING(DIMENSIONLESS)
DSM2	DEMANDED SHARE OF THE MARKET FOR HIGH-COST HOUSING(DIMENSIONLESS)

DSN3	DEMANDED SHARE OF THE MARKET FOR NON-HOUSING BUILDINGS (DIM.LESS)
EM	EXPANSION MULTIPLIER(DIMENSIONLESS)
EQCC	EQUIPMENT COST IN CONVENTIONAL CONSTRUCTION($/SQ FT)
ER	ERROR(SQ FT/YEAR)
F	FRACTION(DIMENSIONLESS)
FCPAT	FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
FCPPM	FUNDS FOR CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY($/YEAR)
FLM	FACTORY-LABOR MULTIPLIER(MANHOURS/SQ FT)
FM	FRACTION OF THE MARKET(DIMENSIONLESS)
FOOH	FACTORY OPERATING OVERHEAD($)
FOOHA	FACTORY OPERATING OVERHEAD($)
FOOHB	FACTORY OPERATING OVERHEAD($)
FORD	FORECASTED DEMAND(SQ FT/YEAR)
FRAD	FUNDS FOR RESEARCH AND DEVELOPMENT($/YEAR)
GF	GOVERNMENTAL FUNDS($/YEAR)
GHM	GROWTH IN THE HOUSING MARKET(DIMENSIONLESS)
GNHBM	GROWTH IN THE NON-HOUSING BUILDINGS MARKET(DIMENSIONLESS)
IECI	INDUSTRIAL EQUIPMENT COST INDEX(DIMENSIONLESS)
IF	INDUSTRIAL FUNDS($/YEAR)
IML	INFLATION MULTIPLIER(DIMENSIONLESS)
INTRST	INTEREST(1/YEAR)
LA	LABOR(MANHOURS/SQ FT)
LB	LABOR(MANHOURS/SQ FT)
LC1	LABOR COST IN THE LOW COST HOUSING MARKET($/SQ FT)
LC2	LABOR COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
LC3	LABOR COST IN THE NON-HOUSING BUILDING MARKET($/SQ FT)
LCC	LABOR COST FOR COMPONENTS($/SQ FT)
LCC1	LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE LOW COST HOUSING MARKET($/SQ FT)
LCC2	LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE HIGH COST HOUSING MARKET($/SQ FT)
LCC3	LABOR COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING

	BUILDINGS MARKET($/SQ FT)
LM	LABOR MULTIPLIER(DIMENSIONLESS)
LRC	LABOR RESISTANCE COEFFICIENT(DIMENSIONLESS)
LWC	LABOR WAGES IN CONVENTIONAL CONSTRUCTION($/HOUR)
LWF	LABOR WAGES IN THE FACTORY($/HOUR)
M	MULTIPLIER(1/$)
MARKT1	MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE (SQ FT/YEAR)
MARKT2	MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST RANGE (SQ FT/YEAR)
MARKT3	MARKET FOR CONCRETE NON-HOUSING BUILDINGS(SQ FT/YEAR)
MARKT1J	MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE LOW COST RANGE LAST YEAR(SQ FT)
MARKT2J	MARKET FOR CONCRETE MULTI-UNIT HOUSING IN THE HIGH COST RANGE LAST YEAR(SQ FT)
MARKT3J	MARKET FOR CONCRETE NON-HOUSING BUILDINGS LAST YEAR(SQ FT)
MATC	MATERIALS COST($/SQ FT)
MATC1	MATERIALS COST IN THE LOW COST HOUSING MARKET($/SQ FT)
MATC2	MATERIALS COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
MATC3	MATERIALS COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
MATCC	MATERIALS COST FOR COMPONENTS($/SQ FT)
MATCC1	MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR LOW COST HOUSING($/SQ FT)
MATCC2	MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR HIGH COST HOUSING($/SQ FT)
MATCC3	MATERIALS COST IN CONVENTIONAL CONSTRUCTION FOR NON-HOUSING BUILDINGS($/SQ FT)
MATCM	MATERIALS COST MULTIPLIER(DIMENSIONLESS)
ML	MULTIPLIER(1/$)
MLTP	MULTIPLIER(DIMENSIONLESS)
MLV	MATURATION LEVEL(UNITS OF PERFORMANCE)
MM	MAINTENANCE MULTIPLIER(DIMENSIONLESS)

MME	MECHANIZATION MULTIPLIER FOR EQUIPMENT(DIMENSIONLESS)
MML	MECHANIZATION MULTIPLIER FOR LABOR(DIMENSIONLESS)
MRCPAT	MAGNITUDE OF REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY(UNITS OF TECHNOLOGY)
MRCPPM	MAGNITUDE OF REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY(UNITS OF PERFORMANCE)
NM	NOVELTY MULTIPLIER(DIMENSIONLESS)
NP	NUMBER OF PLANTS(DIMENSIONLESS)
OC1	OVERHEAD COST IN THE LOW-COST HOUSING MARKET ($/SQUARE FEET)
OC2	OVERHEAD COST IN THE HIGH-COST HOUSING MARKET ($/SQUARE FEET)
OC3	OVERHEAD COST IN THE NON-HOUSING BUILDING MARKET ($/SQUARE FEET)
OCC	OVERHEAD COST FOR COMPONENTS ($/SQUARE FEET)
OCC1	OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/SQUARE FEET)
OCC2	OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/SQUARE FEET)
OCC3	OVERHEAD COST IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING BUILDING MARKET ($/SQUARE FEET)
P11,P12,....P110	PROBABILITIES FOR COST.LOW-COST HOUSING
P21,P22,....P210	PROBABILITIES FOR COST.HIGH-COST. HOUSING
P31,P32,....P310	PROBABILITIES FOR COST.NON-HOUSING BUILDINGS
PAPC	PERCIEVED AVERAGE PRECAST COST ($/SQUARE FEET)
PAT	PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS OF TECHNOLOGY)
PATM	PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER (DIMENSIONLESS)
PATMC	PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR CAPITAL (DIM.LESS)
PATML	PRODUCTION AND ASSEMBLY TECHNOLOGY MULTILPIER FOR LABOR (DIM.LESS)
PATMO	PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD (DIM.LESS)
PC	PRODUCTION CAPACITY (SQUARE FEET/YEAR)
PCC1	PERCENT OF CONSTRUCTION COST IN THE LOW-COST HOUSING MARKET(DIM.LESS)
PCC2	PERCENT OF CONSTRUCTION COST IN THE HIGH-COST HOUSING MARKET (DIMENSIONLESS)
PCC3	PERCENT OF CONSTRUCTION COST IN THE NON-HOUSING BUILDING MARKET

