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ALINET, A MODEL FOR ASSESSING ENERGY CONSERVATION
OPPORTUNITIES IN THE FOOD PROCESSING INDUSTRY

Final Technical Report, September 1977—December 1979

By
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MASTER

December 1979

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Systems Control, Inc.
Burlington, Massachusetts

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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ALINET :

A Model for Assessing Energy Conservation Opportunities
in the Food Processing Industry

FINAL TECHNICAL REPORT
SEPTEMBER 1977 - DECEMBER 1979

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PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
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ALINET

A Model for Assessing Energy Conservation Opportunities in the Food Processing Industry

ABSTRACT

ALINET is a network model designed for the analysis of energy use in the food processing and distribution sector and for the evaluation of the potential effectiveness of energy conserving technologies. The conceptual framework of the model, as well as the design and implementation of the computer software are described. The wheat system at the national, state, and facility-specific level is used to illustrate the model's operation and use. A pilot project, carried out in cooperation with industry, is described in which energy use in (a) hard wheat milling, and (b) durum milling and pasta manufacture is analyzed. Finally, the introduction of an alternative technology for pasta drying is assessed in terms of energy conservation and cost. Recommendation for further applications and institutionalization of the model are made.

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PREFACE

This report contains the results of a two-year effort to develop a model that can be used by government and industry to assess proposed energy conservation technologies in the food processing sector. The identification of the need for such a model and its conceptual development evolved from the work done from 1976 to 1977 on energy inputs to U.S. agriculture and food production. That work was supported by the Office of Conservation of the Energy Research and Development Administration and was based on the use of AGRIMOD, a dynamic simulation model of the U.S. food production system. AGRIMOD was developed with support primarily from the Science and Technology Policy Office of the National Science Foundation (1974-1976).

Since the inception of our work on the agricultural sector, a large number of persons from government, industry, and academia have contributed to the project in a wide variety of ways: as consultants, as reviewers, as members of consulting panels, as participants in several workshops, and, most importantly, as providers of information. The support received in the development of AGRIMOD has already been acknowledged in the series of reports that describe that model.

As this developmental phase of ALINET -- proof of the concept and demonstration of its use -- is coming to a close, the project team would like to express its appreciation to Mr. Larry R. Kelso of the Office of Industrial Programs, U.S. Department of Energy, who guided and supported this project not only during the times of accomplishment, but also during periods of difficulty and uncertainty. Professors Donald R. Price of Cornell University and Stanley J. Clark of Kansas State University were technical monitors of the project at the earlier stages; Mr. Paul Jensen and Mr. Ted Reichelt of E.G.&G Idaho, Incorporated have been technical monitors during the later stages. Their interest, advice, and encouragement are gratefully acknowledged.

The success of the pilot project - a crucial step in demonstrating the usefulness of ALINET as a practical tool for industry and government and in establishing its credibility - depended critically on the cooperation of the

Pillsbury Company. The project team was very fortunate in obtaining the active involvement in the project of Dr. John Haaland, Vice President for Information Management and Environmental Systems, and Mr. Donald R. Paugh, Director of Environmental Quality. Through their interest and support we received exceptional cooperation from many different individuals and organizations within Pillsbury who gave generously of their time. Pillsbury managers and staff members not only answered a very large number of questions over a six month period - essentially educating us in the complexities of wheat processing - but also assisted in the development of the network representation of material flows, collected and organized important data, and shared with us their insights on energy use throughout the system. While it is impossible to mention everyone, we would like to express our sincerest appreciation to Mr. Paul Stepner, and Messrs. Dick Fisher and Ted Austin in Minneapolis, Messrs. John A. Meier and Robert W. Morton in Atchison, Kansas, and Mr. John Jordan in Kansas City, Kansas. Ms. Bonnie King coordinated our visits and our interactions within Pillsbury. The efficiency with which we were able to move within a large organization such as the Pillsbury Company and meet our tight deadlines attests to her contribution. Our thanks. We would also like to thank Mr. Bill Engebretson, Plant Engineer, the Peavey Company, who explained patiently and clearly the intricacies of durum milling during our visit to the mill in Hastings, Minnesota. His experience and insights on a wide range of energy conservation issues were of much help in formulating a portion of the second case study.

Since January 1979, the Electric Power Research Institute has been supporting in part our investigation. The contribution to the project of Dr. Quentin Looney of the Energy Utilization and Conservation Technology Program of EPRI, especially concerning the impact of alternative technologies on demand for electricity, is gratefully acknowledged.

The successful development of a large computer model is critically dependent on reliable software support. Thus, we would like to extend our thanks to the staff of Information Systems Design (ISD), particularly, Mr. Dennis Talbert and Ms. Linda Arterburn, for their efforts in providing the commercial software packages and adapting them for our use.

Over the three year period of development of ALINET we had to produce a substantial amount of documentation including two interim technical reports and innumerable technical memoranda. Furthermore, we conducted two workshops and many presentations to diverse audiences - from the Food Industry Advisory Committee to plant engineers. The timely help of the staff of the graphics department at Systems Control, Inc. and later at the Laboratory for Information and Decision Systems of M.I.T. in producing drawings, charts, and slides on very short notice is gratefully acknowledged.

Finally, I would like to thank all my colleagues and associates for their patience and understanding. When, in the middle of a demanding project, we moved - in stages - the project from the West Coast to the East and introduced many complexities in the institutional arrangements.

This project was supported principally by the Office of Industrial Programs, U.S. Department of Energy under Contract No. DE-AC-03-77CS40021. It is also being supported in part by the Electric Power Research Institute under Contract No. RP-1466-1. Any opinions, findings and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the U.S. Department of Energy or the Electric Power Research Institute.

Burlington, MA
January, 1980

Alexander H. Levis

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EXECUTIVE SUMMARY

I. INTRODUCTION

In the past, increase in food production was achieved to a substantial degree through the extensive substitution of non-renewable resources (fossil fuels) for labor. However, the abundance of cheap energy supplies on which these technologies are based can no longer be taken for granted. Consequently, a prevailing theme in energy policy has been conservation and the development of energy conserving technologies.

Very little food makes its way directly from farm to table; for example, wheat, the most important food cereal grown in the U.S., is typical of a commodity that must pass through a number of processors and distributors before reaching the consumer. Energy use is a factor in every step of the movement from farm to final destination: in transportation from farm to elevator and market, elevator to miller, miller to baker, and baker to distributor, as well as in maintenance of the establishments handling grain and grain products - elevators, mills, bakeries, wholesalers, and retailers. The milling of grain, the baking of bread or biscuits, the production of pasta, and the packaging of the final products - all processes consume energy in various amounts.

The interrelationships affecting agricultural production, food production and distribution, and non-renewable resource use are complex. Each proposed new technology or proposed means of energy conservation must be viewed not only independently as it affects the particular process involved, but also in conjunction with other likely changes occurring at other points in the food production system. The need to provide the capability of analyzing energy use in the energy intensive processing sector and to evaluate specific energy conserving technologies has provided part of the motivation for the development of ALINET (Alimentary Industry Network), a dynamic network model of the food processing and distribution sector. The modeling system, furthermore, has been designed so that it can be of use to government agencies

concerned with energy conservation in industry, to electric utilities concerned with future demand, and to the food processing industry which is concerned with energy efficiency and the costs of production.

In order for ALINET to be useful in policy analysis and be effective as an aid in decision-making, it must be credible. It is credibility that forms the interactive links between the modeler, the model user, and the decision maker. Five objective and subjective tests have been proposed for establishing the credibility of a model and, by inference, of the analysis based on the model's use [1]. The tests are those of (1) coherence, (2) correspondence, (3) clarity, (4) workability, and (5) reliability. The first two, coherence and correspondence, can be interpreted as tests for validation and verification, while the clarity test is one of understandability. The workability test is one applied by the decision maker when he evaluates whether the indicated outcomes are a direct consequence of the proposed actions and whether the results indeed provide a solution to his problem. Reliability measures the consistency over time with which a model generates understandable and workable results.

The approach taken in the design of ALINET, which influenced the scope of work and, consequently, the results of the study, was one based on the above tests and, especially, on the first three, which are more directly related to the developmental phase of a model. The last two tests concern more the institutionalization and use of such a model in the policy process, part of the proposed future scope of work.

To facilitate establishing the model's credibility, a pilot project was carried out with the cooperation of the Pillsbury Company. The project focused on the engineering and energy conservation aspects of wheat processing. Two realizations of ALINET were developed: CERES I (hard wheat milling) and CERES II (durum milling and pasta manufacture). The direct participation of experts in the various facets of the operations was an essential component in model verification and validation.

II. MODEL SPECIFICATIONS

ALINET is a network model in which the fundamental quantities that flow through the system are materials - specifically, agricultural commodities. They start as agricultural products at the farm level, e.g., wheat, soybeans, or milk and are converted into food products - bread, oil, or cheese. The processing of the commodities is represented by a sequence of transformations, each one of which changes the state of the material. Typical examples of states are wheat grain at the farm, wheat at the mill, flour at the mill, or bread at commercial bakeries. A state is represented by a *node*. The transformation of the material - the process - is characterized by a production (or throughput) function and is represented by a *link* that interconnects two nodes. Typical processes include transportation, milling, baking, canning, or drying. The use of nodes and links results in the representation of the food processing and distribution sector by a directed graph.

The simplest use of the structural model is to carry out a static annual simulation - as a sequence of twelve monthly simulations - of the food processing sector. Specification of the inputs at the source nodes, of the allocation coefficients that determine the flows along the links, and of the processing coefficients that quantify changes in weight due to processing, is sufficient to establish the material flow. Material flow is characterized fully by the quantity at each node of the system as a function of time. Adding the twelve monthly quantities at each node yields the annual quantity. This is the version of ALINET that has been used for the pilot project described in this report.

The next level of complexity is obtained by solving a local maximization problem - an optimum resource allocation problem subject to constraints - for each link. The first order conditions are, of course, conditions of the marginal productivities and the costs of each factor of production [2]. This version has been analyzed, but not implemented.

The extension of the static model to the adaptive one is direct. If resource allocation problems are solved in each stage and productivities are determined, then it is possible, using expected price information, to make investment decisions that lead to changes in capacities of existing processes, in the phasing in of new processes, and phasing out of less productive ones. The procedure takes into account the delay between the time investment decisions are made and the time that the new plant capacity comes on line.

The conceptual model as described above provides the framework within which a variety of questions may be posed. Depending on the point of view of the user, the focus of such questions may be different. For example, decision-makers concerned with establishing priorities for R&D funding for new energy conserving technologies within the overall food processing and distribution sector, and evaluating technologies once proposed, will require different information at a different level of detail than the manager in industry whose interest is the assessment of priorities for energy conservation and the analysis of the cost effectiveness of proposed measures at the plant level.

III. THE COMPUTER MODEL

The intended use of the model, to provide a framework for the analysis of new or proposed energy conserving technologies, motivated the specification of the computer modeling system. As the perceptions changed regarding the underlying behavior of the physical system represented by the model, an overall design was sought by which the development of the model and its software could *evolve* gracefully and in parallel with these changing perceptions. The notion of evolution of software rather than the more traditional one of development is introduced for two reasons. First, because of the fundamental *expectation* that both the questions of interest and the focus of the users *will* change with time. Second, in recognition of the effect on the design of increased understanding of specific problems and issues.

This point of view has influenced many of the design and implementation decisions made throughout the development of the model and has resulted in

a system that can be characterized primarily by the concerns for high dimensionality and flexibility. The structure of the ALINET system was decomposed at the outset into three major functional entities, the Data System, the Flow Graph Generator, and the Simulation System. The interconnections between these entities are depicted in Figure E.1; the comparison between the existing ALINET model and the eventual ALINET system is indicated by an asterisk (*).

Figure E.1 Structure of ALINET

In order that the design for the Data System remain workable over time, given the addition of new technologies or the expansion and contraction of subsectors within the network, the structure of the data base was centered

on the individual system elements (nodes, links, and processes) and the information required to characterize them. The description of each element is decoupled, to the extent possible, from the remaining entries. Geographical information and the attributes of the particular commodity (type, qualifier, form, location, end use and ownership) are associated with the node. The one step process descriptions for transforming the commodities (origin, destination, allocation and process coefficients, distances, and use of inputs) are associated with the links. This approach clearly implies a separate function to generate the network representation, which allows many different partial flow graphs to be drawn from the same basic data base.

In order to simulate the flows of materials through the system, an identifiable set of nodes, links, and processes must be associated to create an ordered network, representing the sequence of channels through which the materials flow. Indeed, the more generalized the Data System, and the greater the scope of the structural representation under study, the greater the need for comprehensive graph generation procedures. The recognition of this need, including the desirability of using graphical display techniques to aid the user in the verification of his network, led to the specification of the Flow Graph Generator.

The algorithm employed by the Flow Graph Generator translates the notion of sequential flows in the physical system to the simple graphical requirement that all transitions *advance* from left to right. The additional restriction that a node appear no more than once in a given representation allows a unique graph to be generated from a series of starting points or source nodes, the "one step forward" information contained in the link definitions which specify origin and destination and the left to right progression. Loops, resulting in a right to left transition, and implying an error in the data specification, can be detected as the graph is constructed. The result of the graph generation procedure, stored in the network data base, is the organization of the selected data elements into a sequence of levels, each containing a set of nodes, which are related to the stages of processing within the physical system. The paths through the network, along which material flows, correspond to the sequence of links interconnecting these nodes. The

function of the Flow Graph Generator was extended to include the software for creating the visual displays of the graph automatically in a way that permits both verification and structural insight.

Together these two entities, the Data System and the Flow Graph Generator, are used iteratively to create the representation of the portion of the food processing and distribution system suitable for study. However, these tools, as described, fail to meet one of the critical needs in the development of a large modeling system such as ALINET. This is the ability to insure consistency and validity of the data in the data base, both internally and with respect to external sources. The software designed to augment the Data System and Flow Graph Generator permits the examination of the data at periodic intervals from different points of view. The notion of data verification is treated by creating a linkage to a parallel automated data resource containing plant and facility type statistics against which, for example, the existence of a particular form of processed commodity in a particular state can be verified. The aggregation of data elements, from state level to regional and national levels, on the other hand, relates to data consistency and is therefore contained within the Data System. Both algorithms are based primarily on information describing the state of the material contained in the definition of each node and result in a set of data placed in the data base with the following characteristics: 1) each element can be traced to the entries of a particular state(s), and 2) the overall graph of the aggregate elements will have the same properties as the individual state graphs - a loop free representation of the material flow.

The Simulation System, the third of the functional entities within ALINET, is required only after the user is satisfied with his definition of the network. The representation of the network structure, acquired through interactions with the Data System and the Flow Graph Generator, provides a framework within which a variety of studies or analyses of the material flow under different conditions can be performed.

Several alternative simulation systems are possible in which the depth of the algorithmic sophistication (from static to adaptive) depends on the types of models of the system that have been developed. In each case, however, a similar structure is anticipated according to the following pattern. A complete simulation requires the execution of three distinct steps: 1) extraction of process and material data for the specific network and appropriate time of interest, 2) determination of the material flow and the use of process inputs and 3) analysis of the results. These steps are ordered so that beginning with the same basic graph, many different simulations can be specified at each point based on the output of a preceding step. The data extraction routine creates the baseline simulation input file according to user requests which permits a complete pass through the network using baseline or default values for all system inputs. Two forms of baseline modifications are accepted at this point: 1) changes to single data values via entries in a temporary update file, and 2) global changes through the introduction of user specified process models. The existence of a temporary update capability was considered essential in that it permits a variety of "what if" questions to be posed without affecting the permanent data base.

The Simulation Post Processor is presented with a tableau of information containing not only the structural network data and the input to the simulation but the results of each run of the simulator as well. At the heart of this software that integrates these results for the overall system, defines and evaluates specific measures of interest, and performs the desired analysis is the algorithm by which the use of process inputs within the system can be attributed to the production of a specific commodity. It is clear that such accounting cannot be performed concurrently with the forward determination of the flow, since the knowledge of the disposition of the flow through later points in the system would be required. One begins therefore from the commodity of interest and traces backwards through the network to identify the paths by which the commodity was produced. The backward sweep through the network from a selected node

traverses each path to that node from any other part of the network only once, and permits the portion of the flow arriving at the endpoint (and therefore the process inputs used) to be determined in the process.

IV. THE PILOT PROJECT: WHEAT

The processing of wheat was selected for the pilot project because it is a leading food crop and a major factor in the U.S. economy. Furthermore, wheat is a non-uniform commodity with different varieties growing in different regions and at different times of the year. Each kind is best adapted for specific end use in different wheat products.

Within the wheat system, it was decided to focus initially on the seven state North Central region, consisting of Kansas, Nebraska, South Dakota, North Dakota, Minnesota, Iowa, and Missouri. These seven states, a self-contained geographical unit, represent and exemplify the important aspects of wheat production, processing, distribution and consumption in the United States; they also, within a relatively limited area, exemplify the great variety and complexity of the wheat system from state to state.

The first stage of the pilot project consisted of the development of ten distinct, interconnected state-level networks for hard red winter, hard red spring, and durum wheat. In these representations some processes were represented in a simplified form (e.g., baking); milling and pasta manufacture, however, were modeled in detail. These processes were emphasized because the Pillsbury Company, who had agreed to participate in the project, had expressed special interest in hard wheat milling and pasta manufacture. Furthermore, both processes showed promise in terms of energy conservation opportunities.

Following the structural analysis of the state networks, two case studies were carried out. The first one, CERES 1, focused on the Atchison, Kansas, mill of Pillsbury. It is a relatively simple three stage model of hard wheat milling -- grain input to the mill, milling, and distribution of mill output.

Wheat is transported from Kansas, Nebraska, and Missouri to Atchison, where it is milled into flour and by-products. The milling process itself is represented in an aggregated form, but the overall energy used in making many products is clearly indicated. The model ends with the transportation of multiple products to users and Pillsbury warehouses. The CERES I model contains 41 nodes, two sub-nodes, and 55 links, as shown in Figure E.2.

CERES II, durum milling and pasta manufacture, is a much more complicated and comprehensive five stage model. More detail was included partly because more detailed data were available and, more importantly, because pasta manufacture provided greater opportunity for demonstrating the uses of ALINET in addressing a realistic industrial problem. The American Beauty Macaroni Co. facility in Kansas City was placing in operation a new microwave drier in place of a conventional drier. While it was assumed that one of the advantages of introducing an alternative technology would be an increase in plant productivity, it was not clear whether overall energy conservation would be achieved. Not only was there a change in the mix of energy inputs, but also the throughput parameters of the plant were changed. Analyzing and comparing combinations of alternative material flows and energy consumption is one of the design features of ALINET.

In order to trace the processing of durum into pasta products, it was necessary to model the movement of durum from the farm to the mill, the milling into semolina and durum flour, and the transportation of the pasta ingredients to the pasta plant. Data on durum milling were obtained from the Peavey Company's mill in Hastings, Minnesota, a major supplier for the American Beauty pasta plant (ABPP) in Kansas City. Thus, CERES II has five stages: movement of durum grain to Hastings; durum milling in Hastings and other durum mills; transportation of semolina and flour to Kansas City; pasta manufacture; and distribution of pasta products. The CERES II flow-graph* contains 70 nodes, 8 sub-nodes and 118 links.

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* See Figure 6.2 in body of report.

Figure E.2 The CERES I Model

The models for the two test cases are similar in many respects to the state models designed earlier. The underlying philosophy is the same, and many of the nodes and links (although designated and numbered differently) are identical with the corresponding nodes and links in the state and national level networks. However, because *specific* facilities are modeled, in contrast to the generic models of the earlier versions of ALINET, modifications, additions, and different kinds of aggregation were required.

Method of Approach

The procedure used in developing the detailed simulation model consists of two steps. The first one concerns the material flow in the network, and the second addresses the use of energy and other inputs in transforming grain into final products.

The first quantities to be determined are the supplies at the source nodes which are then distributed to the various links that leave the nodes through a set of coefficients that express the fraction of the supply allocated to each link; these fractions are called "allocation coefficients." A second set of parameters, the "process coefficients," specifies weight changes that occur while the material undergoes processing, i.e., moves along a link. These coefficients reflect, in an aggregate form, the engineering aspects of the processes.

Energy use is expressed in terms of a set of energy coefficients that denote the amount of electricity, natural gas, oil, and diesel fuel used for each unit of material in each link. Transportation coefficients, a subset of the energy coefficients, denote the amount of diesel fuel used by the various modes to transport one unit of product one mile. The coefficients are assumed to be invariant in time and space.

Once the flow and energy coefficients were specified and the quantities at the initial nodes established, static simulations were run for the two case studies. Twelve computer runs were made for each, one for each month of the respective baseline year. These simulations of the behavior of the system

allowed examination of the overall material flow and energy use, and computation of ingredient and energy requirements for specific products or groups of products.

Results: CERES I

Three distinct steps were required to carry out the analysis of CERES I:

- 1) Data extraction to create the simulation input file;
- 2) The actual simulation to determine the monthly flow of material and the use of resources; and
- 3) Use of the post processor to analyze the data produced by the simulation.

The simulation input file contained the description of the network and the allocation coefficients. Then the process coefficients and energy coefficients for electricity, natural gas, oil, and diesel, were added within the simulation input processor. As the determination of the material flows progressed, the use of the specific process inputs, by link, was computed. The post-processing function was performed on the twelve monthly simulations together, and the results, both for individual months and on an annual basis, displayed. The per unit energy requirements were computed for each one of the output commodities and for all of them collectively.

While electricity accounts for 38.7% of the energy used, it accounts for more than 55% of the costs. Conversely, natural gas contributes 15.1% of the energy, but only approximately 4% of the costs. However, as further and probably rapid increases in prices take place and the relative costs of fuels are readjusted as a result of the nation's evolving energy policy (e.g., deregulation), the importance for energy conservation will become even more pronounced. In milling, as Table E.1 shows, the emphasis should be on improving the efficiency of electricity use in the mills: better motors, fewer losses due to friction, better material handling that reduces the height and

the distance bulk material is moved, improved temperature and humidity controls, etc. The other major user of energy is transportation. Achieving a reduction in energy use in transportation is a more complex undertaking because it requires the simultaneous consideration of component aspects (e.g., fuel efficiency of engines), of systems aspects (e.g., optimum distribution systems), and economic aspects (impacts of regulations).

TABLE E.1 COST OF ENERGY BY SOURCE FOR CERES I

ENERGY SOURCE	ENERGY USE		1977 COST		1979 COST	
	10 ⁶ BTU	%	\$	%	\$	%
Electricity	46,260	38.7	338,160	55.2	541,242	55.7
Natural Gas	17,990	15.1	26,445	4.3	35,980	3.7
Oil	1,160	1.0	3,898	0.6	5,800	0.6
Diesel	53,980	45.2	243,989	39.9	388,656	40.6
TOTAL	119,390	100.0	612,492	100.0	971,678	100.0

Cost per pound of total output	0.15 ¢/lb.	0.24 ¢/lb.

Results: CERES II

The procedure used to carry out the simulations for CERES II was similar to the one for CERES I. The material flow was calculated first and then the backward sweep process was used to obtain estimates of energy use. Twelve monthly simulations were made for the period June 1978 to May 1979. Two alternatives were constructed. In the first one, the material flow remains the same and a microwave drier, operating at the same capacity level, is used to replace a conventional drier in the production line for short goods. This is denoted "Alternative I." In the second case, material flow is increased by 16.8 million pounds to utilize the full capacity of the drier. This is

"Alternative II." Since the material flow was the same for both the baseline case and Alternative I, only the backward sweep was carried out for the microwave alternative. The material flow for Alternative II was different, so adjustments had to be made to the baseline solution. The increased demand for semolina was allocated to the seven durum mills in proportion to their previous sales to American Beauty.

Analysis of direct energy use in the five stages of CERES II provides insight into energy conservation questions (Table E.2). The processing of semolina and flour into packaged pasta products accounts for 64-66% of the total energy use. The second major component is transportation, 26-27%. Thus, it is apparent that the most promising area for introducing energy conserving technologies and improving energy productivity is in pasta manufacture.

TABLE E.2 ENERGY USE BY PRODUCT GROUP
FROM FARM TO CONSUMERS-BASELINE CASE

PRODUCT GROUP	ENERGY PER POUND OF PRODUCT			
	BTU/lb	%		
		MILLING	PASTA MFR	TRANSPORT
LONG GOODS	1978	8	66	26
SHORT GOODS	1981	8	65	27
NOODLES	2036	9	64	27

The two microwave drier alternatives concern the production of short goods only. A comparison of energy use in the plant per pound of packaged short goods is presented in Table E.3. As expected, there is an increase in electricity use for Alternative I but a slight decrease for Alternative II. This occurs because the overhead component of electricity use is distributed over a much larger production base in Alternative II. The effect is even more pronounced in the case of natural gas which has a substantial overhead component. The net amount of energy conserved is 1,315 million Btu.

TABLE E.3 ENERGY USE AT THE PLANT: SHORT GOODS

	BASELINE (CONVENTIONAL)	MICROWAVE ALTERNATIVE I	MICROWAVE ALTERNATIVE II
ELECTRICITY	417	467	406
NATURAL GAS	669	524	448
OIL	208	169	145
TOTAL	1,294	1,160	999

UNITS	Btu/lb Packaged Product

In order to obtain an overall perspective of energy use in durum milling and pasta manufacture, total energy use, by fuel type, is presented in Table E.4. Consumption figures include energy used in transportation, milling, pasta manufacture, and distribution of retail and institutional products.

TABLE E.4 DIRECT ENERGY USE FOR ALL PASTA PRODUCTS: FROM FARM TO CONSUMER

	ENERGY-FUELS				ENERGY COSTS - 1977		ENERGY COSTS - 1979	
	ELECTRICITY	NATURAL GAS	OIL	DIESEL	TOTAL	PER POUND	TOTAL	PER POUND
BASELINE* (CONVENTIONAL)	5.09×10^6	21,632	47,971	108,913	253,868	0.781	389,360	1.190
ALTERNATIVE I* (MICROWAVE)	5.25×10^6	20,071	45,000	108,913	255,116	0.785	390,560	1.201
ALTERNATIVE II* (MICROWAVE)	8.01×10^6	27,359	61,743	175,850	387,240	0.772	594,190	1.115

UNITS	kWh	MBtu	Gallons	Gallons	\$	c/lb	\$	c/lb

* Production for Baseline and Alternative I is 31.6 million pounds; for Alternative II it is 49.2 million pounds.

The conclusions that can be drawn from analyzing the results can be summarized as follows. Replacement of conventional driers by microwave driers reduces fossil fuel use but increases electric energy use. If the design specifications of the driers are used in the analysis, then there is a net decrease in energy use. However, because of price differentials between different fuels (when measured in dollars per Btu) the cost of energy remains approximately the same. Whether the substitution of electricity for fossil fuels is desirable depends on local conditions and long term expectations of availability and price.

The introduction of the microwave drier allows for substantial increase in production using the same plant. It is much more compact and allows for higher throughput. Thus, the main contribution of the alternative technology is in increasing the productivity of a given facility - this is the dominant effect. This increase in productivity is feasible because the market for pasta goods is large and can absorb the increase in production. The strength of the pasta market is due not only to population increases, but also to the recent increase in per capita consumption.

V. CONCLUSIONS AND RECOMMENDATIONS

ALINET has been developed in three phases. In the first one, the conceptual design and the specifications of the system were made and then presented at a workshop to an advisory group for review and criticism. In the second phase, the computer model was designed and implemented while data and structural information on wheat processing were collected. In the last phase, a pilot project on wheat processing was carried out in cooperation with industry - the Pillsbury Company. Each phase provided a different perspective of the project's objective: the development of a model for analyzing proposed energy conserving technologies in the food processing sector and for identifying opportunities for research and development. Each perspective led in turn to several conclusions on the development of models, on their utilization, and on energy conservation.

On Models

- *A model to be useful in the policy process should be explainable and understandable.*

If a model is to be effective as a decision aid, then its underlying philosophy and its assumptions should be articulated clearly and concisely. Furthermore, the explanation of the model's premises and the limits of its applicability should be understandable not only to other modelers, but - most importantly - to model users. A substantial portion of the effort in developing ALINET was directed to documentation and interaction with potential users. In addition to two workshops that included representation from government, industry, and academia, many presentations were given to industrial and professional organizations.

- *Procedures for using the model should be simple and direct; the interface between the model and the user should be attuned to the concepts and terminology of the application area.*

If a model is to be used, then it should be accessible to persons with diverse backgrounds. Thus, the pre-processor, the input interface between the modeler and the system, and the post-processor, the output interface, should require and present information in terms of parameters, indices, and variables that are drawn from the applications area. In ALINET, some effort was expended in developing algorithms that accepted data in the form collected by plant or corporate management information systems. The output was expressed in terms of variables that are useful in decision making such as cost per unit, total amount of fuel oil required, monthly cost of electricity, etc.