(DIMENSIONLESS)

PCDR PRODUCTION CAPACITY DEPRECIATION RATE (SQUARE FEET/YEAR/YEAR)

PDCPSF1 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE LOW-COST HOUSING MARKET (DIMENSIONLESS)

PDCPSF2 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE HIGH-COST HOUSING MARKET (DIMENSIONLESS)

PDCPSF3 PERCENT DIFFERENCE IN COST PER SQUARE FOOT IN THE NON-HOUSING BUILDING MARKET (DIMENSIONLESS)

PDQ PERCENT DIFFERENCE IN QUALITY (DIMENSIONLESS)

PF1 PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)

PF1A PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)

PF1B PREFERENCE FUNCTION FOR THE LOW-COST HOUSING MARKET (DIM.LESS)

PF2 PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)

PF2A PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)

PF2B PREFERENCE FUNCTION FOR THE HIGH-COST HOUSING MARKET (DIM.LESS)

PF3 PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM.LESS)

PF3A PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM.LESS)

PF3B PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDING MARKET (DIM.LESS)

PGHM PERCIEVED GROWTH OF THE HOUSING MARKET (DIM.LESS)

PGNHBM PERCEIVED GROWTH IN THE NON-HOUSING BUILDING MARKET (DIM.LESS)

PIC PERCENT INDUSTRIALIZED COEFFICIENT (DIM.LESS)

PIM PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)

PIML PERCENT INDUSTRIALIZED MULTIPLIER (DIM.LESS)

PMARKT PRECAST MARKET (SQUARE FEET/YEAR)

PML PRODUCTIVITY MULTIPLIER FOR LABOR (DIM.LESS)

PMLC PRODUCTIVITY MULTIPLIER FOR LABOR IN CONVENTIONAL CONSTRUCTION (DIMENSIONLESS)

PP PUBLIC POLICY (DIM.LESS)

PPBQ PROBABILITY THAT PRECAST HAS BETTER QUALITY (DIM.LESS)

PPC PER PLANT CAPACITY (SQUARE FEET/YEAR)

PPDQ PERCIEVED PERCENT DIFFERENCE IN QUALITY (DIM.LESS)

PPLC1 PROBABILITY THAT PRECAST HAS LOWER COST IN THE LOW-COST HOUSING

MARKET (DIM•LESS)

PPLC2 PROBABILITY THAT PRECAST HAS LOWER COST IN THE HIGH-COST HOUSING MARKET (DIM•LESS)

PPLC3 PROBABILITY THAT PRECAST HAS LOWER COST IN THE NON-HOUSING BUILDING MARKET (DIM•LESS)

PPM PRODUCT PERFORMANCE AND MARKETABILITY (UNITS OF PERFORMANCE)

PPMC PRODUCT PERFORMANCE AND MARKETABILITY OF COMPETITOR (UNITS OF PERFORMANCE)

PPMMC PRODUCT PERFORMANCE AND MARKETABILITY MULTIFLIER FOR CAPITAL (DIMENSIONLESS)

PPMML PRODUCT PERFORMANCE AND MARKETABILITY MULTIFLIER FOR LABOR (DIM•LESS)

PPMMO PRODUCT PERFORMANCE AND MARKETABILITY MULTIFLIER FOR OVERHEAD (DIMENSIONLESS)

PPP PER PLANT PRODUCTION (SQUARE FEET/YEAR)

PPP1 PER PLANT PRODUCTION OF LOW-COST HOUSING (SQUARE FEET/YEAR)

PPP2 PER PLANT PRODUCTION OF HIGH COST HOUSING (SQUARE FEET/YEAR)

PPP3 PER PLANT PRODUCTION OF NON-HOUSING BUILDINGS (SQUARE FEET/YEAR)

PPS1 PERCEIVED PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM•LESS)

PPS2 PERCEIVED PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM•LESS)

PPS3 PERCEIVED PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET (DIMENSIONLESS)

PQ1,PQ2,....PQ10 PROBABILITIES FOR QUALITY

PSAVGS1 PERCENT SAVINGS IN THE LOW-COST HOUSING MARKET (DIM•LESS)

PSAVGS2 PERCENT SAVINGS IN THE HIGH-COST HOUSING MARKET (DIM•LESS)

PSAVGS3 PERCENT SAVINGS IN THE NON-HOUSING BUILDING MARKET (DIM•LESS)

PSM PRECAST'S SHARE OF ITS MAIN BUILDING MARKETS (DIM•LESS)

RC REQUIRED CAPACITY (SQUARE FEET/YEAR)

RCPAT REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY (UNITS OF TECHNOLOGY)

RCPATI REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY INTERVAL (YEARS)