- *A new model should be able to solve efficiently some traditional problems as well as the new classes of problems for which it has been designed.*

This consideration is very important in establishing a model's credibility in terms of workability and reliability. While ALINET has been designed for the assessment of energy conserving technologies, it can also be used as a

vehicle for solving a wide variety of traditional operations research problems such as optimum resource allocation, or determination of flows in the network, i.e., determination of optimum allocation coefficients, minimizing transportation costs, etc. The ability to use the model's network structure to formulate and solve such problems - which can be solved with alternative model formulations - enhances the model's usefulness and allows the user to develop confidence in using the model.

On the Analysis of Energy Conservation in the Industrial Sector

- *The method of approach in analyzing energy conservation opportunities should be based on detailed and specific case studies from which general, abstract results could be inferred.*

This is an affirmation of the approach usually referred to as "from bottom up" rather than "from top down." It is appropriate to note that the original approach to the problem was one based on going from the general and abstract to the detailed and specific. The first examples constructed with ALINET were national aggregate network representations of several industries in the food processing sector. The difficulties that would be encountered with such an approach were first pointed out by the participants in the Phase A workshop. First, a national aggregate representation does not capture the geographic diversity of agricultural production and food processing. Second, conclusions drawn on the basis of typical plants and typical costs are not credible in an industry with such technological diversity and wide variety of products. It is preferable to examine energy conserving technologies in the context of specific facilities and operations and then broaden the basis of the study. Furthermore, the introduction of a new technology in a plant is not an isolated event, but it usually stimulates other changes in production. The case study CERES II is such an example. While a specific technology may conserve energy, the reduction in energy use may not justify the capital investment. However, when it is coupled with plant modernization, or is part of new production facilities, then the resulting increase in plant productivity justifies the investment and leads to energy conservation. Thus, two interrelated conclusions are:

- *Energy conserving technologies should be studied in the context of the changes in production that they may stimulate, and*
- *Energy conserving technologies in the food processing industry should be analyzed in the context of productivity improvement.*

The main objective of the work thus far has been the development and proof of the concept of ALINET. This is an essential first step in the long process of establishing the model's credibility in its use in policy analysis by government agencies or industry. The next steps should be directed mainly toward model utilization and adoption. The effort should address primarily the last two of the five tests for credibility: workability and reliability [1].

To increase the model's usefulness and increase its applicability to food industry problems, a small set of projects, similar to the one carried out with Pillsbury, should be undertaken. Their purpose will be threefold: (a) to model issues of concern and provide useful quantitative analyses of proposed alternatives - either by industry or by government agencies; (b) to extend the resource base of the system by augmenting the data base and by creating the structural representations - the networks - of various sectors of the food processing industry; and (c) to identify the model's limitations and thus motivate the development of algorithms that solve different classes of problems (e.g., resource allocators, planning algorithms, etc.).

The selection of the specific sectors and technologies would depend on the importance of the sector as an energy user, the existence of potential opportunities or proposed technologies for energy conservation, and the cooperation of one or more firms or industrial institutions. Thus, the first recommendation is:

- *Several projects should be carried out in different sectors of the food processing industry. These projects should be so designed that they expand the data base of ALINET, contribute toward the development of a structural representation of the industry, and provide analyses on specific energy conservation issues.*

In parallel with this work, effort should be directed toward the development of a user oriented version of ALINET. As indicated earlier, ALINET is operational and can be used to carry out selected analyses on aspects of wheat processing. However, in order for the model to become a truly effective tool in the decision process, it must be easily accessible to diverse users and be transferable to different organizations. In addition to reviewing and revising the computer code accordingly, further attention should be given in specifying inputs and presenting both inputs and outputs in a format that is easily understood by model users. Already some effort has been expended in this direction: quantities are entered in units usually encountered in the industry (bushels, tons, KWh, MCF, gallons, etc.), converted to a consistent set for numerical computations, and then reconverted to traditional units.

Another aspect of this activity should be the implementation of a set of routines for presenting results in tabular and graphical format. This approach has already been tested; a commercially available software package was used to generate graphical representations of the network.

While these activities should constitute a small part of the overall effort for further development, implementation, and use, they are essential for establishing ALINET as a credible and useful tool. Therefore, it is recommended that:

- *A user-oriented version of ALINET should be developed from the currently operational version. It should be an easily transferable version and should include input and output processing routines that permit the operation of the model by diverse users.*

The third recommendation concerns the development of the dynamic and adaptive version of ALINET. As mentioned earlier, the current implementation allows for static monthly and annual simulations. The second level, the solution of a sequence of local decision problems to simulate resource allocation, has been studied, but not implemented. The third level, the dynamic and adaptive cases, need further research and development. This direction was not pursued more vigorously because it became apparent early in Phase B that the required data to support dynamic simulations were not readily available and could not be developed

in the context of this first project. But as the ALINET data base expands through additional case studies, it will become possible to carry out credible dynamic analyses. Thus, it is recommended that

- *Research and development effort should be undertaken to design and implement the dynamic and adaptive versions of ALINET. This effort should be carried out in conjunction with case studies from which the required data will be drawn.*

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I. INTRODUCTION:
ENERGY CONSERVATION, THE FOOD SYSTEM, AND ALINET

1.1 ENERGY USE IN THE FOOD SYSTEM

The developments during the last decade in the world food and energy markets have focused attention on U.S. agricultural production and U.S. energy policy. A prevailing theme in energy policy has been conservation and the development of energy conserving technologies.

Energy use in the food production sector more than doubled between 1947 and 1970 [1]; in 1970 the food and fiber sector required 12 to 13 percent of total energy used [2]. A study published in 1977 [3] estimated the proportion of the U.S. energy budget used on food production and preparation at 16 percent, and that it took eight quadrillion Btu of fuel to operate the total food system (production, processing, delivery, sales, and home preparation). Out of this, only one quadrillion Btu of food were consumed.

In the past, increase in food production was achieved to a substantial degree through the extensive substitution of non-renewable resources (fossil fuels) for labor. However, the abundance of cheap energy supplies on which these technologies are based can no longer be taken for granted. The decline in fuel availability and rapid rise in fuel costs are having a significant impact on food production: they may force changes in farming methods, in the mix of crop types, in the methods of processing, transporting, and storing commodities, and ultimately, in diet.

Very little food makes its way directly from farm to table; for example, wheat, the most important food cereal grown in the U.S., is typical of a commodity that must pass through a number of processors and distributors before reaching the consumer. Energy use is a factor in every step of the movement from farm to final destination: in transportation from farm to elevator and market, elevator to miller, miller to baker, and baker to distributor, as well as in maintenance of the establishments handling grain and grain products - elevators, mills, bakeries, wholesalers, and retailers. The milling of grain,

the baking of bread or biscuits, the production of pasta, and the packaging of the final products - all processes consume energy in various amounts.

A report published by FEA in 1976 [4], which examined studies to date on energy use in the food system, pointed out that all the discussions were dependent on the individual writer and that in all cases there appeared to be limitations in scope and viewpoint. Conflicts and inconsistencies, both in data used and conclusions drawn, could be attributed to differing coverage of food system components, use of differing energy units and conversion factors, consideration of different time periods, general deficiencies in energy consumption data available, as well as difficulties in accurately projecting from sample data. Consequently, the report concluded that the existing studies could not be considered adequate as a basis for energy policy decisions and that the most reliable data were those published by the *Bureau of Census* on which, indeed, most of the studies were based.

A study made by Development Planning and Research Associates in 1976 [5] made recommendations about the percentages of feasible energy savings in all food industries. However, at the same time the report conceded the difficulty in prescribing technologically feasible and economically viable energy savings for a given industry because of the broad variability in the applicability and/or degree of energy efficiency improvement which could be expected among plants. Thus, the procedure followed by DPRA was to prescribe composite industry averages based on the *data available*; and, the report argued, although such averages were not applicable to individual plants, the measure of energy savings potential would apply to the composite industry. Even given that the data available could be considered adequate, one might argue with policies that might be theoretically applicable to an entire industry without taking into account the regional and technological constraints facing the individual plants responsible for implementing measures for energy conservation.

The interrelationships affecting agricultural production, food production and distribution, and non-renewable resource use are complex. Each proposed new technology or proposed means of energy conservation must be viewed not only independently as it affects the particular process involved, but also

in conjunction with other likely changes occurring at other points in the food production system. The need to provide the capability of analyzing energy use in the energy intensive processing sector and to evaluate specific energy conserving technologies has provided part of the motivation for the development of ALINET (Alimentary Industry Network), a dynamic network model of the food processing and distribution sector.

It is not the purpose of ALINET to present definitive data - if such were possible - or propose definitive policies of energy conservation in the food system. Rather, by means of detailed and meticulous modeling of the network, ALINET is intended to provide a framework within which a variety of analyses may be carried out to determine the effects of such policies on the food processing sector.

1.2 ALINET: PHASE A - MODEL SPECIFICATIONS

The purpose for the development of ALINET is to provide a comprehensive set of tools for analyzing energy policies and for evaluating energy conservation and the attendant new technologies in food processing and distribution. It was stated elsewhere [6] that versatile and comprehensive policy analysis models demand the reconciling of two essentially conflicting objectives. If the results are to be of use in decision making, *accuracy* is essential; if the model is to allow for structural changes of the type that occur in a socio-economic system, an *adaptive structure* is necessary. The following criteria were considered essential in designing a model capable of providing the framework necessary for analyzing and evaluating energy use and energy conserving technologies in the food processing sector.

ALINET had to be dynamical in nature to reflect the structural changes that will continue to occur in this sector, and at the same time sufficiently detailed to permit the study of innovations in specific processes. The flow of commodities had to be traceable from the farm to the retail food market in such a way that the seasonal nature of crop production is incorporated. The processes which the farm commodities undergo during the conversion to food products had to be characterized explicitly, in order to account for the factors

and costs of processing and distribution. Measures of productivity had to be included to provide insight into the effectiveness of the new and alternative technologies under study. Ultimately, the model would have to be fully adaptive to represent the response to the feedback effects of price and quantity indicators from the crop and retail food markets, and to the feedforward effects of expected prices for goods and expected costs for the factors of production.

ALINET is a network model in which the fundamental quantities that flow through the system are materials - specifically, agricultural commodities. They start as agricultural products at the farm level, e.g., wheat, soybeans, milk, potatoes, and are converted into food products - bread, oil, cheese, whole potatoes or processed potatoes. The processing of farm products into food products can be thought of as a sequence of transformations, each one of which changes the state of the material. Typical examples of states could be: wheat grain at the farm, wheat in commercial storage, wheat at the mill, flour at the mill, flour at commercial bakeries, bread at retail outlets, flour at retail outlets. A state can be represented by a *node*.

For a material to be converted from one state to another, it must undergo a transformation - it must be processed. Typical processes include transportation, milling, baking, canning, refrigeration, freezing, cooking, dressing, etc. A process is characterized by a production (or throughput) function and is represented by a *link* that interconnects two nodes.

In order to carry out the transformations from one state to the next, capital, labor, other materials, and energy must be used in different amounts. Let these be considered inputs necessary to carry out the processes. The level of disaggregation depends on the types of question considered. If $\{U\}$ is the set of inputs, then, for each transformation or process that takes material i from $x_i(k)$ directly to state $x_i(k+l)$, $\{u(k)\}$ denotes the specific set of inputs required to effect the transformation from stage k to stage $k+l$, where $l=1,2,\dots$.

Although ALINET is designed to be used independently, in the analysis of some far-reaching issues, it may be desirable to use it in conjunction with

AGRIMOD [7], [8], [9]. AGRIMOD is a dynamic simulation model of the U.S. food production system designed for the analysis of (a) the implications of alternative national policies on the food supply, (b) the effects of possible natural resource and energy constraints on food supply and prices, (c) the impacts of policies on imports, exports, and reserves, and (d) the effects of technological change. The model consists of seventeen submodels (including a highly aggregated model of the food processing industry), fully integrated through material and information flows.

Agricultural processes are basically seasonal. Energy and fuel usage also have important seasonal components. In AGRIMOD, it was sufficient to establish a multistage sequence of events within the annual cycle. Since energy conserving technologies are the primary focus of ALINET, a more disaggregated structure is needed in which absolute time - a clock - is introduced. For this reason, a set of attributes is used, $\{a\}$, that includes as one of its elements the time of the year, which can be the month or the quarter, or some other appropriate unit. Both nodes and links - states and processes - are characterized by attributes; the mapping between the analytical and graphical representation is indicated in Table 1.1.

TABLE 1.1 ELEMENTS OF THE MODEL

ELEMENT	ANALYTICAL REPRESENTATION	GRAPHICAL REPRESENTATION
Commodity	i	-
State	x	Node
Process	$f(\cdot)$	Link
Inputs	$\{u\}$	-
Attributes	$\{a\}$	-

The food processing and distribution sector is represented by a directed graph. The graph is constructed by interconnecting nodes by links which

represent the transformations of commodities from one stage in the sequence of processes to another. The properties of the network which allow for the sequential determination of the flows and the explicit consideration of time can be depicted in the simplified graph of a typical sector, as shown in Figure 1.1. Node 1 represents the *entry* of a basic commodity, such as hard red wheat grain, into the system. It represents an example of a *source* node from which only outgoing flows are permissible and through which exogenous supply series for the crops considered could be introduced.

Figure 1.1. A Typical Sector

The *coalescence* indicated at Node 4 depicts the combination of commodities, e.g., the blending of soft wheat flour with flour milled from hard wheat to produce flour suitable for making cookies. Node 2 depicts the *interconnection* of this sector with another, as in "eggs destined for a bakery point." *Parallel processes*, representing alternative technologies for producing the same commodities, are depicted via parallel links from Node 4 to 6. A final market point at the retail level is represented by Node 5, while Node 3 represents either a sink node or an interconnection with another sector. The *sink* nodes represent points where material flows exit the system without going through a market; an important inclusion because, in addition to permitting consideration of conservation of mass checks, such nodes allow for consideration of the future use of by-products and of pollution/waste issues.

The basic flow graph starts with the commodity at the farm (including crop and livestock products) and terminates at the retail food market. Specification of the flows and of the parameters of the processes for a specific year establishes the initial condition for the system. The material flow graph is directional and does not include loops. This is a structural property of major importance because it allows for the explicit consideration of time and the sequential determination of the flows in the network. Associated with the material flow, there is information flow, and, specifically, information about prices and quantities of commodities and inputs. This information is fed back to all earlier stages and is used in the calculation of expected prices that are fed forward to all subsequent stages. An alternative conceptualization of the information flow that avoids the problems inherent in flow graphs with loops or circuits is the following: Consider a large matrix, or tableau, whose elements contain price and quantity information associated with each element of the input set $\{U\}$ and with each state x . The tableau is partitioned with each partition corresponding to a stage in the material flow graph. The information on the tableau is available to the whole system at each instant of time. At the end of each annual cycle, the tableau contains the realized prices and the quantities used or processed. Prior to starting the next cycle, expected prices are estimated, wherever appropriate, and substituted for the corresponding realized prices in the previous year. As the computations in each stage of the processing sector are carried out and information about realized prices and quantities is generated, the corresponding partition is updated. The result is an information matrix that evolves with time within the annual cycle.

The simplest use of the structural model is to carry out a static annual simulation of the food processing and distribution sector. It is assumed that all levels of inputs for each production function are predetermined. Then each process can be examined for its contribution to selected measures of performance. For example, total energy consumption in converting a portion of a certain crop into a specific food (e.g., wheat to bread) can be estimated by adding up all the energy inputs along the trajectory that converts wheat into bread; or the total labor and the associated cost for labor can be computed. This is the version of ALINET that has been used for the pilot project described in this report.

The next level of complexity is obtained by solving a local maximization problem - an optimum resource allocation problem subject to constraints - for each link. The first order conditions are, of course, conditions on the marginal productivities and the costs of each factor of production [12]. Since the flow graph does not contain loops and since the information tableau has been partitioned so that each partition corresponds to a stage in the flow graph, it is possible to solve all allocation problems in the same stage simultaneously, thus incorporating time-dependent resource limitations (short term dislocations in supply). This version has been analyzed, but not implemented.

The extension of the static model to the adaptive one is direct. If resource allocation problems are solved in each stage and productivities are determined, then it is possible, using expected price information, to make investment decisions that lead to changes in capacities of existing processes, in the phasing in of new processes, and phasing out of less productive ones. The procedure takes into account the delay between the time investment decisions are made and the time that the new plant capacity comes on line.

In the context of a postulated future scenario, it is straightforward to identify (a) the trajectories and (b) the links where the average and marginal productivity of energy is low or is decreasing and where alternative links or paths do not exist. This information is useful in establishing priorities for the development of new energy conserving technologies.

Once a new technology has been developed or even proposed, it is possible to place into the system the appropriate production functions/links and then analyze the resulting perturbation on the overall sector. The economic viability of the new process can thus be evaluated. Such an evaluation is complicated by the fact that new technologies may require high initial investment and may not be competitive economically in the short run, although they may be highly desirable for the long run. Therefore, consideration of possible tax incentives, subsidies, regulations, and other instruments to foster the use of venture capital in developing and marketing products or processes, based on energy conserving technologies, and to encourage market penetration of these products,

allows the assessment of the viability of the new process, and effectiveness of the policies instituted to promote the change.

The conceptual model as described above provides the framework within which a variety of questions may be posed. Depending on the point of view of the user, the focus of such questions may be different. For example, decision-makers concerned with establishing priorities for R&D funding for new energy conserving technologies within the overall food processing and distribution sector, and evaluating technologies once proposed, will require different information at a different level of detail than the manager whose interest is the assessment of priorities for energy conservation and the analysis of the cost effectiveness of proposed measures at an industry level.

1.3 ALINET: PHASE B - PILOT PROJECT: ENERGY USE IN THE WHEAT SYSTEM

During the first phase (A) of the project, detailed specifications of the model were developed, the basic structure implemented, the elements of the system defined at an aggregated level, and additional data sources identified. The design of the overall computer system was formulated in terms of criteria based on certain fundamental notions of the structure and behavior of the physical system, and consideration for the use of the computer system as an analysis tool. The considerations that influenced the implementation decisions were based on a preliminary assessment of the processing and distribution networks for several crops and livestock products: Wheat, Corn, Soybeans, Rice, Dairy Products, Meat, and Poultry and Eggs. This parallel, coordinated activity - the specification of the model and the supporting software and the study of the physical system - constituted the technical scope of work of the first phase of this project. The culmination of this activity was a workshop in which the modeling concepts, the computer system specifications, and an overview of the physical material flow networks were presented to an audience consisting of experts in energy use in food processing, as well as researchers working on the development and testing of energy conserving technologies. In addition to providing review and criticism of the work, the participants advised on data availability, on the status of various related efforts in industry and universities, and on the selection of the test case for analysis during the second phase of the project [10], [11].

On the basis of recommendations by the workshop participants, wheat was selected as the commodity for detailed study and modeling during Phase B. A key factor in the selection of the wheat system was the interest indicated by the Pillsbury Company, identified by the workshop participants as a leader among industries concerned in exploring possible areas of future energy conservation, and therefore most likely to have access to necessary information in the area of wheat processing. The Pillsbury Company expressed special interest in cooperating in the study of the transformation of hard wheat into bakery flour and family flour, and the transformation of durum wheat into pasta products.

Therefore, during the second phase (B) emphasis shifted to the detailed study of one commodity, namely wheat, the modeling of selected processes within the wheat system, the transfer of data to the data base, and the testing and verification of the model. In the first stage of Phase B, the emphasis of the research and development tasks was placed on resolving questions of system structure, both of the actual and the computer system. The second, and key part of Phase B, consisted of the pilot project carried out in cooperation with the Pillsbury Company, which included the development of two ALINET realizations, CERES I (hard wheat milling) and CERES II (pasta production). The technical effort focused on the engineering and energy conservation aspects of the wheat processing sector. In particular, the energy used in each link or process of the material flow network had to be established. The quantity of material that flows through each link had to be determined and link capacity limitations estimated. This type of information was necessary first for simulating the existing system, and then for considering the impact of technological changes.

Milling, emphasized in CERES I, is the most crucial step in the transformation of wheat into food products, and a necessary first stage for baking, cereal processing, or pasta manufacture. Milling itself includes a number of variations according to the wheat milled. For example, it takes an estimated 20% less energy to mill soft wheat than hard wheat or durum; also, extraction rates vary according to type and quality of wheat. Hard wheat milling can also serve as a representative example of the importance of location in determining the costs and availability of various types of energy, and different transportation modes for grain and flours permit the calculation of different energy inputs. The

modeling of pasta manufacture, emphasized in CERES II, permits the detailed study of another type of wheat - durum - and the modeling of alternate technologies within the wheat system. The recent introduction of microwave driers for short pasta goods and noodles makes possible the analysis and comparison of different uses of energy in processing.

1.4 THE REPORT IN OUTLINE

In the report that follows, two parallel, interdependent activities are documented, emphasizing the step by step development of an operational modeling system capable of handling the complexities of energy use in the food system, and of providing the necessary insights for its users into the behavior of the physical system. Specifically, the efforts to establish a realistic representation of the wheat processing and distribution system are described, along with the coordinated evolution of the design and implementation of the computer system to support that representation.

Section II, after an overview of the wheat system on the national level, describes the North Central Region, the area of interest for this particular stage of the project. State and regional summaries of wheat processing networks are given, the transportation and marketing issues are outlined, and specific wheat processing operations are described. Sections VI-VIII, which document the pilot project with the Pillsbury Company, shift in focus from the national or state level to the plant-specific level. The modeling experience and knowledge of the physical system gained in implementing the state and national networks were brought to bear on the development of the two pilot submodels, CERES I and CERES II. The structure of the two models is described, and the results of the simulation runs are presented. Special attention is paid to the modeling of an alternate technology and the effects of technological change on energy use, cost, and productivity.

Sections III-V, which form a self-contained unit that can be read separately or in conjunction with the rest of the report, describe the ALINET computer system. Section III presents an overview of the computer model and its underlying philosophy. The incorporation of facility data into the ALINET data

system, the generation of state-level flow graphs, and their aggregation to a national level are described in Section IV. The validation and verification procedures that were employed for state graphs are outlined, and the various national aggregation procedures used are analyzed. Section V details the simulation system developed for CERES I and CERES II.

Finally, Section IX presents the conclusions and recommendations, and indicates some possible areas for further research and development.

II. ALINET AND THE WHEAT SYSTEM

2.1 THE NATIONAL WHEAT SYSTEM

Careful consideration was given to the first food commodity sector chosen for detailed modeling. It had to be of sufficient scope, economic importance, and complexity to warrant the development of a flexible modeling system, adaptable to other sectors as well as responsive to changing questions and technological changes.

Wheat has been the leading food crop and a major factor in the U.S. economy since pre-Revolutionary days; partly because of its importance and long history, the wheat system is also one of the most complex among U.S. food producing and processing industries and exhibits great regional variation. There are many kinds of wheat, varying in color and hardness of kernels, winter or spring growing habit, starch and protein content, milling characteristics, etc. Each kind is best adapted for specific end use in different foods. Different varieties are best adapted for growing in different parts of the country; the same variety grown under different climatological conditions can exhibit considerable variation in characteristics of grain produced. A model of the U.S. wheat processing network, therefore, requires careful regionalization.

2.1.1 Distribution of Production

The five main classes of wheat grown in the U.S. and modeled in ALINET - hard red winter, hard red spring, soft red winter, white, and durum - can also be grouped in three networks - hard, soft, and durum - according to their processing methods and end products. For example, both hard red winter and hard red spring are used for bread and bread flours and have the same milling properties; consequently, they pass through similar processing chains. However, they are grown in different parts of the country; hard red winter is mainly grown in the Central Plains states, including Kansas, Oklahoma, Texas, Nebraska and Colorado, while hard red spring is grown in the Northern Plains, wherever the climate is too cold for winter wheat - the Dakotas, Minnesota, and Montana. Consequently, the spatial distribution, as well as the marketing channels at

the beginning of the processing network, are different. In a similar manner, because most of the white wheat grown in the U.S. is soft, it can be grouped with soft red winter in the soft wheat processing network, ending in such products as cakes, pastries, and biscuits. Again, however, the two varieties are grown in different states, except for Michigan, which produces both soft white and soft red. Otherwise, white wheat is grown mainly in the Northwest Pacific states - Washington, Oregon, Idaho, California - as well as in New York, while soft red is mainly grown east of the Missouri and Mississippi Rivers. Durum wheat, a distinctly separate variety which is used in the making of pasta products, is grown in the same general area as hard red spring wheat - the Dakotas, Montana, and Minnesota - as well as in California.

Figures 2.1 - 2.5 indicate the general production areas for different wheat varieties. However, the varieties grown in any one area can change from year to year, and sometimes new varieties are grown before they are officially reported. For example, *Varieties of Wheat Grown in the U.S. in 1969*, issued by ERS [37], showed California growing mainly white wheat, as well as some hard red spring and durum. The wheat variety reports issued by the California Crop Reporting Board in recent years, however, show that since 1975, hard red winter has accounted for over 75% of the acreage planted, durum for about 7-8%, and the rest has been white, with hard red spring negligible. Arizona grew considerable amounts of durum in 1975 and 1976, although in 1975, it was not reported separately; in addition, this "desert durum" was grown as a winter wheat. However, because many millers tended to be dissatisfied with its quality, much of Arizona durum was phased out.* Colorado is generally classed as an all-hard wheat state; nevertheless, in recent years it has tried to develop its own soft wheat supply.**

2.1.2 Markets, Storage, and Processors

There are two separate wheat markets in the U.S., one for cash grain and one for grain futures. Grain futures are traded only in Chicago, Kansas City,

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*Personal Communications, Arizona Crop Reporting Service (Horace Mays, 3/78) and *Milling and Baking News* (Mel Sjerven, 10/78).

**Personal Communication, Peavey Co. Eagle Mill, Denver, Colorado (7/78).

Figure 2.4. Leading States Producing Soft Red Winter Wheat.

Figure 2.5. Leading States Producing White Wheat.

and Minneapolis, but cash grain prices may be quoted for Kansas City, Houston, Omaha, Chicago, Toledo, St. Louis, Minneapolis, Portland, Denver, Baltimore, etc.; export prices may be quoted for Duluth, Pacific Northwest, Gulf Coast, and East Coast. The three futures markets for wheat provide cues for most wheat pricing, although saying that futures prices determine cash prices would be an oversimplified answer to a complex question [13]. Each of the three markets tends to be dominant in pricing one type of wheat, determined by the types of wheat grown in the area where the market is located, though all types are traded. Thus, Kansas City is most significant in pricing hard winter wheat, Chicago in soft wheat, and Minneapolis in hard red spring and durum.

The prices on all markets are close because the bidders will buy in the most attractive market. Transportation costs will account for most of the difference in prices.

The three major markets mentioned above are tremendously important because they provide reference prices for cash sales throughout the country. Because of the hedging techniques used by farmers and mills, prices are often quoted in terms of the futures prices even for cash sales. For example, Portland is a cash market that is primarily important for local mills and for export trade to the Pacific. Since the Northwest grows soft white wheat, its prices are similar to Chicago's. Some of the cost difference is due to transportation, the rest because it is a separate market, and particularly if there is a higher export demand, the price may not always track the Chicago quotation.*

The proportion of off-farm vs. on-farm wheat storage varies greatly from state to state. As can be seen from data in *Grain Stocks*, published quarterly by USDA, in such major producing states as Kansas, Oklahoma, and Washington, 75% or more of the stocks are stored off-farm, but in North Dakota and Montana, over 70% are stored on-farm. One should note, also, that the grain in off-farm storage in any one state need not have been produced in that state. For example, Wisconsin produced, in the crop year ending in 1976, only 3.24 million bushels of wheat [14], but on October 1, 1976, it had 20.72 million bushels in commercial storage [15]. Much of this grain obviously was stored at port and terminal elevators in Milwaukee and Superior, destined for shipment on the Great Lakes, and did not originate in Wisconsin.

While data on off-farm grain storage capacity have been compiled by USDA since 1943, the first *comprehensive* storage capacity survey was conducted only recently by the USDA agencies: on-farm storage data were gathered by the Agricultural Stabilization and Conservation Service, while capacity of commercial elevators was surveyed jointly by ASCS and ESCS [16]. Grain storage capacity, of course, is utilized for other grains and oil seeds as well as wheat. The ALINET data base contains storage capacity at terminal elevators and at flour mills.

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* Personal Communication, Portland Grain Exchange (Dick Copeland, 7/78).

Processors in the wheat system include mills, flour packaging plants, bakers of bread, cake, and biscuits, breakfast cereal processors, and pasta makers. All are distributed throughout the country, but concentration of any one type of processor varies greatly, and is not always determined by areas of production. For example, hard wheat milling is concentrated in hard-wheat producing areas, especially in Kansas and Minnesota, and mills that grind only soft wheat are located mainly in soft wheat producing states, but capacity for milling both hard and soft wheat is distributed all over the U.S. However, Missouri, which grows mainly soft wheat, has a much larger capacity for hard wheat milling, and must import its hard wheat grain. New York, which in 1976 grew only 5.94 million bushels of wheat [14], mostly soft white, ground 60.815 million bushels [17] in its 13 mills that year, drawing much of its supply from North Dakota and Minnesota. Moving grain from production areas to millers, and flour from mills to bakers or other processors, often involves elaborate distribution networks and transportation routes. Some of the complexities of wheat processing can be illustrated by a brief summary of the distribution of durum processing. .

Table 2.1 shows the durum producing states, while durum mills and their capacities are indicated in Table 2.2. Durum is also milled in California and Montana, on an alternating basis with hard wheat flour. The Minnesota and Wisconsin durum mills mainly receive their grain via rail from North Dakota; North Dakota durum also supplies the New York mills, being shipped either via rail or over the Great Lakes. Montana has been the main supplier of the Oregon mills, although durum milled on the West Coast can also originate in California and even Arizona. The Louisiana mill obtains its grain from North Dakota and Minnesota via barge on the Mississippi River and subsequently by rail. The durum mills serve as sources of supply of durum products for pasta makers in their general area: the Midwest pasta makers obtain their semolina from Minnesota, North Dakota, and Wisconsin, New York mills supply the East, the Oregon, California, and Montana millers supply the West, and the pasta plants in Louisiana and Texas (the only ones in the South) draw their supply from the durum mill in Louisiana.*

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*Personal communications with millers and pasta producers.

TABLE 2.1 DURUM PRODUCTION, 1976, 1977*

STATE	PRODUCTION	
	1976	1977
North Dakota	90.5	60.5
Montana	8.6	4.8
South Dakota	1.6	3.3
Minnesota	2.7	2.8
California	6.4	2.1
Arizona	23.9	6.1
New Mexico	1.2	0.3
TOTAL	134.9	80.0

UNITS	Million Bushels

*Source: *Agricultural Statistics*, 1977, 1978 [14].

TABLE 2.2 U.S. DURUM MILLS*

STATE	NO. OF MILLS	CAPACITY
Minnesota	5	31,100
New York	3	14,800
Wisconsin	1	12,000
Oregon	2	8,750
North Dakota	1	5,000
Louisiana	1	1,000
TOTAL	13	72,650

UNITS	cwt/day

*Source: ALINET data base, *Milling and Baking News Directory*, 1978 [39].

The ALINET data base currently contains information about the number and capacity of U.S. wheat flour, durum, and bulgur mills, but is being extended to include information about other processors as well.

The requirement for definite types of wheat for different products in turn necessitates the movement of wheat between different parts of the country; for example, a state producing mainly soft wheat needs to import hard wheat or hard wheat flour for its bread. Transportation is the vital link connecting

areas of production with areas of processing and consumption. Theoretically, the differential between grain prices at any two points represents the cost of transportation between them. Changes in transportation costs can profoundly affect all relationships among terminal, domestic, and export markets, transportation modes, individual carriers, and the location of grain elevators and milling or processing plants. Any disruption in the transportation system may have far-reaching economic effects. As a result of the 1978 rail strike by Norfolk and Western, and actions by unions on some 70 carriers, flour mills in practically all areas were faced with the necessity of reducing running time, in some cases to only two or three days, at a time when six-day grinds are normal [18].

Each mode of transportation has certain advantages. Railroads and barges are generally used for long hauls, while trucks specialize in shorter hauls - such as moving of grain from farm to country elevator, or bread from baker to retailer.

Railroads have been the principal movers of wheat and wheat products since the mid-1800's. However, rising costs for railroads, as well as improved highways and freight rates which have expanded the areas accessible to trucks and barges and reduced their costs, have sharpened the competition between the various carriers and necessitated various rate adjustments. Traditionally, rail grain rates were designed to minimize location advantage. Rates were adjusted to provide many local country elevators, as well as terminal markets, with the same rates to the same destination, even though distances varied. In-transit privileges were an important part of this rate structure; grain could be stopped for storage or milling in transit and continue to the final destination with the remainder of the through rate. As new producing areas came into the picture, and wheat shipments by water increased, new rate adjustments had to be made. In many cases grain carries the same rate as grain products. Under such conditions storage and processing functions may be performed in the production area, in the consumption area, or at intermediate points. However, once facilities have been established under one set of rate conditions, if or when rate relationships change, market areas, supply areas, or even location of storage and processing centers may change significantly [13], [19].

The current ALINET data base contains information about transportation modes for receiving and loading for all terminal and port elevators in the U.S. These include rail, truck, barge, lake vessel, and ocean vessel. Any combination of them may be utilized by different elevators; more information in this area is presented in the discussion of facilities and processors in Section IV. The information about transportation to and from terminal elevators establishes the crucial transportation links in grain movement in each individual state. Other transportation links in both the state and national wheat networks - for example, from farm to country elevator, miller to baker, or pasta manufacturer to retailer, were established and verified in a number of ways: geographical study of the area and transportation modes existing, information published in state statistics and *Grain Market News*, consultation with State agricultural and marketing departments, *Milling and Baking News*, and many of the marketing agencies, millers, bakers, and pasta makers involved.

2.1.3 Seasonal Factors

Harvest dates in individual states may vary slightly from year to year because of the weather, although the variation is not very great. The following generalizations can be made for the U.S. The harvest starts late in May in Texas and moves north, finishing by early September in North Dakota and Montana; in fact, the same combines that harvested in Texas in May might be in North Dakota in September, and the ones who harvested in Southern California in early June may be in August - September in Washington. In most states, the harvest will last less than a month, unless the state happens to grow both winter and spring wheat. Most winter wheat, even in the most Northern states, has started being harvested by the end of July, and by the middle of September at the latest, all spring wheat has been harvested. The two months immediately following harvest are the heaviest periods of grain marketing. For example, Missouri farm sales of wheat amounted to 39% in June and 36% in July for 1976, dropping to 6% in August and 3% in September [20]. In Minnesota, where more grain is stored on farm all year, 22% was marketed in August of 1975 and 17% in September, dropping to 8% in October and 5% in November [21].

Generally, wheat prices nationwide are lowest when the harvest begins and they peak in late August, after most of the harvest is over [22]. However, these trends may be influenced by numerous factors. For example, in a year where a considerable part of the crop was destroyed prior to harvest, these trends would not hold, since the expected amount and quality harvested are important determinants in the futures market.

The number of days of operation for all flour mills varies from 3 to 7 days a week, computed on a 24-hour basis. Running times vary seasonally, but generally operation is continuous throughout the year, except for traditional holidays. Mill operation for 1977-78 is summarized in Table 2.3.

TABLE 2.3 SEASONAL VARIATIONS IN MILL GRIND

SEASON	WEEKLY GRIND (Days)
August - November	6 - 7
December - May	5 - 6
May - Early June	4 - 6
Late June - July	3 - 5

These grind rates hold fairly constant for all types of wheat products, though bakery flour mills seem to run a little longer, and durum mills a little shorter. In any given week, there are deviations of a day or less between different areas, with higher grind resulting from the particular orders received by each mill [23]. For the entire U.S., the average output of all flour mills is around 1 million hundredweight (cwt) per day [24]. Factors influencing mill operation may include:

- Seasonal demand for products (lower pasta demand in summer, back-to-school increases in demand for family flour),
- Seasonal price changes for grain,
- Availability of transportation (with rail car shortages, mills will run below normal rates),
- Balances of flour on hand by bakers,
- Export demand for flour.

Wheat flour is sold to bakers anywhere from 1 week to 4 months before it is used. All bakers keep some stockpile coverage, which fluctuates depending on prices and availability of transportation. Semolina and durum flour users keep a fairly steady 30 day coverage, increasing their stocks slightly before Thanksgiving (45 day coverage) and in the late spring. Spring coverage may reflect the slowdown in demand, rather than a conscious building up of stocks.

West Coast hard wheat flour users tend to have wildly fluctuating coverage, though they seldom let stocks fall below the 30 day level, nor does coverage exceed the 120 day level. Coverage tends to depend on the company buying, though it is usually about 60 days. It falls in the 30 to 60 day range right before harvest, and peaks at 90-120 days during November - January [23].

2.2 WHEAT IN THE NORTH CENTRAL REGION

Within the wheat system, it was decided to focus initially on the 7-state North Central region, consisting of Kansas, Nebraska, South Dakota, North Dakota (which correspond to AGRIMOD Region III, Northern Plains) [8] with the addition of Minnesota, Iowa, and Missouri. These seven states, a self-contained geographical unit, represent and exemplify the important aspects of wheat production, processing, distribution and consumption in the United States; they also, within a relatively limited area, exemplify the great variety and complexity of the wheat system from state to state. The area includes the two leading wheat producing states - Kansas (for hard red winter) and North Dakota (for hard red spring and durum) and the two leading flour millers - Kansas and Minnesota (the latter being also first in durum milling and a leader in pasta production). Two of the three central markets, for cash grain as well as wheat futures, are centered in Kansas City and Minneapolis. Kansas and North Dakota represent the two extreme examples in modes of wheat storage; Kansas holds first place in amount of commercial storage space, while in North Dakota, on-farm storage is still predominant. The various modes of transportation, and the problems associated with them, are represented in the region: rail (still the leader in wheat transport), truck, and, because of the Missouri and Mississippi rivers, barge traffic, while Minnesota (Duluth) is an important point for grain shipment via the Great Lakes. In addition, Nebraska processes breakfast cereal,

while Missouri produces and exports soft wheat. A brief summary of the important features of wheat production, processing, and distribution in each state follows.

2.2.1 Kansas

Kansas holds first place in the U.S. in wheat production (339 million bushels in 1976 [14], almost all hard red winter), and in flour milling (70.37 million bushels of wheat ground and 31.57 million hundredweight (cwt) of flour produced in 1976 [17]). *Milling and Baking News Directory* currently lists 18 mills in Kansas, with a daily milling capacity of 118,050 cwt, which includes a capacity for 5,160 cwt of soft wheat flour and 810 cwt of whole wheat flour [39]. Kansas also has a bulgur mill with a capacity of 5,000 cwt/day; bulgur is, however, almost exclusively used for export.

Kansas has over 60 terminal grain elevators, and its off-farm grain storage capacity rose from 780 million bushels in 1976 to 830 million bushels in 1978 [25], making it first in the nation. Grain storage facilities, of course, are used for storing other grains besides wheat. For example, *Grain Stocks* reported Kansas wheat stocks as 374.24 million bushels off farm and 74.58 million bushels on farm for October 1976 [15].

Kansas millers import some hard spring wheat from the Dakotas or Minnesota for producing winter-spring flour blends. In addition to its mills, Kansas has numerous family flour packaging plants, prepared mix manufacturers, wholesale bakers, biscuit and cracker manufacturers, and a pasta plant [26], [27].

2.2.2 North Dakota

North Dakota is second only to Kansas in total wheat production (286.1 million bushels in 1978 [28]) and leads in hard red spring (180.1 million bushels in 1978) and durum (102.1 million bushels in 1978). However, unlike Kansas, North Dakota has relatively few terminal elevators (the *Milling and Baking News Directory* listed eight elevators in 1978 and four in 1979); therefore, the country elevators play the dominant role in wheat marketing. Most storage is on-farm (238.9 million bushels on-farm vs. 67.45 million bushels off-farm in October 1976 [25]).

North Dakota has only one mill with a capacity of 7,000 cwt/day for hard wheat flour and 5,000 cwt for durum [39]. It ships out most of its production, via truck and rail, through the Minneapolis or the Duluth - Superior area, although some grain is also shipped west [28]. North Dakota is the chief supply source for the majority of U.S. durum mills, although the mills in the West get most of their supply from Montana, California, and even Arizona. North Dakota has no prepared mix manufacturers, biscuit and cracker manufacturers, or pasta plants [27], [39], although a proposal to build a combined durum mill and pasta plant in Cando was put forward early in 1979 [41].

2.2.3 Nebraska

Nebraska is second only to Kansas in the 7-state region in the production of hardred winter (94.4 million bushels in 1976 [14]). Nebraska also has six mills with a daily capacity of 28,970 cwt, including 200 cwt/day of whole wheat flour [26]. It mills considerably more flour than needed for local consumption; therefore, it exports flour as well as grain. Export movement is similar to that in Kansas - by rail to Texas Gulf ports and via rail and barge to ports in Louisiana. Nebraska is also a major producer of breakfast cereal. Like Kansas, Nebraska imports hard red spring wheat for flour blends and soft wheat flour for its sweet goods (Nebraska has no soft wheat milling capacity).

2.2.4 Minnesota

Minnesota produces a considerable amount of hard red spring wheat (87.8 million bushels in 1978, second only to North Dakota) as well as some durum (3.77 million bushels in 1978 [21]). The state is even more prominent as a miller; it is second only to Kansas in amount of wheat flour milled and first in the U.S. in durum milling (70.40 million bushels of wheat, including durum, ground and 31.94 cwt of flour produced in 1978 [38]). Minnesota sends its durum products to pasta manufacturers all over the U.S., especially the Midwest; it also has four major pasta plants [27]. Minnesota mills process a great deal of the wheat grown in the Dakotas; in addition, the state serves as the central market and export point for both hard wheat and durum grown in the area.

2.2.5 South Dakota

South Dakota exhibits some unique characteristics. It produces considerable hard red winter, hard red spring, and durum, though not as much as some of the other states in the region. The state has no terminal elevators, but numerous large country elevators. Its country elevators ship grain to central markets out of state, especially the Minneapolis and Sioux City areas; or country elevators may use subterminals as collecting points to ship grain directly for export, either via rail to the Great Lakes or by barge to Louisiana.* South Dakota has only one hard wheat mill, and needs to bring in both hard and soft wheat flour from out of state for its bakeries [27], [39].

2.2.6 Missouri

Missouri is mainly a soft wheat state (over 85% of production), and soft wheat is a leading Missouri export, to neighboring states as well as via the Mississippi to the Gulf. However, Missouri has a hard wheat milling capacity of 68,948 cwt/day as well as 13,550 cwt/day for soft wheat and 500 cwt/day for whole wheat flour (milled from hard wheat). In 1976, Missouri produced 47.43 million bushels of soft wheat and 7.02 million bushels of hard red winter; ** the same year it ground 52.81 million bushels and produced 23.59 million cwt of flour [17]. Thus, Missouri mills more hard wheat than it grows, utilizing grain from Kansas, Nebraska, and Minnesota.

Missouri also has a unique position in the transportation network, because of the presence of both Mississippi and Missouri rivers. Both are main arteries in grain transport, and St. Louis especially is a focal point in the movement of grain from the North for export through the New Orleans area.

2.2.7 Iowa

Iowa is mainly a producer of corn and soybeans. It grows little wheat, therefore needing to bring in both grain for its mills and flour for its

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*Personal Communication, Division of Markets, South Dakota Dept. of Agriculture (Dale Gullickson, 8/78).

**Computed from *Missouri Farm Facts*, 1977.

bakeries. Iowa, however, has extensive terminal elevator facilities, which can be used not only for corn and soybeans, but also for wheat produced out of state. The Sioux City area on the Missouri River, for example, is a focal point for wheat collection from South Dakota and Nebraska.

The tables that follow (2.4 - 2.7) illustrate some of the most important characteristics of wheat production, storage, and processing in the North Central Region.

TABLE 2.4 WHEAT VARIETIES GROWN IN THE NORTH CENTRAL REGION, 1976, 1977*

STATE	HARD RED WINTER		HARD RED SPRING		DURUM		SOFT RED WINTER	
	1976	1977	1976	1977	1976	1977	1976	1977
Kansas	339.0	344.9	-	-	-	-	-	-
North Dakota	3.8	2.4	193.6	167.0	90.5	60.5	-	-
Minnesota	4.2	3.5	123.5	125.6	2.7	2.8	-	-
Nebraska	94.4	103.3	-	-	-	-	-	-
South Dakota	17.5	17.0	20.5	51.7	1.6	3.3	-	-
Missouri	7.02	7.8	-	-	-	-	47.4	52.7
Iowa	4.6	3.1	-	-	-	-	-	-
UNITS	Million Bushels							

*Source: Agricultural Statistics, 1977, 1978 [14].

TABLE 2.5 WHEAT STOCKS IN THE NORTH CENTRAL REGION*

STATE	ON FARM		OFF FARM		TOTAL	
	OCT. 1, 1976	JUNE 1, 1976	OCT. 1, 1976	JUNE 1, 1976	OCT. 1, 1976	JUNE 1, 1976
Kansas	74.6	30.5	374.2	218.1	488.8	248.7
No. Dakota	238.9	161.2	67.5	32.6	306.4	193.7
Minnesota	70.5	44.4	49.3	30.4	119.7	74.8
Nebraska	40.6	23.6	72.4	43.8	113.0	67.4
So. Dakota	30.4	18.6	15.3	7.4	45.7	25.9
Missouri	10.4	2.7	49.8	28.0	59.7	30.7
Iowa	0.5	0.1	4.3	2.4	4.8	2.5
UNITS	Million Bushels					

*Source: Grain Stocks, Oct. 1976 and June 1977 [25].

TABLE 2.6 GRAIN STORAGE CAPACITY IN NORTH CENTRAL REGION*

STATE	ON FARM	OFF FARM COMMERCIAL	TOTAL
Kansas	370.1	830.6	1,200.7
No. Dakota	691.3	141.8	833.1
Minnesota	1,191.8	367.9	1,559.7
Nebraska	832.8	487.9	1,320.7
So. Dakota	442.6	85.0	527.1
Missouri	346.5	210.4	556.8
Iowa	1,492.5	635.0	2,127.5
UNITS	Million Bushels		

*Source: *Milling and Baking News*, August 22, 1978 [16].

TABLE 2.7 WHEAT PROCESSORS IN THE NORTH CENTRAL REGION

STATE	WHEAT FLOUR MILLS		DURUM MILLS		BULGUR MILLS		FAMILY FLOUR PACKAGING	PREPARED MIX MANUF.	WHOLESALE BAKERIES		PASTA MANUFACTURERS
	NO.	CAPACITY	NO.	CAPACITY	NO.	CAPACITY			BREAD AND CAKE	BISCUITS AND CRACKERS	
Kansas	10	116,910	-	-	1	7,000	7	5	9	3	1
No. Dakota	1	5,000	1	5,000	-	-	1	-	5	-	-
Nebraska	6	28,970	-	-	-	-	3	2	11	1	2
Minnesota	12	79,100	5	31,300	-	-	5	1	18	3	4
So. Dakota	1	3,000	-	-	-	-	1	-	4	1	-
Missouri	9	82,298	-	-	-	-	4	4	22	8	3
Iowa	2	11,100	-	-	-	-	1	-	14	4	-
UNITS	cwt/day		cwt/day		cwt/day						

*Source: ALINET Data Base, *Milling and Baking News Directory 1977* [26], [27].

2.2.8 Transportation in the North Central Region

The transportation links in both the state and national networks were established and verified in a number of ways: geographical study of the area and transportation modes existing, information published in state statistics and *Grain Market News*, consultation with State agricultural and marketing departments, *Milling and Baking News*, and many of the marketing agencies, millers, bakers, and pasta makers involved. Certain unique features about transportation modes in individual states in the North Central region may be noted.

North Dakota, for example, has no navigable waterways, and the bulk of its grain is shipped via rail and truck to the Minneapolis or Duluth - Superior areas [28]. South Dakota has access to the upper Missouri River, which is navigable for parts of the year; thus, it may ship its grain by rail toward Minneapolis or via barge to collecting points in the Sioux City area and points south.* The eastern border of Nebraska and the northeast corner of Kansas are formed by the Missouri River, enabling those states to utilize barge traffic; however, the bulk of their export grain travels via rail lines to Texas Gulf ports [29]. Minnesota export grain may travel down the Mississippi River or be shipped out via Duluth on the Great Lakes to the St. Lawrence Seaway. Because the upper reaches of the Mississippi freeze in the winter, large amounts of grain may be barged down early in the marketing year and stored in elevators in Missouri to be used by processors later. The Missouri and Mississippi rivers make Missouri (especially St. Louis) a focal point in grain movement and trade.

2.3 WHEAT PROCESSING OPERATIONS

2.3.1 Hard Wheat Milling

The milling process, basically, has not changed very much since the introduction of corrugated steel rolls and purifiers in the second half of the 19th century, although other improvements have been added - installation of dust collectors, development and refinement of tempering, addition of roller bearings, and perfection of pneumatic handling of stock, to name but a few. [44] Flour milling is essentially the process of separating the outer husk, or bran, and the germ from the starchy endosperm of the grain, and finally grinding the endosperm. The entire process includes cleaning, tempering, numerous stages of grinding, as well as blending, treating, and enriching. The sequence of operations is indicated in Figure 2.6; they may vary, however, in number and complexity from mill to mill.

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*Personal Communication, Division of Markets, South Dakota Dept. of Agriculture (Dale Gullickson, 8/78).

HOW FLOUR IS MILLED

(A SIMPLIFIED DIAGRAM)

NOTE: This chart is greatly simplified. The sequence, number and complexity of different operations vary in different mills.

Figure 2.6 A Simplified Diagram of Flour Milling

Blended wheat from storage is conveyed to the cleaning house where it is weighed and passed through a series of cleaning, scouring, and sizing machines to remove dirt, sticks, stones, undesired grains, weed seed, and other foreign material. Action of the equipment is designed to loosen impurities attached to kernels, so that air currents within the machines can carry away dust and other light particles. Usually the wheat is next washed and scrubbed under a flowing stream of water in a specially constructed wheat-washer.

After cleaning and washing, wheat is tempered and conditioned. This involves adding sufficient water to make the bran tough and the endosperm more friable, bringing the wheat moisture content up to a level that is optimum for milling the particular type of wheat employed. A suitable moisture content might be as low as 14% for soft wheat, or as high as 18% for some hard wheats. After excess water has been removed, the grain is usually stored long enough to permit the water to penetrate the bran and toughen it, but leave the endosperm in a friable condition. It is then given a final cleaning by a scourer-aspirator machine to remove all loosened particles from the surface of the kernel.

The conditioned wheat is then conveyed to a roller mill in which it is passed between a pair of corrugated or fluted, chilled-iron rolls known as the "first break rolls," of which one roll revolves at two and a half times the speed of the other. The differential speed of revolution, and the fluting of the rolls, bring about a shearing action of the grains. Moreover, the space between the first break rolls is such that grains are broken mainly into relatively coarse pieces, with a minimum of crushing, so as to avoid powdering the bran. Some of the bran is peeled off the endosperm in flakes. But at this stage of grinding, the main product consists of relatively coarse pieces of endosperm, many of which have bran adhering to them.

The material from the break rolls passes to sifter machines, which, by means of sieves of varying fineness, separate the particles according to size. The finest material (flour) passes directly to the flour bag or bin. Fine and intermediate-sized particles, larger than flour particles, are sent to machines called "purifiers," which employ air suction to remove bran or other light fluffy material. The coarsest particles from the sifter machines are sent

through the "second break rolls," which have finer flutings and are set closer together than the first break rolls, and the resulting material is processed by sifters and purifiers. The procedure of grinding the coarsest material is continued through third, fourth, and, in some cases, fifth break rolls, followed in each case by sifting and purifying. After the final break, the coarse material passing over the sieves of the sifters is bran from which almost all endosperm has been removed.

While the coarser particles composed of endosperm, bran, and germ are thus being dealt with in the break mills, sifters, and purifiers, the purified particles of endosperm are sent to appropriate "reduction mills" having smooth rolls whose function is to crush them into flour. The reduction rolls (designated as the first, second, etc.) are set progressively closer together. Besides crushing the endosperm to flour, they flatten out any remaining pieces of wheat germ, which facilitates the removal of such pieces by sifting. The material from the reduction rolls is sorted, by means of sifters, into different grades of flour. A large variety of flours can be produced. "Straight flour" is the flour produced in which all of the mill streams are mixed into one. Otherwise, from 70% to 80% of the earlier streams may be classified as patent flour, and the remainder as first and second clears. Also, protein, ash, and fat content of flours can be varied by selecting different mill streams. After milling, flour may be improved in various ways, such as ageing, bleaching, or enriching. The milling of whole wheat flour (which can be milled from either hard or soft wheat) essentially consists of grinding the whole kernel without removing the by-products by sifting.

Flour stock has to be transported from machine to machine. Some mills depend upon gravity; the wheat flour is moved up by bucket elevators (that is, endless belts having attached buckets which pick up the flour at the bottom and dump it at the top), and then the flour flows by spouts to the rolls and to sifters. Several elevations are needed for the complete milling system. Bucket elevators have two serious disadvantages: they are dusty and they are prone to insect infestation. Consequently, most modern mills, while they still depend upon gravity for downward flow, have gone to air conveying of flour,

called pneumatic conveying. This is more efficient and sanitary, but it requires more energy to operate.

Under appropriate air velocities, solid matter such as flour is lifted and will flow like a liquid. The air force may be pressure or vacuum; in flour mills, vacuum is used, with powerful suction fans providing the negative pressure. The air intake is through the roller mills, and the air also keeps rolls and flour stock cool during grinding. The higher energy costs are offset by cheaper construction, less mill cleanup, less infestation, and cooler stocks. In addition, some millers claim greater yields caused by the detachment of endosperm from bran during conveying.

The finished flour may be sent in bulk to customers via special air-slide, covered railcars, or tank trucks designed for flour transport. The flour can be unloaded at customer sites to storage bins. Flour may also be packaged in the standard size packages or bags, although such sales have been declining due to cost advantages in bulk movement and the trend to commercial baking.

Bran, shorts, and screenings from the cleaning house can be drawn from bulk storage, blended, and sifted. The larger particles are ground by a hammermill and then resifted; material ground to proper size is weighed and pneumatically conveyed to bulk loadout bins. From the bulk bins, the millfeed can be loaded out to either railroad cars or trucks [36], [42], [43].

A visual representation of the milling of hard wheat, created in preparation for the development of data elements for ALINET, is presented in Figure 2.7. For simplicity in interpreting the graphs, the break system representing a sequence of passes through the breaking, sifting and purifying system has been depicted as a single sequence of operations and the multiple by-products (e.g., bran, shorts, germ, etc.) indicated as a single sink node. These simplifications do not affect the data elements as defined for the data base or the computer generated graphs of these processes. However, since they facilitate the interpretation of the sequences described, similar simplifications will be used throughout the remainder of this section.

2.3.2 Durum Processing

The milling of durum wheat is carried out much like that of hard or soft wheat, but the purpose is somewhat different. In the milling of hard or soft wheat, flour is the desired product, whereas in the milling of durum, a coarser endosperm fraction, the middlings, usually is wanted. These middlings from durum are called "semolina" in the trade. The end use for durum semolina is in pasta products, i.e., macaroni, spaghetti, noodles, and the like.

The major differences in the milling of durum as compared to other wheats is a shorter temper time, the use of the reduction system for sizing only and not for making flour, and a heavy reliance on purifiers for sifting. Rolls in the reduction system function the same as sizing rolls in a flour mill, that is, the coarse particles (middlings) are reduced to a uniform particle size. In the durum mill, the uniform product is sold as such, whereas in the flour mill this product is ground further on reduction rolls to flour. Generally, in a durum mill there is a sizing roll for each break roll. In some durum mills flour is also made, as durum flour is preferred for noodles; this means that more rolls are used than in producing semolina. Making semolina consumes less energy than making flour, as it need not be ground as much (fewer rolls). Some durum flour is produced as a by-product of semolina milling.

The durum milling process was graphically represented in simplified form as shown in Figure 2.8. Similar graphs were drawn to represent the further refinement of durum products into pasta. The process of pasta making which was expanded and modeled in ALINET is depicted in Figure 2.9; it is a continuation of Figure 2.8.

Semolina is the basic ingredient in pasta, although granular durum, durum flour, as well as, sometimes, a certain proportion of hard wheat farina or hard wheat flour may be included. The use of hard wheat flour is generally avoided in the highest quality pasta products, unless the high price of durum necessitates it. Pasta is produced by mixing semolina and water, then forming the dough into the desired shapes, and drying.

Figure 2.8. Durum Milling.

Figure 2.9. Pasta Making.

About 26 to 30 parts by weight of water at a temperature of about 100°F. (38°C.) are added for each 100 parts of semolina, and the mixture is kneaded mechanically to form a stiff dough. The dough is given a short rest period, then placed in a strong cylinder, the lower end of which is closed with a disk pierced with openings of a particular shape. For macaroni, a piston subjects the dough to great pressure, to squeeze it out in long tubular strands through the opening in the disk. For spaghetti and vermicelli, the dough is extruded through different dies to produce the product in different forms. Noodles are made from a similar dough, usually with eggs added; they are manufactured in various forms, of which the most common is a flat, ribbon-like one. A rotary cutter at the bottom of the die surface cuts the product to the desired length.

Drying is without doubt the most difficult and critical step to control in the processing of pasta products. The objective is to lower the moisture content from 31% to 12 or 13% so that the pasta will be hard, retain its shape, and will store without spoiling. Most pasta drying operations use a preliminary dryer to quickly dry the product surface immediately after extruding; predrying case-hardens the surface so that the pieces will not stick together, but the interior of the product remains soft and pliable. The final dryer is used to remove the bulk of the moisture from the interior of the product. Since the surface of pasta products dries more rapidly than the inside, a moisture gradient develops across the surface to the interior of the product. As the product dries, the interior shrinks more rapidly than the outer crust, setting up strains inside the product. If the strain becomes too great, cracks may develop below the surface, [42], [43]. Humidity is thus an important factor in pasta production. A great deal of energy may be expended in humidity control (particularly in the winter) as well as for drying.