RCPATT REVOLUTIONARY CHANGE IN PRODUCTION AND ASSEMBLY TECHNOLOGY TIME

	(YEARS)
RCPPM	REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY (UNITS OF PERFORMANCE)
RCPPMI	REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY INTERVAL (YEARS)
RCPPMT	REVOLUTIONARY CHANGE IN PRODUCT PERFORMANCE AND MARKETABILITY TIME (YEARS)
RFA	REQUIRED FIXED ASSETS ($/YEAR)
RISK	RISK (UNITS OF RISK)
RISK1	RISK (UNITS OF RISK)
RISK2	RISK (UNITS OF RISK)
RISK3	RISK (UNITS OF RISK)
RISK4	RISK (UNITS OF RISK)
RISKH	RISK AS DETERMINED BY THE HOUSING MARKET (UNITS OF RISK)
RISKNH	RISK AS DETERMINED BY THE NON-HOUSING BUILDING MARKET (UNITS OF RISK)
RLC1	REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE LOW-COST HOUSING MARKET (MANHOURS/SQUARE FEET)
RLC2	REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE HIGH-COST HOUSING MARKET (MANHOURS/SQUARE FEET)
RLC3	REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING BUILDING MARKET (MANHOURS/SQUARE FEET)
RLF1	REQUIRED LABOR IN THE FACTORY FOR LOW-COST HOUSING (MANHOURS/SQ.FT.)
RLF2	REQUIRED LABOR IN THE FACTORY FOR HIGH-COST HOUSING (MANHOURS/SQ.FT.)
RLF3	REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS (MANHOURS/SQUARE FEET)
RLS1	REQUIRED LABOR ON SITE FOR LOW-COST HOUSING (MANHOURS/SQUARE FEET)
RLS2	REQUIRED LABOR ON SITE FOR HIGH-COST HOUSING (MANHOURS/SQUARE FEET)
RLS3	REQUIRED LABOR ON SITE FOR NON-HOUSING BUILDINGS (MANHOURS/SQ.FT.)
S	STEP(DIMENSIONLESS)
SCN	SMOOTHING CONSTANT(DIMENSIONLESS)
SD	SMOOTHED DEMAND(SQ FT/YEAR)
SDC	STANDARD DEVIATION FOR COSTS($/SQ FT)

SDC	STANDARD DEVIATION FOR QUALITY(UNITS OF PERFORMANCE)
SDJ	SMOOTHED DEMAND PREVIOUSLY($/SQ FT)
SDSDT	SAVINGS DUE TO SHORTENED DEVELOPMENT TIME(DIMENSIONLESS)
SER	SUM OF ERRORS(SQ FT)
SERJ	SUM OF ERRORS PREVIOUSLY(SQ FT)
SLM	SCARCITY OF LABOR MULTIPLIER(DIMENSIONLESS)
SO	SITE OVERHEAD($/SQ FT)
T	TIME (YEARS)
TBM	TABLE FOR THE BRIDGE MARKET
TCA	TABLE FOR CAPITAL
TCB	TABLE FOR CAPITAL
TCC	TABLE FOR COST ($/SQUARE FEET)
TCC1	TOTAL COST IN CONVENTIONAL CONSTRUCTION IN LOW-COST HOUSING ($/SQ.FT.)
TCC2	TOTAL COST IN CONVENTIONAL CONSTRUCTION IN HIGH-COST HOUSING ($/SQ.FT.)
TCC3	TOTAL COST IN CONVENTIONAL CONSTRUCTION IN NON-HOUSING BUILDING ($/SQ.FT.)
TCIFA	TOTAL CAPITAL INVESTED IN FIXED ASSETS ($/YEAR)
TCIFAJ	TOTAL CAPITAL INVESTED IN FIXED ASSETS PREVIOUSLY ($/YEAR)
TCVLCMC	TABLE FOR CAPITAL VERSUS LABOR COST MULTIPLIER FOR CAPITAL
TCVLCML	TABLE FOR CAPITAL VERSUS LABOR COST MULTIPLIER FOR LABOR
TDEFL	TABLE FOR DEFLATOR
TDEPRT	TABLE FOR DEPRECIATION TIME
TEM	TABLE FOR EXPANSION MULTIPLIER
TEPI	TABLE FOR EQUIPMENT PRICE INDEX
TFOOHA	TABLE FOR FACTORY OPERATING OVERHEAD
TFOOHB	TABLE FOR FACTORY OPERATING OVERHEAD
THMARKT	TABLE FOR THE MULTI-UNIT HOUSING MARKET
TICPAT	TIME TO IMPLEMENT CHANGES IN PRODUCTION AND ASSEMBLY TECHNOLOGY (YEARS)
TICPPM	TIME TO IMPLEMENT CHANGES IN PRODUCT PERFORMANCE AND MARKETABILITY

	(YEARS)
TIECI	TABLE FOR INDUSTRIAL EQUIPMENT COST INDEX
TIML	TABLE FOR INFLATION MULTIPLIER
TINTRST	TABLE FOR INTEREST
TLA	TABLE FOR LABOR
TLB	TABLE FOR LABOR
TLRC	TABLE FOR LABOR RESISTANCE COEFFICIENT
TLRF	TOTAL LABOR REQUIRED IN THE FACTORY (MANHOURS/YEAR)
TLWC	TABLE FOR LABOR WAGES IN CONVENTIONAL CONSTRUCTION
TLWF	TABLE FOR LABOR WAGES IN THE FACTORY
TMARKT3	TABLE FOR CONCRETE NON-HOUSING BUILDINGS
TMATC	TABLE FOR MATERIAL COST
TMATCM	TABLE FOR MATERIAL COST MULTIPLIER
TMME	TABLE FOR MECHANIZATION MULTIPLIER FOR EQUIPMENT
TMML	TABLE FOR MECHANIZATION MULTIPLIER
TNM	TABLE FOR NOVELTY MULTIPLIER
TNP	TABLE FOR NUMBER OF PLANTS
TOCC1	TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION FOR LOW COST HOUSING
TOCC2	TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION FOR HIGH COST HOUSING
TOCC3	TABLE FOR OVERHEAD COST IN CONVENTIONAL CONSTRUCTION FOR NON-HOUSING BUILDINGS
TNP	TABLE FOR NUMBER OF PLANTS
TPATM	TABLE FOR PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER
TPATMC	TABLE FOR THE PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR CAPITAL
TPATML	TABLE FOR PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR LABOR
TPATMO	TABLE FOR THE PRODUCTION AND ASSEMBLY TECHNOLOGY MULTIPLIER FOR OVERHEAD
TPC1	TOTAL PRECAST COST IN THE LOW COST HOUSING MARKET($/SQ FT)

TPC2	TOTAL PRECAST COST IN THE HIGH COST HOUSING MARKET($/SQ FT)
TPC3	TOTAL PRECAST COST IN THE NON-HOUSING BUILDINGS MARKET($/SQ FT)
TPCC1	TABLE FOR PERCENT OF CONSTRUCTION COST IN THE LOW COST HOUSING MARKET
TPCC2	TABLE FOR PERCENT OF CONSTRUCTION COST IN THE HIGH COST HOUSING MARKET
TPCC3	TABLE FOR PERCENT OF CONSTRUCTION COST IN THE NON-HOUSING BUILDING MARKET
TPCM1	TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE LOW COST HOUSING MARKET
TPCM2	TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE HIGH COST HOUSING MARKET
TPCM3	TABLE FOR PERCENT OF CONSTRUCTION MULTIPLIER FOR THE NON-HOUSING BUILDING MARKET
TPF1A	TABLE FOR PREFERENCE FUNCTION FOR THE LOW COST HOUSING MARKET
TPF1B	TABLE FOR PREFERENCE FUNCTION FOR THE LOW COST HOUSING MARKET
TPF2A	TABLE FOR PREFERENCE FUNCTION FOR THE HIGH COST HOUSING MARKET
TPF2B	TABLE FOR PREFERENCE FUNCTION FOR THE HIGH COST HOUSING MARKET
TPF3A	TABLE FOR PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDINGS MARKET
TPF3B	TABLE FOR PREFERENCE FUNCTION FOR THE NON-HOUSING BUILDINGS MARKET
TPIM	TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER
TPIML	TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER
TPIML1	TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE LOW COST HOUSING MARKET
TPIML2	TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE HIGH COST HOUSING MARKET
TPIML3	TABLE FOR PERCENT INDUSTRIALIZED MULTIPLIER FOR THE NON-HOUSING BUILDING MARKET
TPPMMC	TABLE FOR THE PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR CAPITAL
TPPMML	TABLE FOR PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR LABOR

TPPMMO	TABLE FOR PRODUCT PERFORMANCE AND MARKETABILITY MULTIPLIER FOR OVERHEAD
TR	TOTAL REVENUE($/YEAR)
TRANSPC	TRANSPORTATION COST($/SQ FT)
TREND	TREND(SQ FT/YEAR)
TRENDJ	TREND PREVIOUSLY(SQ FT/YEAR)
TRISK1	TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
TRISK2	TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
TRISK3	TABLE FOR RISK AS DETERMINED BY THE HOUSING MARKET
TRLC1	TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE LOW COST HOUSING MARKET
TRLC2	TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE HIGH COST HOUSING MARKET
TRLC3	TABLE FOR REQUIRED LABOR IN CONVENTIONAL CONSTRUCTION IN THE NON-HOUSING BUILDING MARKET
TRLF1	TABLE FOR REQUIRED LABOR IN THE FACTORY FOR LOW COST HOUSING
TRLF2	TABLE FOR REQUIRED LABOR IN THE FACTORY FOR HIGH COST HOUSING
TRLF3	TABLE FOR REQUIRED LABOR IN THE FACTORY FOR NON-HOUSING BUILDINGS
TRLS1	TABLE FOR REQUIRED LABOR ON SITE FOR LOW COST HOUSING
TRLS2	TABLE FOR REQUIRED LABOR ON SITE FOR HIGH COST HOUSING
TRLS3	TABLE FOR REQUIRED LABOR ON SITE FOR NON-HOUSING BUILDINGS
TSDSDT	TABLE FOR SAVINGS DUE TO SHORTENED DEVELOPMENT TIME
TSLM	TABLE FOR SCARCITY OF LABOR MULTIPLIER

END

APPENDIX B (Reference 37)

Capital requirements for fixed assets, manpower, materials and overhead for a precast concrete plant in the U. S. in 1971, capable of producing 540 dwellings (i. e., about 540,000 $ft.^2$) with a utilization rate of 1 cycle/day over 245 days/year

I. PLANT CAPITAL COST

1. Buildings and Grounds

a. Building: covered floor area of 13,000 $ft.^2$ for the production area and 2,000 $ft.^2$ for auxiliary services, a total of 15,000 $ft.^2$.

The structure is assumed to be a concrete frame type, with precast panel infills, or possibly tilt-up walls. Assuming a 24-foot spacing of the columns to meet bridge requirements for the crane, the cost of the building is estimated at $\$8/ft.^2$.

Thus: Total Cost of Building:

$$8\ \$/ft.^2 \times 15{,}000\ ft.^2 = \$\ 120{,}000$$

b. Land: Land cost is assumed to be 0.25 $\$/ft.^2$

The requirements are:

Plant:	15,000 $ft.^2$ x 0.25 $\$/ft.^2$	= $	3,750
Stockyard:	20,000 $ft.^2$ x 0.25 $\$/ft.^2$	=	5,000
Access and Miscellaneous			
	20,000 $ft.^2$ x 0.25	=	5,000
Total		$	13,750
Add Cleaning of Site and Preparation			10,250
Total		$	24,000

2. Storage Area

The only equipment needed in the storage area is a series of racks and supports for the concrete elements.

The cost of these fixtures has been estimated at $5,000.

3. Production Area

a. Vertical Battery Forms

- one 12-cell battery	$ 165,000
- installation of battery	18,000
- wooden gang-plank installation	2,500
- intermediate side walls, hinge extensions, turn buckles, mould cutouts	12,000
- electric vibrators, high frequency, adjustable force, base plate and clamps, at $400 each	
32 units:	12,800
- 15 KVA, 440/220 volts, 3 phase, 60 cycle transformers, at $750	
2 units:	1,500
Installation:	500
- steam line connections, electric cable installation, switches	1,200
- Monorail track with 4 cu.yd. hopper	34,500
Total	$ 248,000

b. Tilting Tables

- steel mould	$ 14,500
- heat pipe system	500
- tilting mechanism	3,500
- installation	1,500