2.4 THE PHYSICAL SYSTEM AND THE COMPUTER SYSTEM

The preceding description provides insight into different aspects of the wheat processing and distribution system - from the regional differences in production and processing characteristics, the seasonal factors affecting the prices and movements of goods, and the transportation and distribution of

products - to the characterization of individual processes. The initial focus on the seven state North Central Region, coupled with the scope of the pilot project with the Pillsbury Company, motivated the development of ten distinct, interconnected state-level networks, into which the preceding observations were incorporated. Working from the understanding of the structure and operation of the wheat sector in this region as presented in the preceding section, plus the required facility and process information, the appropriate network elements could be defined and the structural data generated. Even with the simple representations of the process (i.e., baking depicted by a single link) used in these initial versions, the individual networks required on the order of 100 nodes and 200 links to characterize the structure of the system. Table 2.8 indicates the distribution of the ten hard winter/spring and durum wheat networks that have been implemented on the computer, by state within this region. The hard red winter and hard red spring representations are shown on the same graph for South Dakota, which produces both varieties.

TABLE 2.8 HARD WHEAT AND DURUM NETWORKS BY
STATE IN THE NORTH CENTRAL REGION

STATE TYPE	IOWA	KANSAS	MINNESOTA	MISSOURI	NEBRASKA	NO. DAKOTA	SO. DAKOTA
Hard Red Winter	X	X		X	X		X
Hard Red Spring			X			X	X
Durum			X			X	X

When the networks indicated above are combined and viewed as a whole, all nodes and links describing hard wheat and durum wheat processing in the United States are represented, and national-level networks for hard wheat and durum can be constructed. In the sections which follow (III-V), these observations are integrated into the description of the computer model and the construction of complete networks within which the key factors affecting the flow of wheat products from the farm to the retail level can be identified and analyzed. In Sections VI-VIII, in which the modeling of hard wheat and durum processing on a plant-specific network is described, emphasis is placed on those parts of the network that are crucial in each case.

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III. THE ALINET COMPUTER SYSTEM

3.1 OVERVIEW OF THE SYSTEM

Three fundamental considerations provided the basis for the specification of the design of the ALINET computer system: (a) a perception of the intended use of the computer system as a tool for the analysis of energy use in the food processing sector and the evaluation of specific energy conserving technologies, (b) an increasing understanding of the behavior of the physical system represented by the model, and (c) an assessment of the attributes of workable large computer models.

The first requirement was to identify the *scope* of the model to be represented by the computer system. In the case of ALINET, the boundaries of the model were derived from the feature that it had to be able to trace the flow of commodities at a suitable level of disaggregation from the farm to the retail food market. The desire to reflect the impact of energy conservation measures, implemented at the process level, on the measures of performance and productivity which represent the behavior of the food processing and distribution sector as a whole, governed the level of detail. The combination of these characteristics with a modeling formulation that includes the explicit characterization of the conversion processes and accounts for the individual factors and costs of processing and distribution led to a computer representation in which *dimensionality* was of major concern.

The intended use of the system dictated that the model allow for the incorporation of new or alternative technologies. Given that the network representing the structure of the food processing and distribution system is not fixed, the precise relationships between elements in this network cannot be prespecified. In terms of the computer system, *flexibility* in the construction of the network, based on internal logic and procedures, became the second major consideration.

A third key software requirement is the need for *efficient manipulation* of the network. This is due to the possible extension of the model to an

adaptive form in which the structure of the network may change in response to the feedback effects of price and quantity indicators from the crop and retail markets, and to the feedforward effects of expected prices of goods and expected costs of the factors of production.

Within the context of considerations such as these, the model, once implemented, may be evaluated by other modelers in terms of algorithmic sophistication, or the faithfulness of the model to the physical system it represents. However, the careful specification of the design in these terms should be viewed as a necessary but not sufficient condition for achieving the objective that the computer system provide an effective tool for analysis.

Of greater concern to the user, once the accuracy of the software is accepted, is likely to be the effect of a particular implementation on (a) the effort required to specify the network, (b) the ease with which alternative questions may be posed and, (c) possibly the run time of the simulation. However, the modification of the design in response to user concerns is not a straightforward process. Even in the event that a single user could be identified, with a unique point of view and set of questions to be answered, the requirement that the system be capable of supporting his analysis (both during the development stage and upon completion) for whatever level of disaggregation, aggregation, or refinement he would choose to declare presents a difficult problem in characterizing "ease of use" for this system. The situation is further complicated when the requirements of multiple users with different points of view are included. As with all large scale modeling systems designed to address a variety of "what if" questions, considerations such as these, involving the manipulation of data and presentation of information, often not only define the types of interactions required between the user and the system but, more importantly, become the ultimate test of the usability of the computer model.

The design considerations outlined in the section above, while they cannot be mapped into specific characteristics of the computer software, represent a distinct point of view that guided the evolution of ALINET. The use of the term "evolution" as opposed to "development" is deliberate. There

is an *expectation* that both the questions of interest and the focus of the users *will* change with time; an expectation which motivated many of the design and implementation decisions made throughout the development of the model.

The structure of the ALINET system was decomposed at the outset into three major functional entities, the Data System, the Flow Graph Generator, and the Simulation System. The interconnections between these entities are depicted in Figure 3.1; the comparison between the existing ALINET model and the eventual ALINET system is indicated by an asterisk (*). The high dimensionality of the system required that the routines for data management, i.e., data entry, retrieval, and editing become major elements in the system. The desire to accomodate ad hoc questions, perform simple operations on the data in the data base, display the results in a useful format, and retain the flexibility to alter the basic data structure, expanded the function of data management to a full Data System. The more generalized the Data System, and the greater the scope of the structural representation under study, the greater the need for comprehensive graph generation procedures. The recognition of this need, including the desirability of using graphical display techniques to aid the user in the verification of his network, led to the specification of the Flow Graph Generator. Together, these two entities permit the user to define the representation of the food processing and distribution system suitable for his needs. The third, the Simulation System, operates on this definition by extracting data from the data base on the basis of the structure of the network created by the Flow Graph Generator, constructing the information tableau, determining the flow of materials through the network and the use of the factors of production, and analyzing the results based either on a single simulation or the aggregation of multiple runs. Given the flexible nature of the system definition, the implementation of the software could progress in parallel with the determination of the appropriate basic level of modeling detail to be used.

The initial view of the food processing and distribution sector was a national one. Considerable detail was envisioned in the sense that alternative technologies were to be represented explicitly, with the evaluation of the alternatives, in terms of energy conservation, to be made in the context

Figure 3.1 Structure of ALINET

of this whole. The development of national measures of the performance and productivity of the system for particular types of processes, sensitive enough to reflect the impact of conservation measures implemented at the process level, was anticipated. The national view of the structure of the overall system had certain advantages. The limited number of connections between major sectors (e.g., wheat, dairy, etc.) allowed a simple decomposition along these boundaries at a national level which could provide a clear indication of the structure of the flows of materials derived from the commodity under study. In addition, such an aggregate depiction, uncomplicated by geographical considerations, could permit one to focus on some of the fundamental issues surrounding the introduction of a particular technology or process innovation. In order to support a modeling effort of this type, considerable data aggregation and the detailed modeling of the individual nodes and links comprising the network representation would be required.

Early in the implementation phase of the model development, however, questions were raised concerning this aggregate picture. The first came from industrial representatives who wanted to join governmental decision makers in applying such a system to the analysis of conservation measures, provided the appropriate level of detail could be achieved. The second arose naturally during the process of developing the representation of the structure of the wheat system - the first subsector selected for study.

Both are based on the following types of observations - presented here for wheat. Changes in existing technologies may require the substitution between two fundamental types of energy consuming processes: those relating to the distribution and storage of wheat commodities (changes in location and time) and those relating to the engineering processes (changes in form). The feasibility of such substitutions is governed not only by national policies, pricing structures, and regulations, but more importantly, by regional considerations. At the basis of these considerations lies the fact that wheat, for example, is a non-uniform commodity. Differences in the wheat requirements, by type of wheat, for specific end uses are becoming increasingly significant as refined products are developed.

Bringing wheat from areas of production to areas of milling and product manufacture, therefore, is more complex than traversing the shortest economic path. A representation of the system which included the regional distribution of major processor and user requirements, the regional differences in quality, as well as the availability of transportation modes and energy sources, was sought.

Many factors have influenced the selection of the level of detail in which the basic representation of the system was made: 1) upward aggregation to a national level should be easily manageable, 2) alternative regional summaries should be possible, 3) the incorporation of regional product and transportation differences should be permissible, and 4) the data requirements should be consistent with the availability of data or with the natural way of combining diverse pieces of unprocessed information.

The disaggregation of information along state boundaries was ultimately selected as the basic level. It is a convenient representation which provides reasonable detail without requiring that the full system be specified at the facility level. Individual studies, representing particular innovations occurring within a specific plant, are formulated in greater detail within this framework.

Since the basic ALINET computer system was designed at the outset to consider a high dimensional representation of the system with a flexible data structure, such a change in emphasis could be accommodated without fundamental modifications to either the design or the implementation. The impacts of the changes to a state level representation were felt in what might be termed auxiliary modeling capabilities; in the cataloguing and processing of raw, plant level information, in the development of automatic aggregation procedures and consistency checks, and in the requirement for increasingly sophisticated plotting capability to display the more highly interconnected flow graphs. Before describing the use of these techniques in the development of the basic representation of the wheat system, a brief review of the basic characteristics of both of the Data System and the Flow Graph Generator, the network definition portions of the ALINET system, may be appropriate.

3.2. THE DATA SYSTEM

The primary component of the Data System is a data base containing information about the processes, commodities, and constraints operating within the food processing and distribution sector. The definition of the format for the representation and storage of the data depended upon the size of the data base and the type of input and output requirements to be met. In order to specify a basic data structure and a design for the Data System that remains workable over time, three distinct facets of the data handling problem were explored. The first of these relates to the natural structure of the data or categories into which the information falls. The second concerns the needs of the model user for the creation and validation of the descriptive data (data base input) and the interrogation of the data base to retrieve information (data base output). The third is derived from the requirements of the analytical system--the Flow Graph Generator and the Simulation System--for data extraction (data base output) and the storage and manipulation of analytical data (data base input). These three facets must be considered in parallel in order that a working definition of the data base be determined.

The description of the structure of the food processing and distribution sector in terms of a material flow graph implies the existence of an ordered set of nodes and interconnecting links representing the transformation of commodities from the farm to the retail food market. Two basic alternatives exist in representing the information required to specify such a system. The first incorporates the order or position within the network structure itself into the data definition. This places the burden of graph generation on the user at the time of data specification. While this approach may lend itself to efficient data processing algorithms, it is inappropriate for a modeling system such as ALINET, which is changing continually through the addition of new technologies and the expansion and contraction of subsectors within the network specification. A far more appropriate data structure centers on the individual system elements and the information required to characterize them. The degree to which the information describing each element can be decoupled

from the remaining ones will determine the natural flexibility of the data structure for this application. This approach clearly implies a separate function to generate network representations, which allows many different partial flow graphs to be drawn from the same basic data base.

3.2.1 Structuring the Information

The grouping of the data associated with the model elements (nodes, links, and processes) is given in Table 3.1. The data definitions and the way in which the data are used by the Data System can be described as follows: The first of the basic elements is the node or state. The node names associated with the state provide a shorthand method by which the nodes can be identified; a name which is arbitrary except for the convention adopted, for ease of recognition, that the first letter of the commodity indicator (W-wheat; D-dairy) become the first character in the node name. Additional characters, indicating the association of a node with a particular U.S. state through the use of the two letter postal code, are incorporated into the node name (e.g., WKSxxx denotes a wheat node in Kansas). An alternate format permits particular studies to be encoded into the name, thus allowing the identifier W2Cxxx to be recognizable as the name of a node belonging to the CERES II study described in Section VIII of this report. The level, as a structural entity, is associated with the processing stage of the state. It is included for selected nodes to capture the structural symmetry. The units indicate the preferred quantity measure for the commodity (e.g., BU representing bushels or MBU denoting million bushels). Conversion factors can be generated directly from these units as the material flow is determined. The node status, like the link and process status, provides structural information which may be required in generating the network representation. The node status indicates the possible introduction or removal of a product form over time, and may be used to determine the validity of the inclusion of a node in a particular flow graph covering a specific period.

The state description is a unique characterization of the node that is based on its attributes as well as selected geographical information. The primary characteristic of the material represented by the node is the basic

TABLE 3.1 NATURAL ELEMENT DATA STRUCTURE

NODE	LINK	PROCESS
Name Level Unit of Measure State Description Node Status - Phase In - Phase Out Attributes* Geographical Description - City or Sub Region - State - Region	Name Topology - Origin Nodes - Destination Nodes Process Identifier Link Status - Phase In - Phase Out Process Coefficient Distance	Name Process Description Process Status - Phase In - Phase Out Attributes** Process Model - Form - Parameters - Inputs
Month Year Material Energy	Month Year Allocation Coefficient Inputs Energy (Process) ⁺ Energy (Transp.) ⁺⁺ Labor Capital Raw Materials Packaging Materials Water Link Capacity	

* Node Attributes: Commodity, Type, Qualifier, Form, Location, End Use, Ownership

** Process Attributes: Age, Technology, Time Requirements, Restrictions, etc.

⁺ Process Energy: Electricity, Natural Gas, Coal, Fuel Oil (#2, #6), Propane, Butane, Solar, Geothermal

⁺⁺ Transportation Energy: Diesel, Gasoline

commodity (e.g., wheat, dairy, etc.) from which it is derived. The commodity appears explicitly as the first attribute in the set describing the node and doubles as a structural indicator in that it is used by the Flow Graph Generator in distinguishing between one major sector and another. The commodity combines with the additional attributes (type, qualifier, form, location, end use and ownership) to create a unique definition of the state. The type provides the first level of additional information about the commodity as indicated by the association of "durum" with "wheat". The qualifier indicates the condition in which the particular form of the commodity is found; e.g., unpackaged (qualifier) flour (form). The location and end use (or market destination) provide further refinements on the definition of the form. Ownership is an optional characteristic, appearing primarily in the description of facility level nodes that are part of specific studies. Careful consideration of the implied processes remove the need for complex qualifiers in order to define the node uniquely. Geographical indicators include the city or sub-region, state, and region (group of states); the absence of geographical specification indicates a national level node.

Time dependent data may also be associated with a node, tagged with a specific month and year. These include the supply of the commodity given in the appropriate units and, if required, the total energy in million BTUs per unit of commodity required to bring the commodity to that state.

The information required to specify the links and processes is equally straightforward. A link name is defined by which the link can be identified (e.g., LWxxx denoting a wheat link). The association between the links and the nodes, as specified by the topology, is indicated by the match between origin and destination node identifiers and the corresponding node names under which the state data are stored. A distinction is made between the link and the process which that link represents in order to distinguish between the process itself (e.g., transportation by barge) and its particular occurrence. The connection between the link and the process model to be used in determining the transformation is indicated by the match between the process identifier associated with the link and the name assigned to the process model itself.

The process coefficient defines the per unit change in weight associated with the transformation of material across the link. It is independent of the unit conversion between units of measure and is associated with the specific occurrence of a given process. The distance indicates the "length" of the link, so designated because of its use to characterize transportation processes. The link status as indicated above fulfills the same function as the status of the nodes.

The time varying functions for the links are extremely important. Like those for the nodes, time tags designate the month and year. The allocation coefficient and the link capacity are required to determine the material flows. Omission of a capacity indicator implies an unconstrained flow. The inputs as listed in Table 3.1 may also be time varying. They are specified in terms of the amount of each factor required by the process per unit of final output.

The data describing the processes are generic. The process models to date have been implemented within the Simulation System rather than appearing explicitly as part of the data base.

3.2.2 Data Management Considerations

From the data requirements given above, a clear indication of the natural data structure emerges. A link, as described, is related directly to at most a few nodes and a single process. Nodes and processes are essentially independent logical entities. These observations provide the starting point for the definition of the formal data structure, to which the elements of the information tableau are added.

Until a number of test cases have been tried using the model, the definition of the data base and its structures will be evolving. One might be tempted to consider a final data structure, against which the particular software for data management can be optimized, to be the outcome of the model development phase of the project. However, to include the objective of fixed data base definition in the specification of the system implies that future changes to the data base are merely modification to the data values, or creation or deletion of additional data records of the same type of form. Such an approach

ignores one of the fundamental notions inherent in ALINET. The model is designed to test innovations and technological advances; as such, the introduction of additional unanticipated types of information required to describe these processes is quite possible. Furthermore, changes in focus, such as a potential interest in the use of by-products, can require the incorporation of additional data describing the environmental considerations or other characteristics as yet not included.

It is clear, therefore, that the ability to change the data definition is a fundamental design consideration. The final version of the Data System had to be able to meet this need in a way which does not require a programming effort or alter the way in which the user interacts with the data base. In deed, the data structure as originally envisioned has undergone modifications which, although not major, could have created difficulties in a more rigid representation. The desire to respond to unanticipated queries, which might take the form "Please list all links for which natural gas use exceeds X", has an equally fundamental impact on the nature of the data management problem. The efficient performance of the data base primitives (e.g., data creation, modification, retrieval, deletion) and the protection of the data base, are assumed as design criteria. However, the additional requirements indicated above lead beyond these criteria and, as a result, a generalized data base management system was selected to perform these functions within the ALINET Data System. A brief description of this commercial package (System 2000) and the motivation for its choice are provided in Appendix A.

Of the data base partitions (element, network and information tableau) depicted within the Data System in Figure 3.1, only the element data sets are under the direct control of System 2000. The formal data structure of this partition parallels the natural one presented in Table 3.1 directly. At the top of the hierarchy is the designation of the data base version, with the first data level occupied by the constant data for nodes and links. Subordinate to this information are the multiple data sets describing the material at the node or the inputs and allocation coefficients at the link as a function of time. It should be mentioned for completeness that several additional data items, pointers, and codes are associated with elements in the data base. Since these are created and used only by the analytical system and are not accessible by the user, they are not described in any greater detail.

The data sets from which the commodity definitions are constructed require some further discussion. It quickly became apparent that the need for consistency in the node description made the direct definition by the user a tedious process. Even the full specification of each attribute (e.g., "cookie and cracker flour", one of the possible forms in which wheat appears) is unnecessarily complicated. Therefore, a dictionary of terms was instituted for each commodity which relates a short code (no more than six characters) to the full definition for each attribute, and a single letter to the designation of a commodity code. The user specifies only the code in indicating the node attribute which acts as a key into the commodity dictionary. Default values for each attribute may be created that are commodity specific. For example a default code for the location of a wheat node retrieves, from the existing dictionary, the attribute "at the farm". The attribute definitions currently represented in the wheat dictionary tables are given in Table 3.2.

The symmetry of the resulting definitions is best illustrated through a simple example. Consider the descriptions of three nodes taken from three different graphs: one, a national aggregate, one, a state level, and one, from the CERES II study. Each represents the same type of physical commodity, defined by the user through a sequence of codes as indicated in Table 3.3. The expanded forms indicate the increasing specificity:

W140 - Wheat, durum: semolina at the mill for wheat products.

WMN140 - Wheat, durum: semolina at the mill *in Minnesota* for wheat products.

W2C20 - Wheat, durum: semolina at the *Peavey* mill in *Hastings* Minnesota for wheat products.

In the preceding discussion, the technique for defining the nodes and links appropriate to a given commodity was presented. The structure of the information follows the natural characterization of the model elements. This has advantages to the user as well as the system in that, with few exceptions, modifications to a given value affect only a single element in the data base. The interaction between the Data System and the first of the analytical users, the Flow Graph Generator, is discussed in the context of graph creation in the section which follows.

TABLE 3.2 WHEAT COMMODITY DICTIONARY

TYPE	QUALIFIER	FORM	LOCATION	END USE
All Types Durum Hard Hard Red Spring Hard Red Winter Soft Soft and Hard	Bakery Bakery Mix Blended Cleaned Coarse Conditioned Dried Dried Dinner Dry Cleaned Dry Cut Dry Stored Enriched Family Fine Fine Ground Fresh Cut Fresh Extruded Grocery Mix Ground Hotel and Restaurant Institutional Low Grade Market Grade Mixed Packaged Packaged Insti- tutional Packaged Retail Processed Retail Sacked Sacked Bakery Sacked Hotel and Restaurant Sold Stored Treated Undried Unpackaged Washed	All Purpose Flour Bitsyn Bran Bread Bread Flour Bulgur Byproducts Cake Flour Cakes Cereal Cookie and Cracker Flour Cookies and Crackers Dried Dinners Dried Dinner Pasta Egg Pasta Farina First Clear Flour Flour Germ Germ #1 Grain Grain Feed Granular Impurities Long Goods Long Pasta Middlings Middlings(Mill Feed) Mill Feed Noodle Dough Noodle Scraps Noodles Other Baked Goods Other Pastries Other Pastry Flours Pasta Pasta Dough Pasta Flour Pasta Scraps Patent Flour Pollards Prepared Mixes Red Dog Reground Rolled Second Clear Flour Self Rising Flour Semolina Short Goods Short Pasta Shorts Whole Wheat Bread Whole Wheat Flour Whole Wheat Middlings	Bakery Bitsyn Plant Break Rolls Bulgur Mill Cereal Manufacture Cookie & Cracker Factory Country Elevator Customer Distributing Point Export Warehouse Facility Family Flour Packaging Plant Farm Feed Manufacturer Feed Merchant Grain Merchants Local Feed Market Mill Packaging Plant Pasta Plant Port Prepared Mix Manufacturer Processors Purifiers Purifiers and Sieves Reduction Rolls Restaurant or Institution Retailer Sifters Sifters and Purifiers Sizing Rolls Storage Subterminal Elevator Terminal Elevator Various Locations Whole Grain Break Rolls Whole Grain Reduction Rolls	Bread Domestic Consumption Domestic & Export Use Export Unspecified Use Waste Wheat Products

TABLE 3.3 COMPONENTS OF THE STATE DEFINITION FOR SELECTED NODES

	National Node W140	State Node WMN140	CERES II Node W2C20
TYPE	DURUM	DURUM	DURUM
QUALIFIER	-NA-	-NA-	-NA-
FORM	SEMOL4	SEMOL4	SEMOL4
LOCATION	MILL5	MILL5	MILL5
END USE	OWHT6	OWHT6	OWHT6
OWNERSHIP	--	--	PEAVEY
CITY	--	--	HASTINGS
STATE	--	MN	MN

3.3 TRANSLATION FROM THE ELEMENT REPRESENTATION TO NETWORK SPECIFICATION

In order to simulate the flows of materials through the system, an identifiable set of nodes, links, and processes must be associated to create an ordered network, representing the sequence of channels through which the materials flow. The Flow Graph Generator has been described as providing this transition between the Data and Simulation Systems. Traditionally, such a transition has been defined as one of abstracting the relevant data from the data base and ordering it into the appropriate data files, with the identification of the composition of the relevant set of elements determined a priori. When the set of elements representing the network is small, the requirement that a list of the links and nodes defining the topology be given explicitly presents little difficulty. For a modeling system such as ALINET, which has been characterized by high dimensionality, such an approach is quickly seen to be inconsistent with the fundamental design criteria of ease of use and flexibility of structure. It was important, therefore, that a method be developed both to identify the relevant elements based on internal logic and selected criteria and to evaluate the resulting structure for reasonableness. In order to expand the specifica-

tions of the Flow Graph Generator, beyond those of data extraction, to include those of structural inference, an examination of the inherent properties of the network, the way in which the topology was described and the considerations for system use, was required.

3.3.1 Structural Characteristics

The representation of the food processing and distribution system as a directed graph was described in Section I. Such a topological view of the paths through which the materials flow reveals a structural property of major importance. Not only is the material flow network as defined for this system directed from left to right, but it is acyclic. These properties, combined with the observation that the interconnections between major sub-sectors are few, provide the basis for the internal logic of the Flow Graph Generator, both in terms of the functions of element identification and of network representation. Many different algorithms could be specified to perform these functions; the appropriate choice was therefore somewhat subjective. The specifications were made according to the broad criteria that the process of element identification be patterned after the way in which the user would construct a network were he required to do so, and that the form of network representation be determined by the requirements of the Simulation System.

The algorithm employed by the Flow Graph Generator, described in detail in Appendix B, translates the notion of sequential flows in the physical system to the simple graphical requirement that all transitions *advance* from left to right. The additional restriction that a node appear no more than once in a given representation allows a unique graph to be generated from a series of starting points or source nodes, the "one step forward" information contained in the link definitions which specify origin and destination and the left to right progression. Loops, resulting in a right to left transition, and implying an error in the data specification, can be detected as the graph is constructed. The result of the graph generation procedure, stored in the network data base, is the organization of the selected data elements into a sequence of levels, each containing a set of nodes, which are related to the stages of

processing within the physical system. The paths through the network, along which material flows, correspond to the sequence of links interconnecting these nodes.

There was theoretically no difficulty in permitting the Flow Graph Generator to access the entire data base and use all available information to represent the structure of the overall food processing and distribution sector. However, certain practical observations that major modifications to the data base (e.g., changes in technologies or studies of alternatives) are often confined for a given study to portions of the network within a single sector, motivated the decision to partition the overall graph into smaller, more manageable logical entities. As each new portion was generated, it could then be saved and pieced together with existing segments at interconnection points for the actual simulation of material flows.

The initial graph boundaries were chosen in terms of basic sectors (e.g., wheat, dairy, etc.) because there are few interconnection points. The technique for linking partial graphs can best be demonstrated in the following simple example. Consider two arbitrary simplified sector graphs, generated independently from wholesale to retail market. At the time of data creation, a single sector, through the commodity attribute (e.g., wheat), is associated with each node. The assignment of letters to nodes in Sector 1 and numbers to nodes in Sector 2 in Figure 3.2 indicates these associations and serves as a reminder that no implicit ordering is assumed in the naming of a node. Link L1 provides the single interconnection between the subgraphs. In the independent generation of the graphs, node E is taken as a *sink* with respect to Sector 1 and a *source* of material to Sector 2. The relative position of the levels, as indicated for the two sectors, together, is tied to the order of processing which will be followed within the simulation.

The picture presented by these interconnected sector graphs highlights the difference in the level structure and leads naturally to the question of what interpretation is to be placed on the levels themselves. In order to provide natural lines along which the graphs should be partitioned for study,

it would be highly desirable that the logical levels assigned to nodes be related as closely as possible to processing stages within the physical system. Since the nature of the processes differs from sector to sector, it is clear that no single set of processing stages can be defined for the entire system and thus the information by which such stages can be introduced must be derived from the element specification. Yet, relying totally on the process of logical level assignment as outlined above may lead to a graph which, although not in error, is difficult to partition along lines of structural symmetry. Such an example may be constructed from Figure 3.2. Related commodities at the same stage of processing are represented by nodes 106, 156, and 118. Nodes 121 and 139 are also at the same stage. Since the commodity at node 139 requires additional intermediate processing, the algorithm, unless modified, would force node 139 to a level beyond that of node 121.

Figure 3.2 Combination of Flow Units for Two Sectors

One straightforward approach would be the introduction of unit processes in order to maintain the desired symmetry. Such a link and appropriate node would be introduced between node 106 and node 121, for example, in order to place 121 and 139 on the same level. The difficulty with requiring the unit processes as placekeepers is one of added complexity. As changes are made to the data base or additional elements required to specify the graph identified, the effort required to keep track of the resulting unit processes becomes considerable.

An alternative was sought which allows the assignment of nodes to selected levels associated with major processing stages. Such assignments preserved the symmetry while allowing the algorithm to create the flow graphs for all intermediate levels in an unconstrained manner. This can be seen in Figure 3.2 in which node E, as the interconnecting node, was assumed to lie on the level immediately preceding node 121. This resulted in the representation of the links from node I to nodes J, H, and E as crossing several levels, as though unit processes had been introduced in each case. In the process of selecting the appropriate elements for inclusion in the graph, the Flow Graph Generator groups nodes with preassigned levels on the same logical level, introduces intermediate levels as appropriate and checks the overall graph for left to right flow in the manner described in Appendix B.

From a set of user requests, a given execution of the Flow Graph Generator results in the creation of a set of ordered lists in a format appropriate as input to the simulation. These lists describe the graph in terms of the order of processing through the system, the relative location of the nodes and the interconnecting links by which the network is traversed. However, information structured in a convenient way for the computer may not meet the needs of the user. Indeed, although it is possible to infer both the composition and structure of the network, little insight into the structure of the system is possible from the lists themselves, without considerable effort. In addition, since the flow graphs are drawn from a data base of information either input directly or derived through aggregation, it is difficult for the user to feel confident that the network which has been created accurately reflects his intention. Therefore in order to provide visual pre-

sentations of the output in a manner similar to Figure 3.2, software that takes the ordered lists from the Flow Graph Generator and creates such graphical displays automatically was created (see Appendix C).

In the section that follows, an understanding of the network definition software (Data System and Flow Graph Generator) is assumed. The focus in Section IV is on the auxiliary tools used to support that software and their use by the project team in the creation of the basic representation of the wheat system in preparation for the test case.