Sub-total	$ 20,000	
8 units:		$ 160,000
- 15 KVA, 440/220 V, 3 phase, 60 cycle transformer, at $750		
2 units:		1,500
Installation:		500
- electrical wiring, switches, cable installation		2,500
- electric vibrator, high-frequency, adjustable force, base plate, clamps, at $400 each		
16 units:		6,400
- intermediate side moulds miscellaneous parts		8,500
Total		$ 179,400

c. Miscellaneous Forms

- two staircase forms	$ 10,000	
installation thereof	1,500	
- one elevator shaft room	12,000	
Installation:	1,800	
Sub-total		25,300
- high frequency external vibrators, adjustable force, base plate, clamp at $400 each, 12 units		4,800
- 15 KVA 440/220V, 3 phase, 60 cycle transformers, at $750 each		
2 units:		15,000
Installation:		250
Total		$ 31,850

Production Area Total: $248,000 + $179,400 + $31,850 = $ 459,250

4. Batching Plant

- 40 cubic yards per hour capacity including: aggregate partitions, 350 bbl cement silo, aggregate and cement hopper, semi-automatic controls, water measuring tank, aggregate scraper, electric wiring, air piping

		$ 85,000
Installation thereof		25,000
- 20 BHP boiler, 50 gpm pump, steam pipe, return heaters, water tank		8,000
Installation thereof		7,000
Total		$ 125,000

5. Materials Handling Equipment

a. Cranes

- in-plant bridge crane, 15 ton, 60' span, floor controls	$ 28,000	
- 2 x 250 feet electrified track, 15/LF	7,500	
- beam and base plate, 24' centers, installation	7,500	
Sub-total:		43,000
- storage portal crane, 15 ton, 60' span, cab controlled	55,000	
- 2 x 400' track, installed at 2/LF	1,600	
- installation of controls	900	
Sub-total		57,500

b. Concrete Handling

- 4 cu.yd. skip at $4,500 each	18,000	
- 2 cu.yd. buckets at 1,500 each		
4 units:	6,000	

- electric carts, at 3,000 each			
	2 units	$ 6,000	
- I fork lift truck		7,000	
- miscellaneous hoists		7,000	
	Sub-total		$ 44,000
Total			$ 144,500

6. Auxiliary Services

a. Heating:

For a maximum temperature differential of 60 °F, heating requirements are estimated at 100 BTU/hour per square foot of covered area. This amounts to: 100 x 15,000 = 1.5 MBTU/hour for the plant.

b. Curing Concrete:

Heating requirements in a vertical battery form amount to 120,000 BTU per cubic yard, for a difference of 110 °F. This is equivalent to: 120,000 x 75 = 9 million BTU at full capacity. The proposed tilting tables require each 1.8 million BTU for the same temperature differential when fully loaded. This represents: 1.8 x 8 = 14.4 million BTU.

Total Heat Required: 23.4 Million BTU

Evidently, curing of elements does not occur simultaneously and at all times, and the boiler capacity used need not equal the maximum heat requirements, as the amount of heat is spread over 3-5 hours.

Also, heat generated by the concrete curing process reduces gradually the excess heat needed in the battery, and except for the coldest months of the year, heat curing for the tilting tables is not needed, as they operate on a one-cycle-per-day basis.

From discussions with manufacturers, a boiler capacity of 10 MBTU per hour was considered sufficient.

The corresponding costs are as follows:

1 50 HP Boiler (1.6 MBTU)	$ 4,500
30 radiating fin sections, 10' each at $20/ft, installed	6,000
Boiler installation	2,500
1 300 HP Boiler (10.04 MBTU)	13,500
Steam pipes, return header, installation	7,500
Total	$34,000

c. Light:

For an illumination level of 30 lux/ft.^{2} and using suspended mercury vapour lamps 35' above floor level, total requirements are:

$$15,000 \times 30 = 450,000 \text{ lux}$$

with a reflection loss factor of 2.0, 30 units of 700 watts each are required.

The corresponding costs are:

30 lamp units, 700 W, installed at $250 each	$ 7,500
Electric installation, junction boxes, starters, etc.	7,500
Total	$15,000

d. Compressed Air:

Compressed air is required for some shop tools and for finishing operations on the precast elements (cleaning, sand blasting, etc.). It is also needed to operate the mechanical parts of the concrete plant. Total requirements have been estimated at a peak of 200 cubic feet per minute. The corresponding equipment costs are:

1 200 cfm Diesel air compressor:	$12,000
Piping, couplings and installation: (including compressed air tank)	8,000
Total	$20,000

e. Steel Shop:

The required equipment and corresponding costs are tabulated below. They represent normal requirements for a small precasting plant and are sufficient to take care of most of the routine maintenance work:

1 bender (max. size 1.5" Bar)	$ 1,800
1 cutter (max. size 2" Bar)	1,800
1 mesh cutter (max. size 1/8" wire)	2,500
1 10 kw welder	400
3 portable steel grinders, $150 each	450
1 fixed stand steel grinder	750
3 benches, at $250 each	400
1 stand drill (max. 0.25")	400
1 electric saw	850
miscellaneous small tools	800
Total	$10,500

f. <u>Joinery Shop</u>:

1 band saw	$ 5,500
1 planar	1,500
1 stand drill	750
1 circular saw	750
1 bench	250
miscellaneous tools	1,500
Total	$ 5,500

g. <u>Laboratory Equipment</u>:

sieve shaker, complete with accessories	$ 500
curing box (40 cylinders)	700
slump test outfit	40
portable beam tester	600
air and pressure meter (2 sets)	400
1 20 kg. balance	150
1 double beam high sensitivity balance	150
moisture tester and accessories	300
1 laboratory oven	100
2 electric motors (110 V, single phase, 60 cycles	300
1 concrete cylinder press	3,500
miscellaneous equipment	1,500
Total	$ 8,240
Say, Total	$ 8,500

h. Office Equipment:

Six office rooms are needed to accommodate the administrative personnel of the plant. The equipment and furniture required are common to typical offices, and the breakdown below is merely a tentative outline to establish the order of magnitude of the overall cost of office equipment.