IV. THE STATE SYSTEM AND THE NATIONAL SYSTEM

4.1 THE INCORPORATION OF FACILITY DATA INTO THE ALINET DATA SYSTEM

The process of serious data collection for the material flow representation of the food processing and distribution sector was initiated following a decision to recognize state boundaries. Gaps in the published statistics were identified even at this level of aggregation, requiring that more informal contacts be established to obtain the information necessary to initialize the model. The problems inherent in insuring consistency and validity of information gathered in this way motivated the search for additional data, including plant level statistics, which could be used to support models based on unpublished information and conjecture. The information, expressed for individual plants and processing facilities, was too detailed to correspond directly to the system elements. However, it was clear that if methods could be developed to provide a direct connection between the detailed data and the ALINET Data System, and if tools for aggregating and processing the information to serve as an aid to the development and validation of the type of data required by the simulation could be implemented, a significant step toward formally justifying each data entry would be achieved. A first test of both the techniques and the tools was made by using information characterizing individual wheat mills and grain elevators throughout the United States.

4.1.1 Facility Data Definition and Inference

Corporate directories published by *Milling and Baking News* were identified as the initial source of information from which facility data could be abstracted. Facilities surveyed in these publications include milling establishments (wheat flour, durum, bulgur, rye, dry corn, soy and buckwheat), bakery mix manufacturers and packaging plants, port and terminal grain elevators, producers of frozen doughs, bread and cake bakeries, pasta plants, and biscuit and cracker companies. The types of information gathered differ for each category of facility - ranging from daily milling capacity by type of flour milled for milling establishments to the methods for receiving and shipping grain in the case of elevator companies. A summary of the selected corporate data by type of facility is presented in Table 4.1. In order that this

collection of information be a true automated resource for data manipulation, it had to be encoded for the computer and made accessible to the ALINET Data System. The data structure and the procedure by which the data are prepared, entered into the system and verified are described in Appendix D.

TABLE 4.1 SAMPLE TYPES OF INFORMATION

WHEAT FLOUR MILLS	TERMINAL AND PORT ELEVATORS	BAKERY MIX MANUFACTURERS	BREAD AND CAKE BAKERS
Corporate Affiliation Address Key Personnel Capacity Throughput Storage Wholesale Brands	Corporate Affiliation Address Key Personnel Storage Capacity License Rail Service Carrier Transportation Shipping Receiving Services	Corporate Affiliation Address Key Personnel Market Class Type Mixes Produced Consumer Brands	Corporate Affiliation Address Key Personnel Sales Wholesale/Retail Method Bulk Delivery of Ingredients Rail Service Products Brands

Once the facility information had been checked for accuracy, a powerful data resource existed. The most straightforward use of the data base is through interrogation to support inferences obtained informally. For example, it has been stated that hard wheat grain may be barged from the north to Louisiana ports for export in stages to avoid the frozen northern waterways. A logical stopping place would be along the Missouri border. An itemized list, as shown in Table 4.2, is produced by requesting the retrieval of records from the data base for terminals which both ship and receive by barge in the relevant states. From those facilities on the list more detailed information can be sought and, as in the case of the Missouri elevator described in Appendix Table D.2, the conclusions are noted directly on the facility form and used later to infer the state specific networks.

A more powerful use of the data base than the simple question and answer approach is achieved by aggregating the facility data by type of information (e.g., state, size of facility, type of capacity or transportation, etc.). Given the need to develop representations of the wheat processing sector on

TABLE 4.2 LIST OF TERMINALS
BOTH SHIPPING AND RECEIVING
BY BARGE*

ELEV ID	ELEV NAME	ELEV CITY	ELEV STATE
PE8	CARGILL INC.	CHICAGO	IL
PE10	CONTINENTAL GRAIN CO. C	CHICAGO	IL
PE11	INDIANA FARM BUREAU U COOP ASSN.	CHICAGO	IL
PE12	FARMERS EXPORT CO.	AMA	LA
PE14	ST. CHARLES GRAIN SL. CO.	DESTREHAN	LA
PE15	PUBLIC GRAIN ELEVA TOR	NEW ORLEANS	LA
PE16	CARGILL INC.	PORT ALLEN	LA
PE17	CARGILL INC.	RESERVE	LA
PE18	COOK INDUSTRIES IN C.	RESERVE	LA
PE22	LOUIS DREYFUS CORP	BALTIMORE	MD
PE23	MICHIGAN ELEVATOR EXCHGE.	CARROLTON	MI
PE26	INTERNATIONAL MILT IFOODS CORP.	DULUTH	MN
PE27	LOUIS DREYFUS CORP	PASCAGOULA	MS
PE28	RAYMASTER OIL	VICKSBURG	MS
PE37	LOUIS DREYFUS CORP	PORTLAND	OR
PE39	CONTINENTAL GRAIN CO.	BEAUMONT	TX
PE40	FARMERS EXPORT CO.	GALVESTON	TX
PE47	CARGILL INC.	PORT ARTHUR	TX
PE48	CARGILL INC.	CHESAPEAKE	VA
PE49	CONTINENTAL GRAIN CO.	NORFOLK	VA
PE50	NO. PACIFIC GRAIN GROWERS INC.	KALAMA	WA
PE55	UNITED GRAIN CORP.	VANCOUVER	WA
PE58	FARMERS UNION GRAI N TERM. ASSN	SUPERIOR	WI
E2	ALLIED MILLS INC.	GUNTERSVILLE	AL
E24	GARVEY INTERNATION AL INC.	CHICAGO	IL
E25	THE PILLSBURY CO.	CHICAGO	IL
E33	THE PILLSBURY CO.	FLORENCE	IL
E53	GENERAL MILLS INC.	SOUTH CHICAGO	IL
E86	THE PILLSBURY CO.	DAVENPORT	IA
E88	THE PILLSBURY CO.	DUNIQUE	IA
E103	CARGILL INC.	RATON RIDGE	LA
E181	THE PILLSBURY CO.	NEWPORT	MN
E209	FAH-HAN-CHU INC.	ST. JOSEPH	MO
E213	HOWLES GRAIN CO.	ST. LOUIS	MO
E268	INTERNATIONAL MILT IFOODS CORP.	RUFFALO	NY
E270	STANDARD MILLING C O.	RUFFALO	NY
E279	EARLY & CARTEL CO. W.E.	CINCINNATI	OH
E282	THE PILLSBURY CO.	CINCINNATI	OH
E317	CONTINENTAL GRAIN	MEMPHIS	TN
E318	FAHRE GRAIN CO.	MEMPHIS	TN
E345	GOLDPASTURE INC.	GALENA PARK	TX
E374	CARGILL INC.	MILWAUKEE	WI

*Computer Generated, ALINET Data System.

a state-by-state basis, the state indicator becomes fundamental to all statistical queries. Table 4.3, which depicts throughput capacity by type of flour milled, provides a first level look at the milling industry. While the high total capacity in Kansas and Minnesota in contrast to the low capacity (only 10000 cwt total) in North Dakota, and the high concentration of mills in New York are at first surprising factors, they are related not only to the historical development of the industry, but also to transportation facilities (e.g., Great Lakes) and the dispersal of the processed wheat toward the centers of population.

A table such as this, providing insight into the location of milling centers within the U.S., allows the development of preliminary node definitions as part of the state level wheat networks. The presence of milling capacity of a particular type implies the existence of durum, hard wheat, or soft wheat grain at the mills in a particular state. This information can be translated into multiple aggregated nodes and links since it implies that, in addition to the grain mill nodes, a sequence of processes and intermediate nodes required to represent the milling process are to be included within the state network as well. Nodes representing the end products at the mill can be inferred from the additional attributes of the facility data. Whole wheat flour, for example, is not produced by all mills; for those which indicate whole wheat grind, additional hard or soft wheat flour capacity is usually noted. This permits the distinction between "soft wheat, whole wheat flour", and "hard wheat, whole wheat flour" to be made despite the combination of data from many individual facilities. In addition, the existence of soft wheat or hard wheat capacities implies the existence of nodes representing patent flour, first and second clear flours, farina, and milling by-products (e.g., shorts, germ, red dog and pollards). The end products of the durum milling process - semolina, durum, flour, and granular durum - also are included in a particular state flow graph on the basis of the existence of durum milling capacity in a given state. Once the existence of these nodes has been established, a framework is provided for the characterization of the particular processes. Table 4.4, indicating the distribution of mill size by capacity, type and location, may prove helpful in establishing process representations. The large mills (5000 - 9999 cwt/day) dedicated to the milling of hard wheat in

TABLE 4.3 THROUGHPUT CAPACITY BY TYPE OF FLOUR MILLED*

STATE	NUMBER	WHEAT	SOFT	FLOUR	DURUM	TOTAL	AVG
AL	1			8800		8800	8800.00
AZ	1			1000		1000	1000.00
CA	10	1400	3300	33925		47725	4772.00
CO	3		5000	12000		17000	5666.00
DE	2			472		472	236.00
FL	2			12850		12850	6425.00
GA	7	100	5530	5020		10650	1521.00
HI	1			2200		2200	2200.00
IA	2	500		10600		11100	5550.00
IL	8	1000	31300	24500		56800	7100.00
IN	8		10840	16600		27440	3430.00
KS	20	805	8560	107545		116910	5845.00
KY	9	25	4040			4065	451.00
LA	3			10000	1000	11000	3666.00
MD	1		2400			2400	2400.00
MI	4	850	21400			22250	2472.00
MN	19	7020	60	71920	31300	110400	5810.00
MO	10	800	13050	68448		82298	8229.00
MT	3	900		9400		13500	4500.00
NC	10		10074	13576		23750	1484.00
ND	2			5000	5000	10000	5000.00
NE	6	200		28770		28970	4828.00
NJ	1	1200		5000		6200	6200.00
NM	2			650		650	325.00
NY	18	3325	2300	96840	14800	117365	6520.00
OH	14	2000	63025	7900		72925	5208.00
OK	4			27500		27500	6875.00
OR	5	300		9800	3750	27450	5490.00
PA	37	57	25119	6500		33936	917.00
PR	2			8500		8500	4250.00
SC	6		2320	900		3220	536.00
SD	1			3000		3000	3000.00
TN	14	192	15130	20500		35830	1990.00
TX	7	1000		27800		28800	4134.00
UT	11	150	12910	17148		30370	2760.00
VA	19	20	7348	12820		20530	1080.00
WA	4	1750	10000	15800		27550	6887.00
WI	1				12000	12000	12000.00
UNITS		cwt/day	cwt/day	cwt/day	cwt/day	cwt/day	cwt/day

*Computer Generated, ALINET Data System.

TABLE 4.4 DISTRIBUTION OF MILL SIZE BY CAPACITY, TYPE, AND LOCATION*

STATE	HAND WHEAT ONLY (CHT/DAY)					10000+	SOFT WHEAT ONLY (CHT/DAY)					10000+
	UNDER 200	200-399	400-999	1000-4999	5000-9999		UNDER 200	200-399	400-999	1000-4999	5000-9999	
AL					1							
AZ				1								
CA	2		1	5	2				1	1		
CO				1		1						1
DE	1		1									
FL					2							
GA	2		1	1				1	2	1		
HI				1								
IA				1	1							
IL					3					4	1	1
IN	1				2		1	1	1	3		
KS	1		1	1	8	4	1			2	1	
KY							5	1	2	1		
LA				1	2							
MD										1		
MI							1			7	1	
MN				4	8	3	1					
MO	1			1	1	4		1			2	
MT				1	1							
NC		2		2	1		5	2	4	3		
ND					2							
NE	1	1			5							
NJ					1							
NM	1		1									
NY	1			1	5	5	2		3			
OH			1		1			2	1	7	1	1
OK				2	1	1						
OR				2	1							
PA					1		13	7	5	9		
PR				1	1							
SC			2				1		2	1		
SD												
TN			1	2	2		6	4	1	4		
TX	1			2	2	1						
UT	1	1	2	8	1		1				2	
VA	1					1	8	4	1	2		
WA					2					1	1	
WI						1						
TOTAL US	14	4	11	38	57	21	45	23	23	47	10	2

*Computer Generated, ALINET Data System.

the hard wheat areas of the Midwest, when compared to the concentration of small soft wheat mills (under 200 cwt/day) in the older milling areas of Pennsylvania, Virginia, Tennessee, and Kentucky, indicate the likelihood of different types of operations. In addition, the data may form the basis for hypothesizing future growth patterns, or the introduction of a new technology, which may be a function of mill size or location. The information on grain storage capacity given for each mill provides the necessary supplemental data by which capacity constraints on the movements of grain may be postulated.

The existence of major storage nodes (terminal and port elevators) for a particular state, when coupled with the distribution of transportation modes for shipping and receiving grain (Table 4.5), provides additional information from which the input links to the mills as well as the other processors can be established.

4.1.2 System Element Verification

The potential for automating the direct creation of system elements - nodes and links - is somewhat limited. Although it was recognized that much of the inference and informal logical procedures could not be readily captured in an efficient algorithm, certain types of consistency checks could be easily initiated. These are based on the following types of observations. A facility, although geographically specific, may not imply a single node, since material at many different stages of processing may be treated within a given plant. Information describing a particular wheat flour mill, for example, includes a description of its milling capacity (e.g., 1000 hundredweight whole grain and 800 hard wheat flour). The existence of many ALINET nodes is implied from this simple statement - from washed and tempered grain, to middlings at different points in the breaking and reduction system, and ultimately, to the different varieties of flour and milling by-products. In addition, the inclusion of whole wheat flour capacity in this example indicates the presence of a different process alternative, the grinding of the whole kernel without sifting the by-products.

Therefore, the first step in the downward verification process was to

TABLE 4.5 NUMBER OF TERMINAL ELEVATORS BY MODE OF RECEIVING GRAIN*

STATE	RAIL ONLY	TRUCK ONLY	TRUCK, BARGE	RAIL, TRUCK	RAIL BARGE	RAIL, TRUCK BARGE	RAIL, TRUCK BARGE, LAKE	OTHER	TOTAL
AL	0	0	0	0	0	2	0	0	2
AR	0	1	0	4	0	0	0	2	7
CA	0	0	0	10	0	1	0	0	11
CO	0	0	0	3	0	0	0	0	3
IA	1	2	0	22	0	2	0	0	27
ID	0	0	0	1	0	0	0	0	1
IL	0	13	1	25	1	4	2	0	46
IN	0	5	0	10	0	0	0	0	15
KS	0	0	0	50	0	0	0	0	58
KY	0	0	0	2	0	0	0	1	3
LA	1	0	0	0	4	4	0	0	9
MO	0	0	0	1	0	2	0	1	4
MI	0	0	0	3	0	1	0	0	4
MN	6	3	0	20	0	1	1	0	31
MO	2	0	0	11	0	3	0	0	22
MS	0	0	0	0	1	1	0	0	2
MT	0	2	0	2	0	0	0	0	4
ND	0	0	0	5	0	0	0	0	5
NE	0	5	0	40	0	0	0	0	45
NY	0	0	0	1	0	0	1	2	4
OH	0	5	0	17	0	2	0	1	25
OK	0	0	0	13	0	0	0	0	13
OR	1	0	0	2	2	2	0	0	7
PA	0	0	0	3	0	0	0	0	3
TN	1	0	0	2	0	2	0	0	5
TX	0	1	0	53	1	5	0	1	61
UT	0	1	0	1	0	0	0	0	2
VA	0	0	0	0	0	2	0	0	2
WA	2	1	0	5	1	1	0	0	10
WI	0	0	0	6	0	0	1	4	11
TOTAL US	28	34	1	312	10	35	5	12	442

*Computer Generated, ALINET Data System.

identify the characteristics of the proposed state level nodes entered in the element data base which could be compared against the characteristics of the facilities existing in the facility data base. In order to test the procedure, a modest set was selected to start - limited only by types of facilities for which data had already been entered into the computer, the level of detail of the data and the way in which the desired comparison could be encoded. A one to one mapping between the attribute set of the nodes in the state data base as defined in Section III and the key characteristics of the facility was created. For example, a state node which represents durum grain at a mill in a particular state requires the following characteristics for verification - a mill located in the state which is either classified as a durum mill or a wheat flour mill with appropriate alternating capacity (i.e., hard wheat and durum, or hard, soft and durum). The same verification characteristics also apply to the milling products: granular durum, semolina, durum flour, and by-products. Examples of the attribute sets which correspond to these verification characteristics, shown here in short code format, are given in Table 4.6.

TABLE 4.6 ATTRIBUTES OF SELECTED STATE NODES
THAT ARE VERIFIED BY DURUM FACILITIES
OR MILLS WITH ALTERNATING DURUM CAPACITY

NODE DESCRIPTION	TYPE	COMMODITY	QUALIFIER	FORM	LOCATION	END USE
Wheat, Durum -- Market Grade Grain at Mill for Domestic Use	DURUM	W	NKTCO	---	MILL5	DOMST6
Wheat, Durum -- Flour at Mill for Wheat Products	DURUM	W	-NA-	FLOUR4	MILL5	OWHT6
Wheat, Durum -- Semolina at Mill for Wheat Products	DURUM	W	-NA-	SEMOL4	MILL5	OWHT6
Wheat, Durum -- Granular at Mill for Wheat Products	DURUM	W	-NA-	GRANL4	MILL5	OWHT6

Similar tables can be constructed for soft and hard wheat milling products which encompass, for the verification set: grain at the mill, flour (patent, first and second clear), farina, and by-products. In both cases the characteristics of the facilities include either dedicated hard or soft wheat

milling capacity or the existence of the appropriate alternating capacity. A node representing whole wheat flour (either soft or hard) at the mill requires the explicit indication of the appropriate whole wheat capacity in at least one facility within the state. Verification requests can also be initiated for grain stored at terminal and port elevators. Care must be exercised in designating the verification as conclusive in this case, since the type of grain stored is not given explicitly for these facilities.

Once the attribute sets have been identified, verification codes are created corresponding to each set. These are then ordered to achieve maximum retrieval efficiency in processing the individual verification requests against the data base. A single query can then be initiated to collect all state nodes which are candidates for verification. A portion of the results of a verification run, in which the existence of a single facility was required to satisfy the request, is shown in Table 4.7. Each verification request is headed by the node identification for which verification is required (i.e. WIA21) followed by the date of the request. The full definition of the node is echoed before proceeding to display the information regarding the facility which justifies the node. The facility is then described by an identifier (i.e. M43 that refers to its facility ID as indicated in Appendix D) followed by the facility name, city, and state. More than one facility may be displayed if desired.

4.2 DEFINITION OF THE GRAPHS

Beginning with published statistics, personal communications, general information, and the facility and process data as described in the previous section, the data elements representing the material flow at the state level were defined and the networks constructed through inference and iteration. Representation of the flow of hard wheat and durum from the farm to the retailer within each of the seven states in the North Central Region was required to provide the appropriate framework within which the CERES I and CERES II studies could be conducted.

Although considerable variation exists in distribution of actual facil-

TABLE 4.7 STATE NODE VERIFICATION FROM THE FACILITY DATA*

NODE WIA21 VALIDATED WITH DEFINITION 12/27/1978		
WHEAT	HARD -- MARKET GRADE GRAIN AT MILL IN IOWA FOR UNSPECIFIED USE BASED ON INFORMATION REGARDING THE FOLLOWING FACILITY	
	CITY	STATE
M43	GENERAL MILLS, INC.	
	CARLISLE	IA
NODE WKS21 VALIDATED WITH DEFINITION 12/27/1978		
WHEAT	HARD -- MARKET GRADE GRAIN AT MILL IN KANSAS FOR UNSPECIFIED USE BASED ON INFORMATION REGARDING THE FOLLOWING FACILITY	
	CITY	STATE
M45	DIXIE-PORTLAND FLOUR MILLS, INC.	
	ARKANSAS CITY	KS
NODE WLA21 VALIDATED WITH DEFINITION 12/27/1978		
WHEAT	HARD -- MARKET GRADE GRAIN AT MILL IN LOUISIANA FOR UNSPECIFIED USE BASED ON INFORMATION REGARDING THE FOLLOWING FACILITY	
	CITY	STATE
M73	ADM MILLING CO.	
	DESTREHAN	LA
NODE WMN21 VALIDATED WITH DEFINITION 12/27/1978		
WHEAT	HARD -- MARKET GRADE GRAIN AT MILL IN MINNESOTA FOR UNSPECIFIED USE BASED ON INFORMATION REGARDING THE FOLLOWING FACILITY	
	CITY	STATE
M65	CUN AGRA, INC.	
	FERGUS FALLS	MN
NODE WND21 VALIDATED WITH DEFINITION 12/27/1978		
WHEAT	HARD -- MARKET GRADE GRAIN AT MILL IN NORTH DAKOTA FOR UNSPECIFIED USE BASED ON INFORMATION REGARDING THE FOLLOWING FACILITY	
	CITY	STATE
M148	NORTH DAKOTA MILL ELEVATOR ASS	
	GRAND FORKS	ND

*Computer Generated, ALINET Data System.

ities by state (see Table 2.7) and the available modes of transportation which affect the movement of grain and wheat products, networks of similar complexity appear for each of the states. However, on a state by state basis, the graphs exhibit considerable variation, as a brief description of the following state durum graphs will indicate. South Dakota has neither terminal elevators, durum mills, nor pasta plants. Consequently, the South Dakota durum network stops at country elevators in South Dakota, whence transportation links indicate its movement to both terminal elevators and durum mills out of state. North Dakota, the chief durum producer, has only one durum mill with a capacity of 5000 cwt/day. Consequently, North Dakota durum grain is shown as also moving to out-of-state mills in Minnesota, Wisconsin, and New York. Also, North Dakota has no pasta plants; therefore, semolina, granular durum, and durum flour milled in North Dakota are also shown as moving out of state. Minnesota, the major durum processor, grows relatively little durum itself; therefore, Minnesota terminal elevators and durum mills are shown receiving durum grain from both North and South Dakota, while durum products milled in Minnesota are shown supplying pasta plants in Kansas, Nebraska, and Missouri.

The hard wheat and durum networks interconnect at the point of pasta production, since pasta is made chiefly from durum products, but hard wheat may be used. Thus, farina and second clear flour from hard wheat, and semolina, granular, and flour from durum are shown being transported to the pasta plant and blended into pasta flour. On the state level - for example, Missouri - durum products milled in Minnesota and hard wheat products milled in Missouri are shown as arriving at Missouri pasta plants and being processed into pasta.

Transportation links for the various states also show considerable variation, according to the geographical characteristics, the marketing and processing facilities, and the transportation means in each state. For example, North Dakota does not have access to waterways, therefore, all grain is shown as moving both within the state and out of state by truck and rail. Minnesota, by contrast, has access to both the Mississippi River and the Great Lakes: therefore, out of state grain shipments are shown as utilizing both

waterways.

It is apparent from the preceding discussion that the decision to approach the data definition and graph generation procedure on a state by state basis complicates the picture presented in Figure 3.2 considerably. No longer can the interconnection points be described as sparse. Interstate transfer of commodities is determined by transportation and economic considerations as well as product characteristics. As the network expands from the wheat production areas to population centers, the representation of the interstate linkages becomes increasingly complex.

In the discussion of the Flow Graph Generator in Section III, the general specification of the level used for node assignments was presented. The level was described as a tie to the physical processing stages as well as the method for interconnecting portions of the system and ordering the operations to be performed within the Simulation System. The levels defined for the interconnected interstate wheat system must serve to provide not only common structural reference points for each state but a framework within which one can focus both on the similarities and differences between states as well.

Therefore, the choice of these key levels, and the level definitions appropriate to the sector under study, form an integral part of the data definition process. For the overall wheat sector, ten levels have been defined as follows in order to provide guidelines for the assignment of nodes: The farm level, W FARM, implies grain at the farm ready for either on-farm storage or sale. The second major level, W COLLECTED, implies a major collection point just prior to dispersal through diverse grain marketing channels. Nodes assigned to this level represent grain sold by country elevators after undergoing all processing by the elevator facility and just prior to shipment. The preprocessed grain level, W PREPROCESS, implies that the grain has passed through a sequence of elevator shipments and broker sales to the major processing facilities or ports. Nodes associated with this level represent grain as it arrives at flour and bulgur mills and cereal manufacturers who grind or otherwise process their own grain. Nodes as-

signed to the fourth level, W PROCESSED, are those representing identifiable products after completion of a major processing sequence, but before sale by the processor. Such products include all types of flour (patent, first clear, second clear, whole wheat) and wheat by-products (germ, pollards, red dog, etc.) at the mill. The blended level, W BLENDED, implies the combination of products transferred to another facility for further processing. Examples include pasta flour at the pasta plant, blended mill feed, and blended flour at cookie and cracker plants, bakeries, and family flour packaging plants. W PREREFINED corresponds to W PREPROCESSED in that the material has been prepared for a major refining sequence. The next level, W REFINED, implies the use of additional ingredients, such as additives for self-rising flour or for bread at the bakery, in the definition of nodes which are assigned to this level. The final levels, W PACKAGED, W WHOLESALE, and W RETAIL follow directly. A listing of these levels, along with examples of the nodes residing on each, is given in Table 4.8.

TABLE 4.8 WHEAT NODE LEVELS

LEVEL	NODE EXAMPLES
W FARM	Hard red spring grain on farm (national level), durum grain on farm in Minnesota (state level)
W COLLECTED	Hard red winter wheat grain sold at country elevator, durum sold at country elevator in North Dakota
W PREPROCESSED	Durum grain at mill, hard wheat grain at bulgur mill in Kansas
W PROCESSED	Whole wheat flour at mill, patent flour at mill in Missouri
W BLENDED	Hard wheat family flour at family flour packaging plant, blended millfeed at mill in Kansas
W PREREFINED	Pasta dough for long goods at the pasta plant
W REFINED	Whole wheat bread at bakery, self-rising flour at family flour packaging plant in Nebraska
W PACKAGED	Packaged cookies at bakery, packaged cereal at cereal manufacturers in Nebraska
W WHOLESALE	Sacked hotel and restaurant flour at Pillsbury customers.
W RETAIL	Packaged bread at retailers, packaged spaghetti at retailers in Minnesota

Within this framework, the individual node and link elements were created on a state by state basis, verified to varying degrees of confidence, and placed in the data base. Short codes which are keyed to entries in the

wheat commodity dictionary (Table 3.2) are used to define the nodes. Examples of the node definitions for wheat nodes in Minnesota were abstracted from the data base using a Data System display command and are presented in Table 4.9. It should be noted that the order of this partial list is not structurally significant in describing the flow of wheat; the command generated an alphabetical list by node identifier with the peculiarity that a blank precedes a zero in the ordering procedure.

With the acceptance of the nodes into the data base, state definitions were created as indicated in Section III such that, for example, WMN130 is described by the phrase "Wheat, durum: Coarse impurities at mill in Minnesota for waste". Once the data elements had been defined, network requests were made and the actual flow graphs constructed. The graphs of interest have been discussed in [11], but for completeness, a brief description of a segment of the Minnesota durum graph is included here. Two ordered lists are required to represent the contents of the network data base, created by the Flow Graph Generator for this segment of the graph. The first, de-

TABLE 4.9 SELECTED MINNESOTA NODES*

NODE	TYPE	QUALIFIER	FORM	LOCATION	ENDUSE	STATE	LEVEL
WMN108	HARD	-NA-	FLOUR4	SIFTR5	---	MN	
WMN109	HARD	-NA-	FARIN4	MILL5	OWHT6	MN	W PROCESSED
WMN110	HARD	-NA-	PTFLR4	MILL5	---	MN	W PROCESSED
WMN111	HARD	-NA-	1CLR4	MILL5	---	MN	W PROCESSED
WMN112	HARD	-NA-	2CLR4	MILL5	---	MN	W PROCESSED
WMN114	HARD	SACK3	WWFLR4	MILL5	BREAD6	MN	
WMN115	HARD	TREAT3	FARIN4	MILL5	OWHT6	MN	
WMN116	HARD	TREAT3	PTFLR4	MILL5	BREAD6	MN	
WMN117	HARD	TREAT3	1CLR4	MILL5	BREAD6	MN	
WMN118	HARD	TREAT3	2CLR4	MILL5	OWHT6	MN	
WMN12	DURUM	MKTGD3	---	TRMEL5	---	MN	
WMN120	HARD	-NA-	WWFLR4	FFPP5	BREAD6	MN	W BLENDED
WMN121	HARD	FAMILY3	FLOUR4	MILL5	BREAD6	MN	
WMN122	HARD	SKBKY3	FLOUR4	MILL5	BREAD6	MN	
WMN123	HARD	ENRCH3	FLOUR4	FFPP5	BREAD6	MN	
WMN125	HARD	---	SRIFL4	FFPP5	BREAD6	MN	W REFINED
WMN126	HARD	PKGD3	SRIFL4	FFPP5	BREAD6	MN	W PACKAGED
WMN127	HARD	-NA-	WWFLR4	BKRY5	BREAD6	MN	W BLENDED
WMN128	HARD	PKGD3	SRIFL4	RETLR5	BREAD6	MN	W RETAIL
WMN129	DURUM	CLEAN3	---	MILL5	DOMST6	MN	
WMN13	DURUM	MKTGD3	---	PORT5	EXPRT6	MN	
WMN130	DURUM	COARS3	IMPUR4	MILL5	WASTE6	MN	
WMN131	DURUM	DRIED3	---	MILL5	DOMST6	MN	
WMN132	DURUM	STORD	---	MILL5	DOMST6	MN	
WMN133	DURUM	DRCLN3	---	MILL5	DOMST6	MN	

* Computer Generated

picted in Table 4.10, contains the nodes associated with each level in order within the segment, progressing from left to right (collection to pre-processing) across the graph. The second, Table 4.11, contains a partial list of the links emanating from node WND6 on the level W COLLECTED. As indicated in Section III, verification of the network is possible from lists of this sort; however, visual presentation of the same data, whether computer generated as is described in Appendix C, or drafted by hand as in Figure 4.1, provides the desired insight into the structure of the system.