6 desks	$ 3,000
6 wheel chairs	950
6 cabinet files	1,500
3 closets	1,500
8 chairs	400
2 typewriters	2,000
1 adding machine	500
1 desk calculator	1,000
miscellaneous furnishing	1,000
office supplies (1 year)	3,650
Total	$ 15,500

i. Miscellaneous Equipment:

2-way communication systems	$ 10,000
telephone installations	10,000
sanitary installations	5,000
cafeteria	5,000
unaccounted for	20,000
Total	$ 50,000

Summary of Capital Costs for Production

Building	$ 120,000
Land	24,000
Stockyard	5,000
Production	459,250
Batching Plant	125,000
Handling Equipment	144,500
Boilers	34,000
Light	15,000
Compressed Air	20,000
Steel Shop	10,500
Joinery Shop	5,500
Laboratory Equipment	8,500
Office Equipment	15,500
Miscellaneous	30,000
Unaccounted for	20,000
Start-up, 1 month	80,250
TOTAL CAPITAL COSTS	$ 1,117,000

To convert this figure into 1967 values, we divided it by 1.185. These are the industrial equipment cost indexes for 1967 and 1971, respectively, taken from Fig. 33.

Required capital for fixed assets for the production of 540,000 square feet in 1967 = $1,117,000 \times \frac{1}{1.185} = \$940,000$

II. MANPOWER REQUIREMENTS (Direct Labor)

Casting areas:	Battery:	5 labourers
	Tilting Tables	6 labourers
	Finishing:	2 labourers
Steel Shop:		4 iron workers
		2 plumbers
Joinery Shop:		2 carpenters
Concrete Plant:		2 labourers
Concrete Distribution:		1 labourer
Cranes:		2 labourers
Stockyard:		2 labourers
Maintenance:		2 labourers
General Plant:		2 labourers
Supervision:		1 foreman
Total		33 persons

33 person x 8 working hours per day x 245 days per year = 64,680 manhours/year.

III. MATERIALS

The cost of materials in the production of precast elements is difficult to estimate precisely given the diversity of products which are used. This holds true even for the basic components of concrete, i.e., aggregates, cement, and steel. The price of the aggregate depends on the type of rock (quartz, limestone, basalt, marble, etc.); that of cement on its properties (high early strength, normal, slow, etc.).

In addition to these basic constituents, wood, electric wirings, ducts, pipes, fittings, etc. are used in the fabrication of panels for such items as doors, windows, sanitary and plumbing fixtures.

Keeping in mind all these factors of uncertainty, the following procedure was used to arrive at an estimate of materials costs:

annual panel production	540 units x 9 panels/unit = 4,860
average panel area	250 ft.^{2}
average thickness	8"
annual concrete volume	4,860 x 250 x 8/12 x 27 = 33,400 cu.yd.
average steel reinforcement	1%
annual steel weight	33,400 x 0.01 = 334 cu.yd. x 6.75 = 2.250 T
average cost of concrete	$20/cubic yard
average cost of steel	$250/ton
average cost of concrete	33,400 x 20 = 668,000
annual cost of steel	2,250 x 250 = 562,000
	Sub-total $1,230,000
Add 48% Misc. Items*	590,000
	Total $1,820,000

$$\frac{\$1,820,000/\text{year}}{540,000\ \text{ft}^2/\text{year}} = \$3.37/\text{ft.}^2 \text{ cost of materials in 1971}$$

$$\text{cost of materials in 1967} = 3.37 \times \frac{1}{1.119} = \$3.015/\text{ft}^2.$$

Where 1 and 1.119 are the indexes of prices of materials used in construction in 1967 and 1971, respectively (see Fig. 37).

*Judgment estimate to cover costs of inserts within panels, doors, wirings, fixtures, costs of sealants on site, etc., etc.

IV. FACTORY OVERHEAD

1. Indirect Labor (Administration, Supervision, and Sales)

1 head engineer	$ 20,000 per year	
1 production technician	14,000	
3 design engineers x $15,000	45,000	
2 draftsmen x $10,000	20,000	
1 salesman	12,000	
1 accountant	11,000	
1 secretary	8,000	
Sub-total	$ 130,000	
Benefits: insurance, taxes, paid holidays x 15% of salary sub-total	19,500	
Total		$ 150,000

2. Power Utilities

a. Electricity		Annual Consumption in kwh	
Light	20 kw, L.F. 1.0	40,000	
Shops	30 kw, L.F. 0.5	30,000	
Cranes	35 kw, L.F. 0.7	49,000	
Concrete Plant	150 kw, L.F. 0.4	120,000	
Vibrators	25 kw, L.F. 0.2	10,000	
Miscellaneous	10 kw, L.F. 0.8	16,000	
Sub-total			265,000
Transmission losses 10%			26,500
Total			$ 291,500
Say			$ 300,000

Average electricity cost: $0.025/kwh

Annual cost: 300,000 x 0.025 = $7,500

b. Fuel

Concrete curing:	8 MBTU x 8 hours x 140 days	$ 8,960
Plant heating:	2 MBTU x 8 hours x 140 days	2,240
Sub-total		11,200
Losses 25%		2,800
Total		$ 14,000

Average Fuel Cost: $1.0/MBTU

Annual cost: 14,000 x 1.0 = $14,000

c. Water

- concrete plant: assuming an average of 500 lb. water per cubic yard of concrete (this includes water used for heating), the annual consumption amounts to:

  20,000 x 500 lb x 1 gallon/7.48 = 1.335,000 gallons

- steam wiring: assuming 200 lb. of water per cubic yard of concrete, a high but conservative figure if recirculation of water is used, this amounts to:

  20,000 x 200 lb x 1/7.48 = 535,000 gallons

  Total annual quantity of water consumed is thus:

  1,870,000 gallons - say 2,000,000 gallons

  Average water cost: $0.20/1,000 gallons

  Annual water Cost: $400

d. Summary:

Electricity	$ 7,500
Fuel	14,000
Water	400
	$ 21,900
say	$ 22,000

3. Maintenance

It is taken as a percentage of initial capital investment. The values used are derived from mechanical plant surveying, and published figures in the literature:

Production equipment:	495,250 x 10%	=	45,925
Shops	16,000 x 25%	=	4,000
Boilers	34,000 x 25%	=	8,500
Handling equipment	144,500 x 10%	=	14,450
Concrete plant	125,000 x 25%	=	31,250
Other equipment	100,000 x 25%	=	20,000
General Plant	$1.5/ft^2 x 15,000	=	22,000
Total			$146,125
Say			$150,000

4. Miscellaneous

Telephone	$ 6,000 per year
Postage	4,000
Travel	12,000
Insurance-general	12,000
Advertising	30,000
Small tools	24,000

Taxes*	$ 10,000
Miscellaneous items	12,000
Total	$110,000

SUMMARY OF FACTORY OVERHEAD COSTS

Indirect Labor	$150,000
Electricity	7,500
Fuel	14,000
Water	400
Maintenance	150,000
Miscellaneous	110,000
Total	$431,900

Say $432,000 Factory Overhead Costs in 1971

Factory overhead costs in 1967 = $432,000 \times \frac{1}{1.21}$ = $357,000

where 1 and 1.21 are the consumer price indexes for 1967 and 1971, respectively taken from Fig. 27.

*To cover miscellaneous municipality and state taxes

APPENDIX C

Derivation of the formula for productivity

Time	Productivity
$t = 0$	$Prod_o = Prod_o$
$t = \Delta t$	$Prod_{\Delta t} = Prod_o + \Delta t\ (a \times Prod_o) = (1 + a\ \Delta t)\ Prod_o$
$t = 2\Delta t$	$Prod_{2\Delta t} = Prod_{\Delta t} + \Delta t(a \times Prod_{\Delta t}) = (1 + a\ \Delta t)\ Prod_{\Delta t} = (1 + a\ \Delta t)^2 \times Prod_o$
$t = 3\Delta t$	$Prod_{3\Delta t} = Prod_{2\Delta t} + \Delta t(a \times Prod_{3\Delta t}) = (1 + a\ \Delta t) \times Prod_{2\Delta t} = (1 + a\ \Delta t)^3 \times Prod_o$
. . . .	. . . .
$t = t$	$Prod_t = (1 + a\ \Delta t)^{t/\Delta t} \times Prod_o$

where a = rate of increase in productivity

$$(I + x)^n = 1 + nx + \frac{n(n-1)x^2}{2!} + \frac{n(n-1)(n-2)x^3}{3!} + \ldots \quad (1)$$

for $x = a\ \Delta t$

and $n = t/\Delta t$

formula (1) becomes

$$(1 + a\ \Delta t)^{t/\Delta t} = 1 + \frac{t}{\Delta t}\ a\ \Delta t + \frac{\frac{t}{\Delta t}(\frac{t}{\Delta t} - 1)a^2\Delta t^2}{2!} + t/\Delta t\ (\frac{t}{\Delta t} - 1)\ .$$

$$.\ \frac{(t/\Delta t - 2)a^3\ \Delta t^3}{3!} + \ldots =$$

$$= 1 + at + \frac{t(t - \Delta t)a^2}{2!} + \frac{t(t - \Delta t)(t - 2\Delta t)a^3}{3!} + \ldots$$

$$= 1 + at + \frac{a^2t^2}{2!} - \frac{a^2t\ \Delta t}{2!} + \frac{a^3t^3}{3!} - \frac{3a^3t^2\Delta t}{3!} + \frac{2a^3\ t\ \Delta t^2}{3!} + \ldots \quad (2)$$

as $\Delta t \to 0$ formula (2) becomes:

$$(1 + a\ \Delta t)^{t/\Delta t} = 1 + at + \frac{a^2t^2}{2!} + \frac{a^3t^3}{3!} + \ldots \tag{3}$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots \tag{4}$$

for x = at formula (4) becomes:

$$e^{at} = 1 + at + \frac{a^2t^2}{2!} + \frac{a^3t^3}{3!} + \ldots$$

$$(1 + a\ \Delta t)^{t/\Delta t} \sim e^{at} \ ;$$

therefore,

$$Prod_t = (1 + a\ \Delta t)^{t/\Delta t} \cdot Prod_o = e^{at} \cdot Prod_o \ .$$

Therefore, for the values of $Prod_o = 1$ and t = TIME.k-1960 appearing in the model:

$$Prod_t = 1.e^{a(TIME.k-1960)} \ .$$

APPENDIX D

<u>Labor, materials and overhead requirements for the construction of structure and skin, finishings and mechanical and electrical equipment</u>

I. ON-SITE LABOR REQUIREMENTS

1. <u>Conventional Concrete Construction</u>

a. <u>Low-cost Housing</u> - Labor cost as percentage of total construction cost:

Labor for structure and skin:	0.38* x 0.37**	= 0.14
Labor for finishings:	0.46* x 0.25**	= <u>0.115</u>
Sub-total		0.255
Labor for mechanical and electrical equipment:	0.45* x 0.28**	<u>0.0126</u>
Total		0.381

Increases in manhour requirements as one moves from structure and skin to structure, skin, and finishings and then to total systems.

For 0.14 ⟶ 1
0.255 ⟶ 1.82
0.381 ⟶ 2.72
} Table TRLC1 in the model

b. <u>High-cost Housing</u> - Labor cost as percentage of total construction cost:

Labor for structure and skin:	0.38* x 0.25**	= 0.09
Labor for finishings:	0.46* x 0.37**	= <u>0.17</u>
Sub-total		0.26

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*derived from Table 7

**derived from Table 6

Labor for mechanical and electrical equipment: $0.45^{*} \times 0.28^{**} = \underline{0.126}$

Total 0.386

Increases in manhour requirements as one moves from structure and skin to structure, skin, and finishings and then to total systems.

For 0.09 → 1
0.26 → 2.8
0.386 → 4.23
} Table TRLC2 in the model

c. Non-Housing Buildings - Labor cost as percentage of total construction cost.

Labor for structure and skin: $0.38^{*} \times 0.27^{**} = 0.102$

Labor for finishings: $0.46^{*} \times 0.31^{**} = \underline{0.143}$

Sub-total 0.245

Labor for mechanical and electrical equipment: $0.45^{*} \times 0.32^{**} = \underline{0.144}$

Total 0.389

Increases in manhour requirements as one moves from structure and skin to structure, skin, and finishings and then to total systems.

For 0.102 → 1
0.245 → 2.4
0.389 → 3.82
} Table TRLC3 in the model

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*derived from Table 7

**derived from Table 6

Actual On-site Manhours Required in 1960

a. Low-cost Housing

Structure and skin:		0.575 manhours/ft^2
Finishings:	0.82 x 0.575 =	0.4715 manhours/ft^2
Mechanical and electrical equipment	0.9 x 0.575 =	0.5175 manhours/ft^2

b. High-cost Housing

Structure and skin:		0.575 manhours/ft^2
Finishings:	1.8 x 0.575 =	1.035 manhours/ft^2
Mechanical and electrical equipment	1.43 x 0.575 =	0.82 manhours/ft^2

c. Non-housing Buildings

Structure and skin:		0.575 manhours/ft^2
Finishings:	1.4 x 0.575 =	0.805 manhours/ft^2
Mechanical and electrical equipment	1.42 x 0.575 =	0.815 manhours/ft^2

2. Precast Concrete Construction

Assumptions:

i. According to the model, 0.144 manhours/ft^2 were required for erection and joining of structure and skin in 1960.

ii. According to Table 47, prefabrication of finishings would save $(1 - \frac{258}{667}) = (1 - 0.387) = 61.3$ per cent of on-site manhours required for finishings done conventionally.

iii. On-site manhour requirements for total systems are not above on-site manhour requirements for structure, skin and finishings.

Accordingly:

a. Low-cost Housing: On-site labor requirements

Structure and skin:		0.144	manhours/ft^2
Finishings:	0.387 x 0.4715 =	0.1825	manhours/ft^2
	Total	0.3265 = 2.27 x 0.144	
Total systems		0.3265 = 2.27 x 0.144	

The above are reflected in Table TRLS1 = 1/2.27/2.27 in the model.

b. High-cost Housing: On site labor requirements

Structure and skin		0.144	manhours/ft^2
Finishings			
	0.387 x 1.035 =	0.4	
	Total	0.544 = 3.87 x 0.144	
Total systems		0.544 = 3.87 x 0.144	

The above are reflected in Table TRLS2 = 1/3.87/3.87 in the model.

c. Non-housing Buildings: On-site labor requirements

Structure and skin:		0.144	manhour/ft^2
Finishings	0.387 x 0.805 =	0.3114	manhour/ft^2
	Total	0.4554 = 3.16 x 0.144	
Total Systems		0.4554 = 3.16 x 0.144	

The above are reflected in Table TRLS3 = 1/3.16/3.16 in the model.

II. MATERIAL REQUIREMENTS FOR DIFFERENT PERCENTAGES OF INDUSTRIALIZATION (INCLUDES CONVENTIONAL CONCRETE AND PRECAST CONCRETE CONSTRUCTION)

a. Low-cost Housing: Materials cost as a percentage of total construction cost:

Materials for structure and skin:	$0.52^{*} \times 0.37^{**}$	= 0.192
Materials for finishings:	$0.44^{*} \times 0.25^{**}$	= 0.110
Sub-total		0.302
Materials for mechanical and electrical equipment:	$0.45^{*} \times 0.28^{**}$	= 0.126
Total		0.428

Increases in material requirements as one moves from structure and skin to structure, skin, and finishings, to total systems.

For 0.192 ⟶ 1
0.302 ⟶ 1.57
0.428 ⟶ 2.223

Tables TPIML1 and TPCM1 in the model

b. High-cost Housing: Materials cost as a percentage of total construction cost:

Materials for structure and skin:	$0.52^{*} \times 0.25^{**}$	= 0.13
Materials for mechanical and electrical equipment:	$0.45^{*} \times 0.28^{**}$	= 0.126
Total		0.419

Increases in material requirements as one moves from structure and skin to structure, skin, and finishings, to total systems.

For 0.13 ⟶ 1 Tables TPIML3 and TPCM3 in the model

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*derived from Table 7

**derived from Table 6

0.277 → 1.98	}	Tables TPIML3 and TPCM3 in the model
0.421 → 3.01		

III. OVERHEAD REQUIREMENTS FOR DIFFERENT PERCENTAGES OF INDUSTRIALIZATION (CONVENTIONAL CONSTRUCTION)

a. Low-cost Housing: Overhead cost as percentage of total construction cost:

Overhead for structure and skin:	$0.1^{*} \times 0.37^{**}$ =	0.037
Overhead for finishings:	$0.1^{*} \times 0.25^{**}$ =	0.025
Sub-total		0.062
Overhead for mechanical and electrical equipment:	$0.1^{*} \times 0.28^{**}$ =	0.028
Total		0.090

Increases in overhead requirements as one moves from structure and skin to structure, skin, and finishings, to total systems.

For 0.037 → 1	}	Table TOCC1 in the model
0.062 → 1.68		
0.090 → 2.43		

b. High-cost Housing: Overhead cost as percentage of total construction cost:

Overhead for structure and skin:	$0.1^{*} \times 0.25^{**}$ =	0.025
Overhead for finishings:	$0.1^{*} \times 0.37^{**}$ =	0.028
		0.090

* derived from Table 7

** derived from Table 6

Increases in overhead requirements as one moves from structure and skin to structure, skin, and finishings to total systems.

For 0.025 →	1	Table TOCC2 in the model
0.062 →	2.48	
0.090 →	3.60	

c. <u>Non-housing Buildings</u>: Overhead cost as percentage of total construction cost:

Overhead for structure and skin:	0.1* x 0.27**	= 0.027
Overhead for finishings:	0.1* x 0.31**	= <u>0.031</u>
Sub-total		0.058
Overhead for mechanical and electrical equipment:	0.1* x 0.32**	= <u>0.032</u>
Total		0.090

Increases in overhead requirements as one moves from structure and skin to structure, skin, and finishings to total systems.

For 0.027 →	1	Table TOCC3 in the model
0.058 →	2.14	
0.090 →	3.33	

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*derived from Table 7

**derived from Table 6