The segment of the graph, depicting the movement of durum grain from the collection level, W COLLECTED, to the durum mills, W PREPROCESS, in Minnesota indicates the effect of partitioning along state boundaries (Figure 4.1). Out of state nodes are recognized as such by the Flow Graph Generator, and the appropriate source or sink nodes are created in the same manner as the interconnection points between subsectors. For convenience in reading the graph, the two character state code is included as part of the node identifier, so that nodes within Minnesota (i.e. WMN23) are easily distinguishable from a New York or Louisiana location (WNY23, WLA23). The basic movement of durum grain within Minnesota is indicated by the shipment from country elevators (WMN6) by truck and rail into the terminal elevator system (WMN12, WMN14 and WMN17) and on to mills within the state (WMN23) and also, by available waterways, to a Louisiana mill (WLA23)* and one in New York State (WNY23)**

Out of state shipments of grain do not necessarily indicate heavy in-state production. Indeed, Minnesota, although a major durum processor, produces relatively little durum grain, and thus must import supplies from out of state to meet its milling needs. North Dakota, growing the most durum, ships grain from its country elevators (WND6) into the terminal system in Minnesota as well as directly from country and terminal elevators (WND17) to the mills (WMN23). South Dakota, also a major durum grower, has no durum processing facilities and thus provides grain to both Minnesota terminals and mills from its large country elevators (WSD6). Minnesota also functions as a major port for the export of durum grain, depicted on the graph as a sink node. Grain is transported through this channel from country eleva-

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* Seaboard Allied Milling Corp., Port Allen, Louisiana

** Seaboard Allied Milling Corp., Albany, New York

TABLE 4.10 ORDERED LIST OF NODES FROM
SEGMENT OF MINNESOTA GRAPH

NODE NAME	DEFINITION
WND6	Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use
WSD6	Wheat, Durum -- Sold grain at country elevator in South Dakota for unspecified use
WSD200	Wheat, Durum -- Market Grade Grain at subterminal elevator in South Dakota for unspecified use
WMN6	Wheat, Durum -- Sold grain at country elevator in Minnesota for unspecified use
WND17	Wheat, Durum -- Sold grain at terminal elevator in North Dakota for unspecified use
WMN12	Wheat, Durum -- Market Grade Grain at terminal elevator in Minnesota for unspecified use
WMN13	Wheat, Durum -- Market Grade Grain at port in Minnesota for export
WMN14	Wheat, Durum -- Stored Grain at terminal elevator in Minnesota for unspecified use
WMN17	Wheat, Durum -- Sold Grain at terminal elevator in Minnesota for unspecified use
WLA23	Wheat, Durum -- Market Grade Grain at mill in Louisiana for domestic consumption
WMN23	Wheat, Durum -- Market Grade Grain at mill in Minnesota for domestic consumption
WNY23	Wheat, Durum -- Market Grade Grain at mill in New York for domestic consumption

TABLE 4.11 SELECTED LINKS EMANATING FROM LEVEL "W COLLECTED"

LINK ID	PROCESS NAME	ORIGIN NODE	DESTINATION NODE
LW912	Rail Transpt	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN13: Wheat, Durum -- Market Grade Grain at port in Minnesota for export.
LW913	Trucking	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN13: Wheat, Durum -- Market Grade Grain at port in Minnesota for export.
LW503	Rail Transpt	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN23: Wheat, Durum -- Market Grade Grain at mill in Minnesota for domestic consumption.
LW504	Trucking	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN23: Wheat, Durum -- Market Grade Grain at mill in Minnesota for domestic consumption.
LW575	Rail Transpt	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN12: Wheat, Durum -- Market Grade Grain at terminal elevator in Minnesota for unspecified use.
LW909	Trucking	WND6: Wheat, Durum -- Sold grain at country elevator in North Dakota for unspecified use.	WMN12: Wheat, Durum -- Market Grade Grain at terminal elevator in Minnesota for unspecified use.

tors in North Dakota and Minnesota and North Dakota terminals, as well as special sub-terminal collection points in South Dakota (WSD200) which ship primarily to port facilities in bulk rail shipments. Clearly this segment, depicting the wheat network from the point of view of Minnesota facilities, provides an incomplete picture of the movement of durum grain into and out of out-of-state nodes. For example, Iowa acts as a major collection point for South Dakota grain which, since it does not pass through Minnesota, does not appear as a marketing channel on this subgraph. Therefore, care should be exercised in drawing conclusions about the existence or absence of links connecting out of state nodes to other points in the network. It should also be noted that the visual display of the flow graph (i.e., Figure 4.1) differs slightly from its internal representation as structured for the Simulation Scheduler. Internally, nodes and links are unique in the overall network regardless of how many state graphs are combined. However, comparison of corresponding segments of the graphical display for both Minnesota and South Dakota, for example, reveal redundant representations (WSD6, WSD200, WMN13, WMN23, WMN13 and the links providing the interconnections. This is done to provide visual completeness; the interconnection points are treated internally as in Figure 3.2.

4.3 AGGREGATION PROCEDURES

The procedure outlined above permits the identification of the structure of the material flow network on a state by state basis. The data elements representing the interconnections and transformations of the commodity for each state, when defined and placed in the data base, supply additional pieces in the specification of the overall flow network. With the completion of the data definition process, a powerful resource existed, containing sufficient information to permit alternative representations of the structure of the system to be created automatically. Given the state level information, different combinations of the data will result in the construction of different aggregate pictures of the system. These pictures can be viewed hierarchically, beginning with the national (in which durum grain on the farm is represented by a single node), through regional definitions in which an increasingly smaller number of states are combined. Each level of aggregation may be best suited to the presentation and discussion of different types of

results. Indeed, even lower level elements and mixed networks may be required for specific studies such as CERES I and CERES II described in Sections VI through VIII. The more detailed the representation, the greater the focus may be on the distribution network and regional issues and constraints. The national representation, on the other hand, may provide a greater perspective for the discussion of the value of a proposed innovation within the overall sequence of transformations.

The ability to maintain these alternative representations was considered a necessary requirement of the ALINET computer model. In order to meet this requirement, two capabilities had to be developed. The first of these, which has been implemented and tested, consists of the generation of the aggregate data elements - nodes and links - from which the alternative flow graphs can be created. The second, which is related to the determination of an aggregate representation of the material flow, requires the specification of aggregate process models for the transformations which have yet to be determined.

The algorithms developed to meet the first requirement are based primarily on the information describing the state of the material contained in the definition of each node. A node is defined according to its attributes. Within each state, a unique combination of six of these attributes defines each node. Across states, corresponding nodes are defined identically except for the associated geographical location. A method was sought by which these similarities could be easily recognized. The use of the expanded node definition, while readily understandable, as shown in Table 4.10, was rejected for two reasons: 1) its length (up to 100 words) and 2) the inclusion of geographical information such as the phrase "in Minnesota". An alternative representation was sought for encoding this same combination of attributes in a short form, more easily manipulated by the computer, for comparing the node definitions.

The most straightforward approach takes advantage of the structure of the commodity dictionary. Consider that for each commodity, five of the attributes subordinate to it (type, qualifier, form, location, and end use) have each been defined by a single computer word (e.g., FFPP5) as well as an

expanded definition of this code (e.g., Family Flour Packaging Plant). The comparison between the two was used, as described in Section III, to create the node definitions. For detecting similarities, however, a further compression of the combined information into at most two computer words seemed desirable. A *minimum* abbreviation of the attribute definition - a small integer value - is one that can be generated automatically. These integers do not provide a convenient mechanism for node definition by the user - hence the retention of attribute codes. However, the suitability of these small integers in the aggregation procedure, which involves internal machine comparisons only, has motivated their inclusion as part of the dictionary definition.

The number one (1) was assigned to the wheat commodity - integers 2 through 10 correspond to the dictionaries for the other major commodities. A series of five counters was initialized for each commodity - set to zero at the outset and later to the highest number previously assigned to codes within each of the five attributes. As entries to the dictionary were made, in random order, the appropriate counter was incremented and the value assigned to the code upon entry in the data base. These entries, designated aggregation parameters, became a permanent part of the dictionary records. Since new sequences of numbers are assigned to the attributes associated with each commodity, the magnitude of aggregation number associated with each entry is small.

In order to indicate the use of these aggregation parameters in creating the short-hand node definitions, consider an arbitrary node, WNE120. After the six attribute codes which characterize it have been processed against the commodity dictionary, the node carries the following definition: "wheat, hard-whole wheat flour at family flour packaging plant in Nebraska for bread". In the following table, 4.12, the correspondence between the attribute codes associated with the node and the descriptive information and aggregation parameters abstracted from the dictionary is shown.

These six aggregation parameters, along with an indicator denoting the level of aggregation with which the data element is associated, (e.g., state, national, regional) are compressed into two computer words. These words, con-

TABLE 4.12 ATTRIBUTES FOR NODE WNE120

ATTRIBUTE	CODE	DESCRIPTION	AGGREGATION PARAMETER
Commodity	W	Wheat	1
Type	HARD	Hard	4
Qualifier	-NA-		10
Form	WWFLB4	Whole Wheat Flour	20
Location	FFPP5	Family Flour Packaging Plant	35
End Use	BREAD6	Bread	1

taining 60 information bits, are constructed according to the following format. Five bits each are assigned to the major data indicators, aggregation levels, and commodity code, with ten bits reserved for each of the remaining five attributes. These are defined as:

A = Data Level Indicator (5 bits)

1 = State

2 = National

3 = Regional

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n = to be determined

B = Commodity Code (5 bits)

1 = Wheat

2 = Dairy

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n = Soybeans

C = Type

D = Qualifier

E = Form - by commodity (10 bits each)

F = Location

G = End Use

Each of the ten bit codes is partitioned into two five bit segments (i.e., C_L = low order bits, C_H = high) and spread across the two 36-bit data words, as shown in Figure 4.2.

Figure 4.2. Structure of the Two Word Aggregation Code

The order in which the parameters are encoded has been chosen to improve selection criteria keyed on the first word and to speed the sorting process. A slight improvement may be possible, depending on the values of the integers, by exchanging the high order bits (E_H , F_H) with the low order portions of C and D; however, it was not felt to be significant. The two word code is defined in text format, rather than integer, since in that mode all data conversion and size limitation checks are inhibited and preprocessing by the System 2000 Operating System is suppressed. The separation of the information bits in codes A-G by a one bit heading each six bit byte is done

to force all six bit bytes to be nonzero. The single exception is the initial bit in word one, set to zero to permit proper sorting to take place. Since A is defined to be positive, this exception does not violate the non-zero requirement - enforced due to a peculiarity of the System 2000 Text Scanner which terminates upon encountering a byte of binary zeros.

Once the aggregation code has been defined for each node in the data base, it is automatically associated with all appropriate links as an indication of either its source or destination node type, as appropriate. Since additions of nodes and links may be made at any time, any interaction between requests for node definitions and the dictionary causes the assignment of aggregation codes to any waiting elements. In this way, links which may have been entered before the source or destination nodes were fully defined will be updated automatically. The data are then ready for aggregation, according to the needs of the user. In the discussion which follows, the description will focus on the most straightforward aggregation - the combination of all states to form a national picture. The creation of regional views, not yet implemented, will require only a slight modification to the general technique in order to recognize the groupings of states and carry the additional geographical information along with the links.

The first step is to create a sorted list of the nodes in the data base, in ascending order, according to the aggregation codes. Since the geographical information is excluded from this representation, all nodes with the same attribute set will appear consecutively in the list. Given the definition of the first word in the aggregation code, all state level nodes will appear first. The procedure begins with the selection of the first node in the list as the master against which succeeding nodes are compared. The list is processed until the first node is encountered with an aggregation code which is different from the master. All intervening nodes are of the same node type as the master, with matching aggregation codes. If the aggregation level is a national one, the existence of any node in this group (or justification set) implies the existence of a node in the aggregate graph. A regional level will require an additional geographical test.

Once the logical existence of a node has been established, the process of constructing a node definition from information common to the nodes in the justification set is initiated. An aggregation code is created by replacing the data level bits from the master node with the appropriate aggregation parameter. Since there is no constraint on the user when creating nodes in the data base which prevents one from specifying an aggregate node directly, the algorithm for node generation must account for this contingency. Therefore, before a new node is defined, the data base must be interrogated using the aggregation code as constructed above to see if an appropriate node has been previously entered. If so, its validation code can be modified to indicate that it is substantiated by state level nodes and the appropriate states in the justification set displayed. If no node has been previously defined, a node entry is created using the attributes of the nodes in the justification set, the aggregation code, the level assignment, if any, and a node identifier constructed by removing the state indicator from the node identifier of the master node and affixing a temporary indicator T as follows.

State Node WKS108

creates
→
National Node W108T

These nodes are then entered in the data base and listed with the list of states in the justification set. Following a complete scan of the state level nodes, the creation of aggregate nodes is complete. Theoretically, at this point, all aggregate nodes are based on the existence of the same type of node specified for some state. However, as a check on the consistency of the data base, a final list can be generated of any aggregate nodes, still residing in the data base, which can no longer be justified from the existing structural information. An example of this process is described in Appendix E.

With the completion of the node aggregation procedure, the process of creating an aggregate representation of the interconnections can be initiated. Similar procedures are developed for determining the elements of the link justification set and developing the definition of the aggregate links. Three criteria must be considered instead of the one used in comparing nodes - the aggregation code of the origin node, the aggregation code of the destination,

and the process name identifying the link type. All three must match for links to belong to the same justification set. Two separate link lists are maintained - one containing all links whose origin nodes are characterized by a state level aggregation code, one containing all other links. These two lists are sorted in ascending order in the same manner; by origin code as the major sort key, destination code and process representation as minor ones. Thus, the state link list groups all links with the same characteristics together before advancing to a different process type. When the process types for a given origin/destination type pair have been exhausted, the next destination type is processed. When the aggregation process is complete, the same two basic conditions exist; either a link as depicted at an aggregate level can be substantiated by state level process definitions or it cannot, i.e., it exists only at the aggregate level. As in the case of nodes, these unjustified links are not deleted - merely flagged for examination by the user to see if their inclusion was deliberate. For any given execution of the data aggregation software, a particular link, once justified, may be indicated either as "newly created" or "already existing" in the data base. Again, study of the first few newly created links, particularly those substantiated by only a single state link in the data base, reveals the use of the portion of the Data System as a verification aid (see Appendix E).

The procedure described above, by which a definition of the overall structure of the wheat processing and distribution sector may be inferred from the composite of the state level specifications, has several positive results. From the point of view of modeling consistency, two obvious characteristics of the national level data are clear: 1) each element can be traced to the entries of a particular state(s), and 2) the overall graph of the aggregate, justified elements will have the same properties as the individual state graphs - a loop free representation of the material flow.

With the completion of the aggregation, a request to generate national level graphs from "farm level" to "retail" was issued. The result of each request is a graph which is visually simpler than the state graphs and allows the structure of the system, in terms of a sequence of transformations, to emerge. Contrast, for example, Figure 4.3, the portion of the national flow

Figure 4.3 Durum from Collection to Mills: National

graph representing the processing of durum wheat, with the state level graph depicting the flow of durum in Minnesota (Figure 4.1). The same segments of the network, from W COLLECTED to W PREPROCESS, are depicted and the simplification that results from collapsing twelve distinct nodes into seven generic ones is clear.

In the preceding discussion, a critical need in the development of any large modeling system has been identified. In the absence of software which permits the examination of the data at periodic intervals from different points of view, the task of maintaining the integrity of the data base becomes an extremely difficult one. In order that the requirements of the computer modeling system for consistent data be met, tools such as these are viewed as a necessary part of the data verification process. It is anticipated that efforts will continue in developing software tools of this type, as well as in automating the data generation process.

V. THE SIMULATION SYSTEM

5.1 INPUT AND SIMULATION

The Simulation System, the third of the functional entities within ALINET, is required only after the user is satisfied with his definition of the network. The representation of the network structure, acquired through interactions with the Data System and the Flow Graph Generator, provides a framework within which a variety of studies or analyses of the material flow under different conditions can be performed.

As indicated in Section I, several alternative simulation systems are possible in which the depth of the algorithmic sophistication (from static to adaptive) depends on the types of models of the system that have been developed. In each case, however, a similar structure is anticipated according to the following pattern. A complete simulation requires the execution of three distinct steps: 1) extraction of process and material data for the specific network and appropriate time of interest, 2) determination of the material flow and the use of process inputs and 3) analysis of the results. These steps are ordered so that beginning with the same basic graph, many different simulations can be specified at each point based on the output of a preceding step.

One might argue that the first two steps, data extraction and the propagation of the material flow, could well have been combined. There is no analytical requirement for the split; the separation of basic input processing from simulation reflects an increasing sensitivity to the economic and practical considerations in dealing with large computer models. In this case the line between the two functions was somewhat subjective. The substantial overhead reflected in terms of core/computer resource requirements to retrieve "permanent" element data for a specific network motivated the creation, once per study, of a baseline simulation input file. Modifications to specific data values, superimposed on this basic input are treated as changes to the scenario and appear within the province of the Simulator.

5.1.1 Data Extraction

The data extraction routine creates the baseline file according to user requests. A simulation time is given (by month and year) and a particular flowgraph of interest identified from which the network data base can be accessed. The input file is patterned according to the progression of levels, by name, across the graph -- each with a set of nodes and, associated with each node, a set of inbound and outbound links. Process names, having been included by the Flow Graph Generator as link labels, appear as the only non-structural data stored in the input file at the end of this step. The element names (nodes and links) in the network file act as requests for data to be processed against the element data base. Values for data items appearing in Table 5.1 are retrieved for the specified month and year.

TABLE 5.1 DATA ITEMS ADDED TO THE
NETWORK DATA FOR SIMULATION

ELEMENT	DATA ITEMS
NODE	Unit of Measure, Material, Energy
LINK	Process Coefficient, Distance, Allocation Coefficient, Capacity, Process Inputs

The immediate question arises regarding the treatment of missing data. The completeness of the structure is guaranteed by the Flow Graph Generator. Simple default procedures are required for the remaining inputs. Certain data items, relating to the flow of materials, must be valued. These include the process coefficient, defined to be the number of units of output from a process for each unit of material input, and the allocation coefficient, which apportions the supply of material at each node along the outgoing links. A default value of unity is assumed for these parameters.

The remaining time functions need not be valued for any particular element; thus a default of zero is accepted by the system. Average values for the time functions, designated by a "13" as the monthly time tag, are sought in the event that a particular time/value request fails to retrieve data from the data base.

5.1.2 Input to the Simulation

The simulation input file presented to the Simulator permits a complete pass through the network using baseline or default values for all system inputs. Two forms of baseline modifications are accepted at this point: 1) changes to single data values via entries in a temporary update file, and 2) global changes through the introduction of user specified process models. The single value requests may be specified for any entry which is not a part of the network data base (Table 5.1) by indicating the node or link name, the component to be changed and the new value. The existence of a temporary update capability was considered essential in that it permits a variety of "what if" questions to be posed without affecting the permanent data base.

The expansion of the change file to include the specification of process models provides several additional advantages. Not only can it be used to simplify the input process by permitting global entry of link data, but it also provides a mechanism by which alternative models of the technologies under study may be tested and manipulated directly. A special FORTRAN subroutine, *PMODEL*, accessible from the input processor, has been designed to provide the interface between the simulation and the user specified process models as desired.

It should be noted that two simple models have been incorporated, as an example, to determine the average use of diesel in transportation - one for truck transportation, the other for rail. These are defined within the simulation as follows:

$$u_d = c D g \quad (5.1)$$

where:

u_d = gallons of diesel per unit of material
delivered

c = conversion factor; number of units of material
per ton

D = distance travelled along the links

g = gallons of diesel per route-ton-mile

$= 7.2684 \times 10^{-3}$, trucking

$= 1.9251 \times 10^{-3}$, rail

The justification of these values is given in Section 7.4. The appropriate process model is applied to determine the per unit input requirement (diesel) for links in the system for which the process description matches that of the model.

Once the user requested changes have been made and the process model results incorporated, the input file is ready for simulation. A final pass through the data is made to determine a unit conversion coefficient, C , for each link - a factor that accounts for any change in units (e.g., MBU to TCWT = 600) between the link origin and destination.

5.1.3 Propagation of Material Flows

The Simulator is then positioned at the first level represented by the network and the determination of the material flow is initiated. For the static simulation, implemented for the test case, this phase in the process merely requires the proper accounting of the flows into each node, the distribution and conversion of material through outgoing process links and the estimation of the use of process inputs.

Nodes are considered from top to bottom along each level, with the supply of material at each node given by:

$$S_j = \sum_{\ell} f_{\ell} ; \quad \ell \in \{L_j\} \quad (5.2)$$

where:

f_{ℓ} = flow along link ℓ

$\{L_j\}$ = set of links destined for node j

It is assumed that the supplies of material at source nodes, or those nodes for which no incoming links appear as part of the network under study, have been specified as data. A single exception is made for *derived* source nodes; nodes that represent other process inputs (e.g., dried eggs added to durum flour in pasta production) which are combined with the major input commodity in fixed proportions. The material available at the derived nodes is given by:

$$S_j = \beta_{ij} S_i \quad (5.3)$$

where:

β_{ij} = input fraction

S_i = material at major node i

Upon completion of the supply computations for the nodes, the determination of the outgoing flows can be made. The nodes are considered again in order. For each, a set $\{L_i\}$ is defined containing all those links with the origin at node i of interest. A preliminary check is made on the flow requests from each node to insure that the sum of the outgoing flows not exceed the supply available. The allocation requests are scaled as follows:

$$\alpha_{\ell}' = x \alpha_{\ell} ; \quad \ell \in \{L_i\} \quad (5.4)$$

where:

α_{ℓ}' = allocation coefficient
associated with link ℓ

$x = \min (1.0, 1/\sum \alpha_{\ell})$

The flow across each of the links is given by:

$$f_{\ell} = \alpha_{\ell}^{\prime} S_i C_{\ell} m_{\ell} ; \quad \ell \in \{L_i\} \quad (5.5)$$

where:

m_{ℓ} = process coefficient
associated with link

C_{ℓ} = unit conversion between unit
of measure at origin and
destination nodes

and the total use of inputs required by the process is determined by:

$$U_{\ell k} = f_{\ell} u_{\ell k} + H_{\ell k} \quad (5.6)$$

where:

k = denotes a process input type
required by transformation along
link ℓ

$u_{\ell k}$ = amount of process input
required per unit of output

$H_{\ell k}$ = overhead input requirement of
type k , independent of flow

The simulation continues across the levels until all values of S_i , f_{ℓ} and $U_{\ell k}$ have been determined. The results are displayed and the simulation snapshot stored for access, aggregation and analysis by the post processor.

5.2 POST PROCESSING AND ANALYSIS

The Simulation Post Processor is presented with a tableau of information containing not only the structural network data and the input to the simulation but the results of each run of the simulator as well. The critical information required for analysis is still fragmented in this format, in the sense that the data representing the material flow and the use of the factors of production are associated with the single system elements (i.e. nodes or links) to which they correspond. What remains is to integrate

these results for the overall system, to define and evaluate specific measures of interest and to perform the desired analysis. A framework was devised within which the simulation output could be combined with study-specific requests for statistics, aggregation and the specification of alternative scenarios.

5.2.1 Assignment of Process Inputs

At the heart of this software is the algorithm by which the use of process inputs within the system can be attributed to the production of a specific commodity. It is clear that such accounting cannot be performed concurrently with the forward determination of the flow, since the knowledge of the disposition of the flow through later points in the system would be required. One begins therefore from the commodity of interest and traces backwards through the network to identify the paths by which the commodity was produced. In the simplest system, in which all commodities (whether final or intermediate goods) are achievable, the association of process inputs with the production of a particular commodity is a problem of assigning flow to particular paths. The description of the algorithm for determining the input content of particular commodities is expressed in this context in the discussion that follows.

Working backward systematically through the network from a selected node traverses each path to that node from any other part of the network only once. When the analytical question is formulated, as it is in this particular example, in terms of inputs used from all sources to arrive at a particular end result, individual paths need not be maintained. It is only important that no contribution be counted more than once; an observation of some importance from an implementation point of view since the number of paths may be extremely large.

The aggregation of paths begins with the determination of a recursive multiplier. For simplicity, this process can be described in terms of a single request commodity, q ; multiple requests are merely processed in parallel. The recursive multiplier or assignment fraction, r_{jq} , represents the proportion of the supply at node j which reaches node q via any path between them. The backward trace is initiated at the level on which node q

resides, and proceeds in reverse order. The first of two computations is made in the following way.

Let the running total of the amount of input k (i.e., natural gas, electricity, etc.) required to produce the material at node q , T_k^q , be given by:

$$T_k^q = r_{jq} \sum_{\ell} U_{\ell k} ; \quad \begin{array}{l} \ell \in \{L_j\} \\ j \in \{N_q\} \end{array} \quad (5.7)$$

where as previously defined:

r_{jq} = assignment fraction between node j and node q

$U_{\ell k}$ = total use of input, k , in processing across link ℓ

$\{L_j\}$ = set of links with destination at node j

$\{N_q\}$ = set of nodes on level n that lie on a path to q

The set of links $\{L_j\}$ can then be used to initiate update requests for the assignment fractions since all origin nodes for links in this set also lie on paths to node q . The requests are ordered by the triplet containing the level n (on which origin node i resides), commodity index q , and node index i . This ordering, as implemented, assures that paths are propagated and traversed only once for each commodity q . The additional information, r_{jq} , is attached to the triplet and particularized as r_{jq}^{ℓ} .

When the first update request for node i reaches the top of the list, it is apparent from the reverse order of level processing that all requests pertaining to node i have been received. A new set of links is created by recognizing the grouping of all remaining requests for updates at i immediately following the first. The set thus formed, $\{L_i^{\sim}\}$, is not in general the same as $\{L_i\}$ in that it contains only those links lying on paths to node q . The update is expressed as:

$$r_{iq} = \sum_{\ell} r_{jq}^{\ell} \alpha_{\ell}^{\sim} ; \quad \ell \in \{L_i^{\sim}\} \quad (5.8)$$

where:

r_{jq}^{ℓ} = assignment fraction between
node j and node q; associated
with link ℓ

α_{ℓ} = allocation coefficient for
link ℓ

The sequence is then repeated traversing backward, so that node i becomes a destination node j for a new set of links, and setting $r_{jq} = r_{iq}$, the total, T_k^q is updated according to equation 5.7. Processing continues until all paths to all sources of material, ultimately reaching node q, have been considered.

5.2.2 Modeling of Joint Products

In the preceding discussion, it was stated that the algorithm for determining the assignment of inputs to the production of a given commodity was conditioned on the existence of a *simple* flow system. The definition of such a system may be said to be one in which the allocation coefficients, α , are not a fixed consequence of the process employed. While this description applies to much of the food processing and distribution system, certain key processes (e.g., milling of wheat into flour and milling by-products) result in the production of different, but joint, products from the same process. The representation of these processes in ALINET, although modeled in such a way that the forward simulation of flows is identical with the rest of the system, assumes a minor modification to the backward flow assignment algorithm described.

Consider the following generic process, represented in Figure 5.1. The single commodity input at node 1 results in the production of joint products at nodes 3, 4, 5 and 6. Node 2 is a sub node, designated in such a way that it can be recognized by the system. All process characteristics, mass conversion and use of process inputs, are associated with link L_1 . The links emanating from node 2 merely serve to represent the allocation of the material in fixed proportions to the various outputs. In the context of the flow assign-

Figure 5.1 Representation of Process with Multiple Outputs

ment algorithm described above, it is apparent that the use of inputs along link L_1 cannot be partitioned among nodes 3-6, since the process must run completely to produce any one of the outputs. Thus a traceback initiated from any of these nodes (3-6) would result in the inclusion of the *total* value of U_{lk} for link L_1 in the calculation of T_k^q .

Some care was required in modifying the existing flow assignment algorithm to treat this case in general. For the situation in which more than one joint product node (e.g., both nodes 4 and 5) lies on the path to commodity q , the straightforward processing of requests would have resulted in the double counting of inputs U_{lk} . A simple modification to the existing traceback procedure was all that was required. In the event that a sub node, such as node 2 in Figure 5.1, appears in the request list as an origin node i , Equation 5.8 for the updating of the assignment fraction is replaced by:

$$r_{iq} = \max_{\ell} (r_{jq}^{\ell}) \quad ; \quad \ell \in \{L_i\} \quad (5.9)$$

and the algorithm proceeds normally.

5.2.3. Aggregation and Results

Upon completion of the algorithm described above, a distinct set of values, T_k^q , broken down by process input category (e.g., natural gas, electricity, etc.) is retained for each of the commodities, q , of interest. A single simulation run is represented by the computations, and within that run, all processes contributing to the production of that commodity have been considered.

As the questions relating to the pilot study described in Sections VI to VIII of this report were formulated, a number of ways of partitioning, combining and displaying the information were identified. The first required the specification of generic stages, highly aggregated, within the overall material flow. Those used in the current study, provided to the post processor in terms of groups of levels, can be expressed as: 1)input to the mill, 2)milling, 3)output from the mill, 4)pasta manufacture, and 5)distribution of pasta. The input totals, T_k^q , are partitioned according to the contributions represented by processes within these generic stages. The assignment rule considers a process to be within a given stage if the destination node of the process link lies on a level with the stated level bounds. The partitioning permits analysis beyond the total input requirement to focus on the places within the overall processing sequence where the various inputs are required.

For each commodity, q , the stage by stage results are displayed, indicating both the total input of type k and the per unit requirement given by:

$$t_k^q(i) = T_k^q(i) / S_q$$

where i identifies the generic stage.

Per unit results are also evaluated across the overall system for the individual commodities, with aggregate results available for groups of commodities as requested by the user.

The capability of aggregating the same type of information across simu-

lation runs was also considered desirable. The post processor, as implemented for these studies, permits the combination of up to twelve distinct runs to generate, for example, annual results from monthly simulations. The aggregate averages are displayed in the same format as those for individual runs. In addition, the time series of the supply of material at key nodes in the system are represented.

It is clear that the types of statistics which may be desired for a specific study are limitless; only a small sample have been implemented to obtain the results described in the remainder of this report. It is anticipated that as additional studies are formulated, the existing simulator and post processor may be enhanced, modified or even replaced depending on the interests of a particular user.

VI. PILOT PROJECT:
HARD WHEAT MILLING AND PASTA MANUFACTURE

6.1 INTRODUCTION

The purpose for the development of ALINET has been to provide an efficient tool for analyzing the effect of alternative technologies on energy conservation in the food processing and distribution industry. The modeling system has been designed so that it can be of use to government agencies concerned with energy conservation in industry, to electric utilities concerned with future demand, and to the food processing industry which is concerned with energy efficiency and the costs of production. In order to demonstrate the effectiveness of ALINET to its potential users, a pilot project was formulated and carried out.

At the workshop held at the end of Phase A (February 1978) wheat was selected as the first commodity to be studied in detail. The Pillsbury Company agreed to cooperate with the project and provide data on wheat processing and technical assistance in the identification of nodes and links for specific wheat networks. On May 15, 1979 a preliminary meeting was held between Dr. John Haaland, Vice President for Information Management and Environmental Systems, the Pillsbury Company, and Dr. A. H. Levis, Principal Investigator for the ALINET project. During the meeting, the scope of the pilot project, the time available for carrying it out, and the budgeted level of effort were discussed.

A second meeting was held on July 12-13, 1979, also at Pillsbury in Minneapolis, Minnesota. Following an introductory presentation of the objectives and the method of approach for the pilot project, a sequence of meetings was held between Pillsbury staff members and SCI representatives. The following persons provided the project team with information regarding the various stages of wheat processing, transportation, and marketing: Dr. John Haaland; Mr. Paul Stepner, Vice President for Transportation; and Messrs. Ernie Badoer, Dick Fisher, Jim Warner, Dan Retoff, L. D. Compton, Bill Wolf, and Ted Austin. Mr. Don Paugh, Director of Environmental Quality, provided coordination within Pillsbury and also expert advice in analyzing and interpreting the data provided by Pillsbury.

Two potential case studies were outlined at that time: hard wheat milling and pasta manufacture. The Atchison, Kansas mill of Pillsbury was selected as the focus for the first study and the American Beauty Macaroni Co. plant in Kansas City, Kansas, for the second one.

With this information, preliminary descriptions of the material flow networks for the two case studies were prepared and detailed data needs were identified. On July 30 and 31, 1979, Dr. Levis and Mr. Webster of SCI, accompanied by Mr. Paugh of Pillsbury, first visited the Atchison mill to obtain data and verify the model. Messrs. John A. Meier and Robert W. Morton, Co-Managers of the facility, demonstrated the operation of the mill and then assisted in correcting the network representation. The American Beauty Macaroni Co. pasta plant was visited next and its operation reviewed. Mr. Don Harper, Plant Manager, Mr. Tom Basile, Manufacturing Manager, and Mr. John Jordan, Plant Quality Assurance Manager, described the various steps in the pasta manufacturing process and also showed a new microwave drier. In Minneapolis, more discussions were held with Pillsbury staff members and additional facilities, such as the terminal at Red Rock, were visited.

Since the Peavey Company's mill in Hastings, Minnesota is a major supplier of ocmolina and durum flour to the American Beauty pasta plant, arrangements were made to visit this facility on August 1, 1979. Mr. Bill Engebretson, Plant Engineer, described the durum milling process used at the plant, gave a tour of the facility and provided the project team members with relevant data.

These site visits and the discussions with plant personnel were of invaluable assistance in developing the correct network representations and in constructing the models presented in Sections VII and VIII.

The models created differ somewhat from those designed earlier and presented in the interim report on Phase B [11]. The underlying philosophy is the same, and many of the nodes and links (although designated and numbered differently) are identical with the corresponding nodes and links in the state and national level networks. However, because *specific* facilities are modeled, in contrast to the generic models of the earlier versions of ALINET, modifications, additions, and different kinds of aggregation were required.

While the purpose of the earlier networks was to encompass all of the important aspects of hard wheat or durum processing within one specific state, or nation-wide, the emphasis in the pilot project is on the unique characteristics of individual plants and on providing a framework for analyzing specific issues of interest. For example, the national and state level networks contain detailed models of the movement of grain from the farm to the mill through country, subterminal, and terminal elevators, including storage en route, and all possible forms of transportation employed (rail, truck, barge, and lake vessel). If the issue of interest were the detailed study of transportation energy, or energy use in grain handling and storage at elevators, these models could be used, either in their present or in a more detailed form. However, the goals for the pilot project have been the assessment of energy conservation opportunities in wheat processing with emphasis placed on plant operations and the identification of alternative technologies that may lead to energy conservation. Thus, the complex movement of grain from the farm to the mills has been aggregated into a few nodes and a few links. The multiple products produced by the individual plants and the multiple destinations where they are sent are of importance, however; therefore, the modeling of product types and destinations was expanded.

In hard wheat milling, data availability determined the level of disaggregation within the mill. Thus, the emphasis in CERES I is on total energy in milling. In CERES II, there are two main processes: durum milling and pasta manufacture. In durum milling, distinction is made between energy used to produce semolina and energy used to produce durum flour. The pasta making process in the national and state networks is modeled rather simply; the various products are not differentiated, and the use of hard wheat flour (which is used by some pasta makers) is included. In CERES II, only durum products (used exclusively by American Beauty) are included, and the pasta process model is made considerably more detailed. This was required not only to achieve a realistic representation of the particular plant and its multiple products, but, above all, to focus on the assessment of an energy conserving technology in the process. The network models for the two case studies, CERES I and CERES II, are described in Sections 6.2 and 6.3, respectively.

6.2 CERES I -- HARD WHEAT MILLING

CERES I is a relatively simple three stage model -- grain input to mill, milling, distribution of mill products. Wheat is transported from Kansas, Nebraska, and Missouri to Atchison, where it is milled into flour and by-products. The milling process itself is represented in an aggregated form, but the overall energy used in making many products is clearly indicated. The model ends with the transportation of multiple products to users and Pillsbury warehouses. In the future, it could be extended to include baking and other processes which use flour, according to the issues or processes that might be of interest. Generic models of the baking of bread, cakes, cookies, or the processing of breakfast cereals are already included in the national and state networks, and can be expanded and augmented as needed to describe specific facilities and technologies.

The CERES I model contains 41 nodes, two sub-nodes, and 55 links, as shown in Figure 6.1. The complete list of nodes is given in Table 6.1. The flowgraph starts with hard red wheat grain in Kansas, Nebraska, and Missouri, the states which supply the Atchison mill. Because the marketing channels in the earlier stages of the wheat flow are not included, the source nodes are designated as "grain at various locations;" this location designation may include country elevators, terminal elevators, and farms. Grain from Kansas and Nebraska is shown arriving by both truck and rail, but grain from Missouri is received by truck only. Another source node is W1C5, "#1 germ at other Pillsbury mills," which is shown as arriving by both truck and rail. "Other ingredients" (W1C17) used in Bitsyn manufacture are not traced back to their origin, but assumed as being already at Atchison.

The milling process produces, from the source node "hard wheat grain at the mill" (W1C4), farina, patent flour, second clear flour, #1 germ, and other by-products (W1C6-10). As all are outputs from the same milling process, theoretically the link "milling" has multiple destinations. However, in order to simplify the software specifications the link is directed to a sub-node, denoted by a circle in the graph, whence sub-links lead to the appropriate output nodes.

Figure 6.1 The CERES 1 Model

TABLE 6.1 CERES I NODE DEFINITIONS

<u>NODE</u>	<u>DEFINITION</u>
W1C1	Wheat, Hard Red Winter; Sold Grain in Kansas for Unspecified use
W1C2	Wheat, Hard Red Winter; Sold Grain in Nebraska for Unspecified use
W1C3	Wheat, Hard Red Winter; Sold Grain in Missouri for Unspecified use
W1C4	Wheat, Hard Red Winter; Market Grade Grain at Pillsbury Mill in Atchison, Kansas for Unspecified use
W1C5	Wheat, Hard Red Winter; #1 Germ at Pillsbury Mills for Wheat Products
W1C6	Wheat, Hard Red Winter; Farina at Pillsbury Mill in Atchison, Kansas for Wheat Products
W1C7	Wheat, Hard Red Winter; Patent Flour at Pillsbury Mill in Atchison, Kansas for Unspecified use
W1C8	Wheat, Hard Red Winter; Second Clear Flour at Pillsbury Mill in Atchison, Kansas for Domestic use
W1C9	Wheat, Hard Red Winter; #1 Germ at Pillsbury Mill in Atchison, Kansas for Wheat Products
W1C10	Wheat, Hard Red Winter; By-products at Pillsbury Mill in Atchison, Kansas for Domestic use
W1C11	Wheat, Hard Red Winter; Flour at Pillsbury Mill in Atchison, Kansas for Export
W1C12	Wheat, Hard Red Winter; Grocery Mix Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C13	Wheat, Hard Red Winter; Bakery Mix Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C14	Wheat, Hard Red Winter; Hotel and Restaurant Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C15	Wheat, Hard Red Winter; Bakery Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C16	Wheat, Hard Red Winter; Family Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C17	Miscellaneous Ingredients
W1C18	Wheat, Hard Red Winter; #1 Germ at Pillsbury Bitsyn Plant in Atchison, Kansas for Wheat Products
W1C19	Wheat, Hard Red Winter; Blended Millfeed at Pillsbury Mill in Atchison, Kansas for Domestic use
W1C20	Wheat, Hard Red Winter; Sacked Flour at Pillsbury Mill in Atchison, Kansas for Export
W1C21	Wheat, Hard Red Winter; Sacked Hotel and Restaurant Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C22	Wheat, Hard Red Winter; Sacked Bakery Flour at Pillsbury Mill in Atchison, Kansas for Bread
W1C23	Wheat, Hard Red Winter; Bitsyn at Pillsbury Bitsyn Plant in Atchison, Kansas for Wheat Products
W1C24	Wheat, Hard Red Winter; Packaged All-Purpose Flour at Pillsbury Family Flour Packaging Plant in Atchison, Kansas for Bread
W1C25	Wheat, Hard Red Winter; Packaged Bitsyn at Pillsbury Bitsyn Plant in Atchison, Kansas for Wheat Products
W1C26	Wheat, Hard Red Winter; Sacked Hotel and Restaurant Flour at Pillsbury Facility for Bread
W1C27	Wheat, Hard Red Winter; Bakery Flour at Pillsbury Facility for Bread
W1C28	Wheat, Hard Red Winter; Packaged All-Purpose Flour at Pillsbury Facility for Bread
W1C29	Wheat, Hard Red Winter; Packaged Bitsyn at Pillsbury Facility for Wheat Products
W1C30	Wheat, Hard Red Winter; Farina at Pillsbury Packaging Plant in Springfield, Illinois for Wheat Products
W1C31	Wheat, Hard Red Winter; Sacked Flour at Port in Pensacola, Florida for Export
W1C32	Wheat, Hard Red Winter; Sacked Flour at Port in Beaumont, Texas for Export
W1C33	Wheat, Hard Red Winter; Sacked Flour at Port in Orange, Texas for Export
W1C34	Wheat, Hard Red Winter; Grocery Mix Flour at Pillsbury Packaging Plant in Springfield, Illinois for Bread
W1C35	Wheat, Hard Red Winter; Bakery Mix Flour at Pillsbury Packaging Plant in Springfield, Illinois for Bread
W1C36	Wheat, Hard Red Winter; Sacked Hotel and Restaurant Flour at Customer for Bread
W1C37	Wheat, Hard Red Winter; Bakery Flour at Customer for Bread
W1C38	Wheat, Hard Red Winter; Packaged All-Purpose Flour at Customer for Bread
W1C39	Wheat, Hard Red Winter; Second Clear Flour at Midwest Solvents Processors in Atchison, Kansas for Domestic Use
W1C40	Wheat, Hard Red Winter; Packaged Bitsyn at Customer for Wheat Products
W1C41	Wheat, Hard Red Winter; Blended Millfeed at Customer for Domestic use

SUB-NODE

W1D1	Wheat, Hard Red Winter; Ground Grain at Pillsbury Mill in Atchison, Kansas for Unspecified use
W1S1	Wheat, Hard Red Winter; Mixed Germ at Pillsbury Bitsyn Plant in Atchison, Kansas for Wheat Products

In the next stage, farina is shipped, in bulk, by rail to the Pillsbury packaging plant in Springfield, Illinois. All second clear flour goes via pneumatic tube to the adjacent plant of Midwest Solvents in Atchison, to be processed into alcohol. "Other by-products" are processed into mill feed, which is shipped, by rail only, to customers in a number of states (which are specified in the data base.) The #1 germ milled in Atchison is processed into Bitsyn ("wheat nuts," a nut-like snack food), packaged, and shipped, by truck only, both to Pillsbury warehouses and direct customers; all locations are specified in the data base.*

Patent flour is divided into various categories. Export flour is shipped, sacked, via rail to Pensacola, Florida; Beaumont, Texas; and Orange, Texas. Grocery mix and bakery mix flour are shipped, by bulk rail, to the Pillsbury packaging plant in Springfield, Illinois. H&R flour is shipped, sacked, both by truck and rail, to Pillsbury facilities specified in the data base, and direct to customers, specified by state. Bakery flour is shipped, both bulk and sacked, by truck and rail, to Pillsbury facilities as well as direct customers. Family flour is packaged as all-purpose flour in Atchison and shipped, by truck and rail, to Pillsbury facilities and direct customers. All destination points, specified as Pillsbury facilities in specific locations and as states for direct customers, are contained in the data base, as are truck and rail distances to all points.

6.3 CERES II -- DURUM MILLING AND PASTA MANUFACTURE

CERES II, in contrast, is a much more complicated and comprehensive five stage model. More detail was included partly because more detailed data were available and, more importantly, because pasta manufacture provided greater opportunity for demonstrating the uses of ALINET in addressing a realistic industrial problem. The American Beauty Macaroni Co. facility in Kansas City was placing in operation a new microwave drier in place of a conventional drier. While it was assumed that one of the advantages of introducing an alternative technology would be an increase in plant productivity, it was not clear whether

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*The graph reflects operations in 1977; now the product is transported in bulk to packaging plants and then distributed.

overall energy conservation would be achieved. Not only there was a change in the mix of energy inputs, but also the throughput parameters of the plant were changed. Analyzing and comparing combinations of alternative material flows and energy consumption is one of the design features of ALINET.

In order to trace the processing of durum into pasta products, it was necessary to model the movement of durum from the farm to the mill, the milling into semolina and durum flour, and the transportation of the pasta ingredients to the pasta plant. Data on durum milling were obtained from the Peavey Company's mill in Hastings, Minnesota, a major supplier for the American Beauty pasta plant (ABPP) in Kansas City. Thus, CERES II has five stages: movement of durum grain to Hastings; durum milling in Hastings and other durum mills; transportation of semolina and flour to Kansas City; pasta manufacture; and distribution of pasta products. The CERES II flowgraph, depicted in Figure 6.2, contains 70 nodes, 8 sub-nodes and 118 links. The nodes and their definitions are listed in Table 6.2.

The material flow begins with durum grain "at various locations" in North Dakota, South Dakota, and Minnesota; because over 90% of the durum originates in North Dakota, that state is further subdivided into its nine agricultural regions. Grain is sent from these eleven source nodes, via truck and rail, to the Peavey Mill in Hastings, Minnesota, a primary source of durum products for the American Beauty pasta plant in Kansas City. Grain from these areas not going to Peavey is sent to a sink node (W2C12), for which transportation modes are not differentiated. The truck and rail distances from each source to Peavey-Hastings were calculated, and the amounts coming from each region were estimated.

Durum milling, which was modeled in detail in the national and state level graphs, is represented for this case study in an aggregated and somewhat different manner. The milling of durum can be modeled as two parallel processes: a shorter one, designated Milling A, is used to produce semolina with some flour as a by-product; and a longer one, designated Milling B, in which durum is milled until flour is obtained. Again, as with the hard wheat model, the milling link has multiple destinations, so two sub-nodes are introduced (one for ground durum and one for fine ground durum); they are denoted by circles in Figure 6.2.

Figure 6.2. The CERES II Model.

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TABLE 6.2 CERES II NODE DEFINITIONS

NODE	DEFINITION
W2C1	Wheat, Durum; Grain at various locations in North West North Dakota for Unspecified use
W2C2	Wheat, Durum; Grain at various locations in West Central North Dakota for Unspecified use
W2C3	Wheat, Durum; Grain at various locations in South West North Dakota for Unspecified use
W2C4	Wheat, Durum; Grain at various locations in North Central North Dakota for Unspecified use
W2C5	Wheat, Durum; Grain at various locations in Central North Dakota for Unspecified use
W2C6	Wheat, Durum; Grain at various locations in South Central North Dakota for Unspecified use
W2C7	Wheat, Durum; Grain at various locations in North East North Dakota for Unspecified use
W2C8	Wheat, Durum; Grain at various locations in East Central North Dakota for Unspecified use
W2C9	Wheat, Durum; Grain at various locations in South East North Dakota for Unspecified use
W2C10	Wheat, Durum; Grain at various locations in South Dakota for Unspecified use
W2C11	Wheat, Durum; Grain at various locations in Minnesota for Unspecified use
W2C12	Wheat, Durum; Sold Grain at various locations for Unspecified use
W2C13	Wheat, Durum; Market Grade Grain at Peavey Mill in Hastings, Minnesota for Domestic use
W2C14	Wheat, Durum; Semolina at Peavey Mill in Superior, Wisconsin for Wheat Products
W2C15	Wheat, Durum; Semolina at ADM Mill in Minneapolis, Minnesota for Wheat Products
W2C16	Wheat, Durum; Semolina at IMF 1 Mill in St. Paul, Minnesota for Wheat Products
W2C17	Wheat, Durum; Semolina at IMF 2 Mill in St. Paul, Minnesota for Wheat Products
W2C18	Wheat, Durum; Semolina at ND Mill Elev. Assc. in Grand Forks, North Dakota for Wheat Products
W2C19	Wheat, Durum; Semolina at General Foods Mill in Pendleton, Oregon for Wheat Products
W2C20	Wheat, Durum; Semolina at Peavey Mill in Hastings, Minnesota for Wheat Products
W2C21	Wheat, Durum; Blended Millfeed at Peavey Mill in Hastings, Minnesota for Domestic use
W2C22	Wheat, Durum; Flour at Peavey Mill in Hastings, Minnesota for Wheat Products
W2C23	Wheat, Durum; Flour at Peavey Mill in Superior, Wisconsin for Wheat Products
W2C24	Wheat, Durum; Flour at ADM Mill in Minneapolis, Minnesota for Wheat Products
W2C25	Wheat, Durum; Flour at IMF 1 Mill in Minneapolis, Minnesota for Wheat Products
W2C26	Wheat, Durum; Flour at IMF 2 Mill in St. Paul, Minnesota for Wheat Products
W2C27	Wheat, Durum; Flour at ND Mill Elev. Assc. in Grand Forks, North Dakota for Wheat Products
W2C28	Wheat, Durum; Flour at General Foods Mill in Pendleton, Oregon for Wheat Products
W2C29	Wheat, Durum; Sold Semolina at various locations for Wheat Products
W2C30	Wheat, Durum; Sold Flour at various locations for Wheat Products
W2C31	Wheat, Durum; Semolina at American Beauty Pasta Plant (ABPP) in Kansas City, Kansas for Wheat Products
W2C32	Wheat, Durum; Flour at ABPP in Kansas City, Kansas for Wheat Products
W2C33	Dried Eggs for Noodles
W2C34	Wheat, Durum; Long Goods Pasta Dough at ABPP in Kansas City, Kansas for Wheat Products
W2C35	Wheat, Durum; Short Goods Pasta Dough at ABPP in Kansas City, Kansas for Wheat Products
W2C36	Wheat, Durum; Noodle dough at ABPP, in Kansas City, Kansas for Wheat Products
W2C37	Wheat, Durum; Fresh Extruded Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C38	Wheat, Durum; Fresh Extruded Short Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C39	Wheat, Durum; Fresh Extruded Noodles at ABPP in Kansas City, Kansas for Wheat Products
W2C40	Wheat, Durum; Fresh Cut Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C41	Wheat, Durum; Long Goods Pasta Scraps at ABPP in Kansas City, Kansas for Wheat Products
W2C42	Wheat, Durum; Fresh Cut Short Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C43	Wheat, Durum; Short Goods Pasta Scraps at ABPP in Kansas City, Kansas for Wheat Products
W2C44	Wheat, Durum; Fresh Cut Noodles at ABPP in Kansas City, Kansas for Wheat Products
W2C45	Wheat, Durum; Fresh Cut Noodle Scraps at ABPP in Kansas City, Kansas for Waste
W2C46	Wheat, Durum; Dried Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C47	Wheat, Durum; Dried Short Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C48	Wheat, Durum; Dried Noodles at ABPP in Kansas City, Kansas for Wheat Products

TABLE 6.2 CERES II NODE DEFINITIONS (Cont'd)

<u>NODE</u>	<u>DEFINITION</u>
W2C49	Wheat, Durum; Dry Cut Pasta Scraps at ABPP in Kansas City, Kansas for Wheat Products
W2C50	Wheat, Durum; Dry Cut Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C51	Wheat, Durum; Dry Cut Pasta Scraps in ABPP in Kansas City, Kansas for Waste
W2C52	Wheat, Durum; Dry Cut Noodle Scraps at ABPP in Kansas City, Kansas for Waste
W2C53	Wheat, Durum; Reground at ABPP in Kansas City, Kansas for Wheat Products
W2C54	Wheat, Durum; Dried Dinner Pasta at ABPP in Kansas City, Kansas for Wheat Products
W2C55	Miscellaneous Ingredients
W2C56	Wheat, Durum; Dried Dinners at ABPP in Kansas City, Kansas for Wheat Products
W2C57	Wheat, Durum; Packaged Retail Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C58	Wheat, Durum; Packaged Institutional Long Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C59	Wheat, Durum; Packaged Dried Dinners at ABPP in Kansas City, Kansas for Wheat Products
W2C60	Wheat, Durum; Packaged Retail Short Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C61	Wheat, Durum; Packaged Institutional Short Goods at ABPP in Kansas City, Kansas for Wheat Products
W2C62	Wheat, Durum; Packaged Retail Noodles at ABPP in Kansas City, Kansas for Wheat Products
W2C63	Wheat, Durum; Packaged Institutional Noodles at ABPP in Kansas City, Kansas for Wheat Products
W2C64	Wheat, Durum; Packaged Retail Long Goods at various locations for Wheat Products
W2C65	Wheat, Durum; Packaged Institutional Long Goods at various locations for Wheat Products
W2C66	Wheat, Durum; Packaged Dried Dinners at various locations for Wheat Products
W2C67	Wheat, Durum; Packaged Retail Short Goods at various locations for Wheat Products
W2C68	Wheat, Durum; Packaged Institutional Short Goods at various locations for Wheat Products
W2C69	Wheat, Durum; Packaged Retail Noodles at various locations for Wheat Products
W2C70	Wheat, Durum; Packaged Institutional Noodles at various locations for Wheat Products

SU3-NODE

W2D1	Wheat, Durum; Ground Grain at Peavey Mill in Hastings, Minnesota for Wheat Products
W2D2	Wheat, Durum; Fine Ground Grain at Peavey Mill in Hastings, Minnesota for Wheat Products
W2D3	Wheat, Durum; Fresh Cut Long Pasta at ABPP in Kansas City, Kansas for Wheat Products
W2D4	Wheat, Durum; Fresh Cut Short Pasta at ABPP in Kansas City, Kansas for Wheat Products
W2D5	Wheat, Durum; Fresh Cut Egg Pasta at ABPP in Kansas City, Kansas for Wheat Products
W2D6	Wheat, Durum; Dry Cut Long Pasta at ABPP in Kansas City, Kansas for Wheat Products
W2S1	Wheat, Durum; Mixed Noodle Dough at ABPP in Kansas City, Kansas for Wheat Products
W2S2	Wheat, Durum; Mixed Dried Dinner Pasta at ABPP in Kansas City, Kansas for Wheat Products

The other durum mills which supply American Beauty are included as source nodes for semolina and durum flour, and the relative amounts coming from each source were calculated on the basis of information provided by Pillsbury and mill capacities. American Beauty receives all durum products by rail; durum products from all mills that do not go to American Beauty are sent to sink nodes, W2C29 and W2C30.

The pasta making process modeled in CERES II differs somewhat from that represented in Figure 2.3. American Beauty does not use any hard wheat flour; semolina is used exclusively for both long and short pasta goods, while durum flour (with the addition of dried eggs) is used for noodles. Therefore, three separate types of pasta processes are modeled. Two sub-nodes for processes with multiple material inputs (one for manufacture of noodles and one for dried dinners) are included, as well as a number of sub-nodes for links with multiple destinations (W2D1-6); the latter involve the various pasta cutting processes. Wet scraps from cutting both long and short goods are re-processed, and dry scraps from cutting dried long goods (i.e., spaghetti) are reground. Noodle scraps are shown as waste, and included as sink nodes. All pasta products were originally dried with conventional driers; now short goods and noodles can be dried both by conventional and microwave driers. This permits the modeling of alternate technologies and different uses of energy for the processes.

The plant produces a wide variety of short and long goods and noodles for the retail and institutional market. Both long and short dried goods are used in the packaging of dried dinners. Information provided by Pillsbury established the distribution portion of the flowgraph; all shipments are by truck.

6.4 METHOD OF APPROACH

The procedure used in developing the detailed simulation model consists of two steps. The first one concerns the material flow in the network, and the second addresses the use of energy and other inputs in transforming grain into final products. Each step is described in the following sections.

6.4.1 Material Flow

Once the topology of the network has been established and checked for consistency by the graph generator software, emphasis is shifted to determining the type and quantity of material at each node as a function of time. Although the model has been developed principally for annual or multiyear analyses, there is no built-in constraint that precludes studies of the behavior of the system over shorter intervals. However, the basic seasonal characteristics of agricultural production and, consequently, of food processing are best captured by using a time increment of one month and then aggregating over one year. A further advantage is that much of the production, energy, and economic data at the facility or corporate level are kept on a monthly basis. Thus, for both CERES I and II, the material flow for each month over a twelve month period had to be determined.

The first quantities to be determined are the supplies at the source nodes. They are represented either by production data for the region the node represents, or by limitless quantities for secondary inputs such as dried eggs in noodle manufacturing. The supplies are then distributed to the various links that leave the source nodes through a set of coefficients that express the fraction of the supply allocated to each link; these fractions are called "allocation coefficients." Clearly, the sum of the allocation coefficients associated with a node must be equal to one. They can be time-varying or time invariant, depending on the process being modeled. For example, the allocation coefficients for different transportation links are the consequence of some decision based on economic factors, availability of vehicles and facilities, etc. In the baseline case, they are estimated from data; in the dynamic case, they would be obtained from the solution of a local resource allocation problem. The allocation coefficients, on the other hand, that represent the outputs of a process are expected to be time invariant. An illustrative example is the flour extraction rate of a mill that shows the amount of flour obtained from a unit of wheat.

A second set of parameters, the "process coefficients," is necessary to define completely the material flow. These coefficients specify weight changes

that occur while the material undergoes processing, i.e., moves along a link. Typical examples are weight change due to change in water content, to extraction of foreign matter, or to addition of ingredients. Packaging also changes the weight of a unit of product. The process coefficients reflect, in an aggregate form, the engineering aspects of the processes and can be calculated in many ways, depending on the reason for the changes. When the moisture content is changed from one specified value to another, then the corresponding process coefficient can be computed analytically. On the other hand, empirical information is used to determine the process coefficient that models the cleaning of the wheat.

Thus, given the supply at the source nodes and the allocation and process coefficients, it is possible to compute the quantity of material at each node in the system as a function of time. This information specifies the flow of material along the network. Adding the twelve monthly quantities at each node yields the annual quantity.

6.4.2 Energy Inputs

Accounting of energy use in the two models was a primary consideration of the pilot project. Energy use is expressed in terms of a set of energy coefficients, e_{ℓ}^i , that denote the amount of electricity, natural gas, oil, and diesel fuel used for each unit of material in each link, ℓ . Thus, each link has associated with it, in principle, a four dimensional vector of energy coefficients, $\underline{e}_{\ell}$. Multiplication of the vector by the quantity processed, q , yields the amount of energy used (by fuel type) in each process, i.e.

$$E_{\ell}^i = e_{\ell}^i q_{\ell}; \quad i = 1, 2, 3, 4 \quad (6.1)$$

The total amount of each type of fuel used in the system is obtained by summing E^i across all links,

$$E^i = \sum_{\ell} E_{\ell}^i \quad (6.2)$$

Let $\{c_i\}$ be a set of factors that convert the energy coefficients into

commensurate units such as BTU per pound. Then the total energy used by the system is given by

$$E = \sum_{\ell} \sum_i c^i e_{\ell}^i q_{\ell} \quad (6.3)$$

The use of energy coefficients simplifies significantly the computational aspects of ALINET. It introduces, however, a potential source of substantial error in the calculations, if care is not taken in estimating. Energy use in a plant or facility can be modeled by three components: (a) a production related component, (b) a base load, and (c) a seasonal component, i.e.,

$$E_{\ell}^i(t) = \bar{e}_{\ell}^i q_{\ell}(t) + b^i + c^i(t) \quad (6.4)$$

The energy coefficient is defined by

$$e_{\ell}^i(t) \equiv E_{\ell}^i(t)/q_{\ell}(t) \quad (6.5)$$

and is valid for problems in which the material flow is approximately equal to the value $q_{\ell}(t)$. Thus, if q_{ℓ} changes in the simulation, it is important that energy coefficients be recomputed. Simply stated, the use of energy coefficients corresponds to using a linearized version of equation (6.4). This does not pose a problem in static analyses because different energy coefficients can be computed off-line. In other cases, such as the dynamic one, the nonlinear expressions must be used.

Transportation coefficients, a subset of the energy coefficients, denote the amount of diesel fuel used by the various modes to transport one unit of product one mile. These coefficients can be found for a wide variety of vehicles in the *Transportation Energy Conservation Data Book* [49]. The coefficients are assumed to be invariant in time and space.

The adequacy of these models of energy use depends on the specific system being studied and the questions being investigated. Indeed, it will be shown in Section VII that the simple linearized model is suitable for CERES I. For CERES II, however, when an alternate technology is introduced in one of the

production lines of the pasta manufacturing plant, it will become necessary to work with more detailed models of energy use.

6.4.3 Remarks

Once the flow and energy coefficients were specified and the quantities at the initial nodes established, static simulations were run for the two case studies. Twelve computer runs were made for each, one for each month of the respective baseline year. These simulations of the behavior of the system allowed examination of the overall material flow and energy use, and computation of ingredient and energy requirements for specific products or groups of products. The results of these analyses are presented in Sections VII and VIII.

VII. CERES I - HARD WHEAT MILLING

7.1 INTRODUCTION

CERES I consists of three stages - grain input to the mill, milling, and distribution of flours and by-products - as described in Section 6.2. The data required to establish the characteristics of the material flow and of energy use were obtained from the Pillsbury Company, from publications of the U.S. Department of Agriculture and the agricultural departments of Kansas, Nebraska and Missouri, and from publications of the U.S. Department of Commerce. The first decision that had to be made was the selection of the baseline year. The period June 1976 to May 1977 was used because detailed data were available.

The following two Sections, 7.2 and 7.3, contain the description of the material flow across the three stages of the model. In Section 7.4 the determination of energy inputs and energy use is described. The simulation for the baseline year and the results for this case study are discussed in Section 7.5.

7.2 THE INPUT STAGE MODEL

The input stage model characterizes the movement of wheat grain to the Atchison mill: its origin and the mode of transport. The model is based on monthly data of wheat received by truck and rail at the Atchison mill from Kansas, Nebraska, and Missouri (Figure 7.1). The largest amount of wheat arrives during the months immediately following harvest, as is to be expected. The peak of Nebraska input is later than Kansas' due to the later harvest time. Rail is the dominant transportation mode; approximately 77% of the grain was moved by rail in 1976-77. Trucking is not very practical from Nebraska, but is more appropriate for the shorter distances within Kansas and for transporting the small amount of hard wheat from Missouri.

In order to improve the accuracy of the estimate of distance traveled to bring wheat to Atchison, each state was divided into subregions on the basis of distance from Atchison. The subdivision of the states is shown in Figure 7.2; the boundaries of the subregions were based on agricultural reporting districts.

Figure 7.1. Hard Red Winter Wheat Inbound to Atchison, Kansas

All wheat from Missouri was assumed to come from the region nearest Atchison since most of the state's hard red winter wheat is grown in this area. The production by region and the average distance from each region to Atchison are shown in Table 7.1. The average distance $\bar{d}$ was calculated using the expression

$$\bar{d} = \frac{\sum_i P_i d_i}{\sum_i P_i} \quad (7.1)$$

where P_i is the production in each district and d_i is the distance from the center of the district to Atchison.

Figure 7.2. Wheat Producing Subregions Supplying Atchison Mill

TABLE 7.1 PRODUCTION OF WHEAT IN SUBREGIONS

SUBREGION	PRODUCTION	DISTANCE
KANSAS - 1	27	63
- 2	168	186
- 3	144	322
NEBRASKA - 1	10	80
- 2	48	203
- 3	65	420
MISSOURI - 1	7	59

UNITS	Million Bushels	Miles

It was further assumed that the amount of wheat Atchison received from a subregion depended on the production level and the distance -- relatively more would be obtained from a given area if it were closer to the mill or if it produced a great deal. The mode of transportation was determined by assuming that shipments from further away would tend to be by rail. The total amount received from any state in each month by each mode of transportation was constrained to be that given by the data in Figure 7.1. Since the CERES I flowgraph requires quantities transported from each state by each transportation mode, the results by subregion were aggregated with the distance computed as the weighted average of the subregion distances with an equation analogous to (7.1). The average distances are given in Table 7.2.

TABLE 7.2 DISTANCES TO ATCHISON FROM EACH STATE

STATE	DISTANCE*	
	RAIL	TRUCK
KANSAS	224	183
NEBRASKA	287	80
MISSOURI	-	59

* Measured in miles

To specify the material flow completely, the allocation coefficients to each transportation mode for each link were required. In this case, they were obtained directly from the data in Figure 7.1.

Thus, given that the quantities from each state by month and by transportation mode were available as data, the only modeling that was required was in the computation of the equivalent distances; they contain the aggregation of the distributed sources into three point sources -- the three source nodes W1C1, W1C2, and W1C3.

7.3 THE MILLING AND OUTPUT STAGE MODELS

The basic data that were available for modeling the flow of wheat through the mill were the input to the mill, as shown in Figure 7.1, the monthly production levels of flour, and the monthly sales data for all the mill's products. Given the time series for flour production, $P(t)$, and the flour extraction rate, r_e , achieved by the Atchison mill during that period, the monthly production of all products, $\hat{P}(t)$, can be estimated by

$$\hat{P}(t) = P(t)/r_e \quad (7.2)$$

The three time series, wheat input $W(t)$, total estimated production $\hat{P}(t)$, and total sales $S(t)$, are shown in Figure 7.3. The production and the sales series track each other quite closely, reflecting the short processing time and the small storage capacity of the mill. The total annual production exceeds the total annual sales by 2%; this can be explained in terms of changes in inventory; no measurement of inventory was available for the beginning and the end of the period 1976-77. Furthermore, there is a small time lag between production and sales data.

The need for storage on the input side is made clear by comparing the input curve $W(t)$ and the production curve $\hat{P}(t)$. Much more wheat arrived at the mill between June and September than could be milled or distributed. Thus the elevator associated with the mill provides a buffering function which is essential for smoothing the seasonal variations in grain production.

The total input of wheat for milling to the Atchison elevator/mill facility in 1976-77 was 422.7 million pounds, while the quantity produced of flour and by-products was 401.9 million pounds. The 5% discrepancy between the input and output figures has been attributed to two causes: weight losses in the processing of wheat (e.g., extraction of foreign matter) and differences in the inventory level at the beginning and end of the year in consideration. Since the storage process was not of explicit interest in this study, no elaborate inventory model to describe the function of the elevator was generated. Instead, a simple buffer model was created from which the appropriate amount of grain for milling was extracted via a time-varying coefficient.

Figure 7.3. Material Input and Output of Atchison Mill (1976-77)

The buffer coefficient was computed from the series $W(t)$ and $\hat{P}(t)$. The fundamental quantity used in the computation of material flow is the monthly production, because energy consumption at the mill depends strongly on the level of production. Neither input nor output measured by sales are appropriate because they are both subject to storage lags.

The third stage of the Atchison model depicts the separation of the millstream into the various products, their packaging, and their transportation, by mode, to their destinations. Allocation coefficients and process coefficients were required to specify the material flow to the final nodes. First, use of the flour extraction rate, r_e , permitted the separation of the millstream into flour and other products. The flour stream is subdivided further into patent flour, second clear flour, and farina. The allocation coefficients were determined from production data. The allocation coefficient for wheat germ posed

some difficulty. The quantity of #1 germ milled at the plant was added to the input stream of the Bitsyn plant that produced the snack food Wheat Nuts.* Germ makes up approximately 2.5% of the wheat kernel by weight. It was assumed that part of this would be the high quality #1 wheat germ and the balance would go to millfeed. Since the production of wheat nuts involves other ingredients in substantial amounts and, furthermore, the process uses wheat germ from other facilities, it was not possible to estimate the actual #1 germ production by the Atchison mill. It was set at 1.5%. The allocation coefficients are shown in Figure 7.4.

Figure 7.4. Allocation Coefficients
for Mill Output (1976-77)

Patent flour is, of course, the primary product. The other products have been modeled as secondary products, i.e., necessarily produced in the process of flour milling. This is not strictly true of farina, which is generally produced in a manner analogous to that used for semolina in a durum mill. Fewer rolls are used so that the endosperm is not ground completely to flour; some

*The Bitsyn process has not been included as part of CERES I.

flour, however, is produced in the process. As farina is such a small part of the Atchison mill production (see Figure 7.4), this distinction has been ignored.

Since the sales data were for packaged products, it was necessary to correct for the weight of packaging and for changes in weight due to processing. The packaging coefficients given in Table 7.3 are used to convert from bulk weight to packaged weight. Four kinds of flour are packaged: export, H&R, bakery, and family flour; all other products are transported in bulk. The coefficients for H&R and bakery flour were estimated to be the same as for family flour.

TABLE 7.3 PACKAGING COEFFICIENTS FOR FLOUR

FLOUR	COEFFICIENT	BAG OR SACK SIZE
Export	1.007	50 kg
Family	1.01	5, 25 lbs.
H&R	~1.01	25, 50, 100 lbs.
Bakery	~1.01	25, 50, 100 lbs.

Patent flour was subdivided into six types which differ in protein content, ash, etc. While these differences are very important to the miller and the baker, they are not very critical from the point of view of energy use. Thus, the allocation coefficients were based on product data rather than from consideration of input data, i.e., variety and grade of wheat. The numerical values are presented in Figure 7.5.

The destination and mode of transport for each product class were shown in Figure 6.1. Grocery mix and bakery mix flours and farina are shipped in bulk, by rail, to the Pillsbury facility in Springfield, Illinois for further processing. All the second clear flour is sent by pneumatic tube to the adjacent plant of Midwest Solvents, Inc. Export flour is shipped by rail to three ports on the Gulf. The relative allocation to each port is approximate; the choice

Figure 7.5. Allocation Coefficients for Patent Flour (1976-77)

of ports depends mainly on availability of port facilities at the required time. The remaining products were sent to many different destinations by both truck and rail (except for millfeed which was shipped in bulk by rail only). The many destinations were divided into two classes - Pillsbury facilities and all other customers. In the data provided by Pillsbury, the company's warehouses were identified by name or location. The distances from Atchison to these facilities were calculated by using rail and road atlases. Direct routes were assumed for trucks, while the most reasonable routes were chosen in the case of rail transport, unless specific information was available. As a result, rail and truck distances for the same origin-destination pair were often different. Shipments to Pillsbury destinations were available in aggregated form - by state. Consequently, for large states, or states near Atchison, distances were computed to several major cities within each state and then an average distance was selected. For small states far from Atchison the direct distance

to the population center of the state was used. Again, separate estimates were made for truck and rail. Finally, weighted averages were used in order to obtain an aggregate representation of all Pillsbury facilities and all customers by single nodes.

7.4 ENERGY USE IN CERES I

There are two major consumers of energy in the model of hard wheat milling: transportation and milling. The energy use computations for transportation are the same whether it is movement of grain or of mill products. However, the numerical values are different depending on the mode.

The basic approach in modeling energy use in transportation is to determine coefficients expressing the amount of energy used to move one pound of material one mile. The coefficients are given in Table 7.4.

TABLE 7.4 TRANSPORTATION ENERGY COEFFICIENTS

MODE	FUEL	ENERGY
TRUCK	3.636×10^{-6}	0.504
RAIL	0.963×10^{-6}	0.134

UNITS	gallons-diesel/lb-mile	BTU/lb-mile

The truck coefficient has been computed on the basis of vehicles with 25 ton load capacity and a fuel consumption rate of 5.5 miles per gallon, when fully loaded. The rail coefficient was estimated from published data on energy intensity in the *Transportation Energy Conservation Data Book* [49]. Information on the utilization of different types of rail cars* allowed the computation

*Personal Communication, Minnesota Department of Transportation (Mr. Babcock, 9/79)

of an average rate. Additional assumptions, consistent with the scope of this study, were that all trucks and all rail used diesel oil as fuel and that energy use per unit of material transported was the same in all regions and for all products. It should be noted that ALINET does not require these simplifying assumptions for its operation.

Energy consumption at the Atchison mill is shown in Figure 7.6. For comparison, the production time series is depicted on the same figure. It is immediately apparent that consumption of oil and natural gas peaks strongly in the winter and that it has little relation to the level of production. Electricity, however, tracks production quite well, but with a delay of one month. Since the electricity time series were taken from billing data, the time lag is understandable. Most of the electric energy is used to drive the machinery at the mill; a small amount is used for lighting and other ancillary activities.

Figure 7.6. Energy Use at Atchison Mill (1976-77)

The consumption of electricity has been modeled by three components: (a) a production related component, (b) a constant level, and (c) a seasonal component. The equation describing electric energy use, E , as a function of production and time is given by:

$$E = aP(t) + C + \frac{A_1}{\sqrt{2\pi} \sigma_1} e^{-\frac{(t - \bar{t}_1)^2}{2\sigma_1^2}} + \frac{A_2}{\sqrt{2\pi} \sigma_2} e^{-\frac{(t - \bar{t}_2)^2}{2\sigma_2^2}} \quad (7.3)$$

where

P : monthly production
 t : time measured in months

The numerical values of the parameters a and C were obtained through a least squares fit after the seasonal effects (winter and summer) had been suppressed. A similar analysis was carried out for the use of oil and natural gas. However, since no alternative technology was considered in CERES I, the analysis of energy use was not carried further. Instead, time series indicating energy use by source per unit of mill product were computed. The results are shown in Table 7.5. The table shows clearly the dominance of electric energy: slightly more than 70% of total energy used is electric. Furthermore, natural gas was the preferred fuel for heating. In January and February, when there was a curtailment in the natural gas supply, the mill switched in part to oil heat.

For a detailed study of the mill, the aggregate coefficients of energy use in Table 7.5 would not be accurate or sufficient. Instead, a model such as the one shown in equation (7.3) would be used in which alternative technologies or procedures would affect specific terms only. Such an approach was taken in the analysis of CERES II.

7.5 SIMULATION RESULTS

As indicated in Section V, three distinct (although in this case simple) steps were required to carry out the analysis of CERES I. First came the data

TABLE 7.5 ENERGY USE COEFFICIENTS FOR ATCHISON MILL

MONTH	ELECTRICITY	NATURAL GAS	OIL
JUNE	173	44.2	
JULY	134	2.6	
AUGUST	112	21.7	
SEPTEMBER	106	29.7	
OCTOBER	112	43.7	
NOVEMBER	113	70.8	
DECEMBER	132	89.7	
JANUARY	116	52.6	28.3
FEBRUARY	103	71.2	0.06
MARCH	103	49.6	
APRIL	105	48.0	
MAY	107	24.1	

UNITS	BTU/lb of Product

extraction step needed to create the simulation input file for each month of the twelve month period June 1976 - May 1977. Then the actual simulation was carried out to determine the monthly flow of material and use of resources. Finally, the post processor was used to analyze the data produced by the simulation.

For this case study, the simulation input file - after the data extraction stage - contained primarily the description of the CERES I network and the allocation coefficients. Then the process coefficients and the energy coefficients were added within the simulation input processor.

With the completion of the simulation file and the selection of energy variables of interest (e.g., electricity, natural gas, oil, and diesel) the

forward simulation was initiated. As the determination of the material flows progressed from left to right (from sources to sinks) across the system, the use of the specific process inputs, by link, was computed.

The post-processing function was performed on the twelve monthly simulations together. The results were then displayed both for the individual months and on an annual basis. Two post-processing requests were issued: one defining the vertical delimiters on the graph (or generic stages such as inbound transportation, milling, outbound distribution) by which the results would be partitioned, and the other defining a quasi-horizontal split of the final output commodities into two groups - those used primarily for human consumption (food) and all others. The per unit energy requirements were computed through the backward sweep method described in Section V for each one of the output commodities and for all of them collectively. The definition of the two groups is given in Table 7.6.

TABLE 7.6 COMMODITY GROUPS IN CERES I

GROUP	DESCRIPTION	NODES
FOR HUMAN CONSUMPTION	Flour Products	W1C31, W1C32, W1C33, W1C34, W1C35, W1C36 W1C26, W1C27, W1C28
	Farina	W1C30
	#1 Germ	W1C29*
OTHER	Second Clear Flour	W1C39
	Milling By-Products	W1C41

* Bitsyn process not modeled.

The first set of results, shown in Figure 7.7, depicts energy use in CERES I by month and by type of fuel. In accordance with the simplifying assumptions used in specifying the energy coefficients, all diesel fuel was used for transportation, both inbound to the mill and outbound to the final destinations in the distribution system. Electricity, natural gas, and oil are used in milling.

Figure 7.7. Energy Use in CERES I by Type of Fuel

In milling, patent flour is the major product (Table 7.7). The energy used for transporting wheat to the mill and milling it can be considered to have been expended to produce flour. The other products - farina, wheat germ, second clear, and millfeed - can be thought of as secondary products and, thus, "energy-free." The meaning of the term "energy-free" is that these products

are obtained without additional energy inputs as by-products of flour production. The energy used in transporting mill products, however, from the mill to their final destination is computed separately for each product. The results are presented in Table 7.8. It should be recalled that #1 wheat germ is used by the Bitsyn plant across from the mill and that second clear flour is sent by pneumatic tube to the adjacent plant of Midwest Solvents.

TABLE 7.7 ANNUAL PRODUCTION BY PRODUCT

PRODUCT	QUANTITY	%
Patent Flour	2844.4	70.4
Farina	5.7	0.5
#1 Germ	60.3	1.5
2nd Clear	225.3	5.6
Millfeed	904.2	22.4
TOTAL	4039.9	100.0

UNITS	10^3 cwt	

TABLE 7.8 ENERGY USE ALLOCATION FOR MILL PRODUCTS

PRODUCT	TRANSP. IN	MILLING	TRANSP. OUT	TOTAL
Patent Flour	70.2	229.9	94.1	394.2
Farina	-	-	45.5	45.5
#1 Germ	-	-	-	-
2nd Clear	-	-	-	-
Millfeed	-	-	87.7	87.8

UNITS	BTU/lb

The average values for patent flour are further examined in Table 7.9, where the total energy use per pound of product, 394.2 Btu/lb., is expressed in terms of energy sources. Electricity is clearly the largest source of energy in milling. Outbound transportation requires more energy (94.1 Btu/lb.) than inbound transportation (70.2 Btu/lb.) even though the inbound figure includes the energy used to transport the material which becomes an "energy-free" by-product. The reason is, of course, that the inbound distances are much shorter and that much of the wheat is moved by rail (78%), while 95% of the patent flour is moved by truck over considerably longer distances.

TABLE 7.9 ENERGY USE BY SOURCE FOR PATENT FLOUR

ENERGY	BTU/LB	%
Electricity	162.6	41.3
Natural Gas	63.2	16.0
Oil	4.1	1.0
Diesel	164.3	41.7
TOTAL	394.2	100.0

With this information, it is possible to carry out various comparisons and analyses of energy costs. Two sets of fuel and electricity prices were considered: the prices that were prevalent in Kansas in 1977, and average prices for the later part of 1979 (Table 7.10). Assuming that the mill operated identically in 1977 and 1979, it is possible to compare energy costs and assess the impact of the relative changes in prices (60% for electricity and diesel and 76% for natural gas). The results of the analysis are shown in Table 7.11.

While electricity accounts for 38.7% of the energy used, it accounts for more than 55% of the costs. Conversely, natural gas contributes 15.1% of the energy, but only approximately 4% of the costs. However, as further and probably rapid increases in prices take place and the relative costs of fuels are

TABLE 7.10 ENERGY AND FUEL COSTS

ENERGY/FUEL	1977 PRICES		1979 PRICES	
		\$/10 ⁶ BTU		\$/10 ⁶ BTU
Electricity	2.60 ¢/KWh	7.31	4.00 ¢/KWh	11.70
Natural Gas	1.47 \$/MCF	1.47	2.00 \$/MCF	2.00
Oil	0.47 \$/gal	3.36	0.70 \$/gal	5.00
Diesel	0.63 \$/gal	4.52	1.00 \$/gal	7.20

TABLE 7.11 COST OF ENERGY BY SOURCE FOR CERES I

ENERGY SOURCE	ENERGY USE		1977 COST		1979 COST	
	10 ⁶ BTU	%	\$	%	\$	%
Electricity	46,260	38.7	338,160	55.2	541,242	55.7
Natural Gas	17,990	15.1	26,445	4.3	35,980	3.7
Oil	1,160	1.0	3,898	0.6	5,800	0.6
Diesel	53,980	45.2	243,989	39.9	388,656	40.6
TOTAL	119,390	100.0	612,492	100.0	971,678	100.0

Cost per pound of total output	0.15 ¢/lb.	0.24 ¢/lb.

readjusted as a result of the nation's evolving energy policy (e.g., deregulation), the importance for energy conservation will become even more pronounced. In milling, as Table 7.11 shows, the emphasis should be on improving the efficiency of electricity use in the mill: better motors, fewer losses due to friction, better material handling that reduces the height and the distance bulk material is moved, improved temperature and humidity controls, etc. The other major user of energy is transportation. Achieving a reduction in energy use in transportation is a more complex undertaking because it requires the

simultaneous consideration of component aspects (e.g., fuel efficiency of engines), of systems aspects (e.g., optimum distribution systems), and economic aspects (impacts of regulations).

ALINET, in its present form, can be used to evaluate proposed alternatives and assess the results in terms of energy use and costs. Such an analysis has been carried out and is presented in the next Section.

VIII. CERES II - DURUM MILLING AND PASTA MANUFACTURE

8.1 INTRODUCTION

The CERES II model covers the period June 1978 to May 1979, for which detailed data were obtained from the American Beauty Macaroni Co. plant in Kansas City, Kansas and the Peavey Company's durum mill in Hastings, Minnesota. Seven mills supply the American Beauty pasta plant with semolina and durum flour. Six of them are located close to the major durum production areas in North Dakota, South Dakota, and Minnesota: the Peavey Company operates one in Hastings, Minnesota and one in Superior, Wisconsin; International Multifoods Corporation has two in Saint Paul, Minnesota; ADM Milling Co. has one in Minneapolis, Minnesota; and North Dakota Mill and Elevator Association operates one in Grand Forks, North Dakota. A very small amount, mainly flour, is also received from the mill in Pendleton, Oregon which probably receives most of its durum wheat from Montana. The semolina and durum flour are processed into a large variety of pasta products that are packaged and distributed widely. The network representation, shown in Figure 6.2, has been divided into five major energy consuming stages.

1. *Transportation of durum from farm to mill.* This stage models the durum flow into the Peavey Hastings mill, including geographical origin of grain, the timing of its inflow, the modes of transportation used, the distance traveled, and transportation energy consumed (Section 8.2).

2. *Milling of durum into semolina and durum flour, the major ingredients of pasta.* A simple energy and material flow model for the Peavey-Hastings mill accounts for weight loss, water addition, and distinguishes between the two milling processes used for making pasta ingredients (Section 8.3).

3. *Transportation of the ingredients to the pasta plant.* In this stage, the contribution of pasta ingredients from each mill to the American Beauty facility, as well as the energy used in transporting them from mill to plant, is calculated (Section 8.4).

4. *Production of pasta.* This is a detailed model of material flow and energy use for four product classes (long goods, short goods, noodles, and dried dinners). Alternate technologies, conventional driers and the new microwave driers, are also modeled (Section 8.5 and 8.6).

5. *Transportation of pasta to customers.* This output model includes all product classes, location of customers, and shipment distances, allowing the computation of energy use and cost in transportation (Section 8.7).

The first two stages of the model, based on the Peavey-Hastings mill, are assumed to apply also to the other mills supplying American Beauty.

8.2 TRANSPORTING DURUM TO MILLS

The amount of grain moved, its geographical origin, and the mode of transportation used are the required data for calculating energy used in the first stage of CERES II. The Peavey Co. provided information about the amount of grain brought to Hastings and the mode of transportation. It was known that the grain originated in the major durum producing states of North Dakota, South Dakota, and Minnesota. By using published agricultural statistics and mill capacities, a more detailed model of geographical origin was developed. Creating a time varying model of the grain's source was not considered appropriate at this time; instead, a constant flow was assumed to come from every area. However, the modal split for transportation was allowed to change over time to reflect important seasonal effects on mode availability and energy use.

The geographical model is based on the following estimates, made from agricultural statistics: total disappearance of durum from the three states; the percentage of disappearance going to the Minneapolis area, which is an important milling and export point; and the fraction of the latter going to Hastings.

Because North Dakota produces over ninety percent of the durum grown in the area, it was divided into nine agricultural regions. Regional production for the 1978 crop year was obtained from state statistics [28]. Stocks for each region were assumed to be proportional to the production of the previous crop

year; the proportionality constant used was the ratio of U.S. stocks to U.S. production [28], [35]. Disappearance, which accounts for export plus domestic use for milling and feed, is calculated as follows:

$$\text{disappearance} = \text{beginning stocks} + \text{production} - \text{ending stocks}$$

Based on figures for U.S. domestic durum milling and U.S. domestic disappearance, it was estimated that 7.7% of production is used for feed [24], [35]. The remainder (which is referred to here as "feed-corrected disappearance") is either milled or exported. The proportion of this sent to the Minneapolis area was estimated from data for the previous year [28]. Since South Dakota and Minnesota produce much less durum than North Dakota, they were not subdivided into regions; the 1978 production was used in place of disappearance in the computations.* The modeling of the geographical origin of durum production is shown in Figure 8.1.

Figure 8.1. Geographical Model of Durum Movement to Minneapolis.
(Fractions indicate proportion of disappearance shipped to Minneapolis.)

*Data obtained from State Crop and Livestock Reporting Services.

The *resulting* estimates of the amount of durum transported to Minneapolis from the various areas are given in Table 8.1. Thus, the total amount of durum that arrived in the Minneapolis area for milling in 1978-79 was estimated to be about 17.8 million bushels.

TABLE 8.1 DURUM MOVEMENT IN THE TRI-STATE AREA, 1978-79

STATE		TOTAL DISAPPEARANCE ⁺	DISAPPEARANCE TO MINNEAPOLIS
NORTH DAKOTA	NW	24.03	4.81
	NC	15.75	2.21
	NE	20.61	2.47
	WC	6.52	2.54
	C	5.98	1.02
	EC	2.72	0.41
	SW	2.39	1.39
	SC	0.71	0.24
	SE	2.57	0.89
NORTH DAKOTA		81.28	15.98
SOUTH DAKOTA		3.51	0.88
MINNESOTA		3.48	0.97
TOTAL		88.27	17.83

UNITS	Million Bushels

⁺ Feed-Corrected

The durum mills in the Minneapolis area have a milling capacity of 24 million bushels per year; the effective capacity, however, is 15.6 million bushels since the estimated average for 1978-79 was 65% of capacity [26], [24]. It has been assumed that the difference between inbound durum (17.8) and milled durum (15.6)

was shipped and milled elsewhere, as Minneapolis-St. Paul is both a railroad center and a Mississippi River shipping point [22], [24].

If the Peavey-Hastings mill operated at its average annual utilization rate of 64%, it would have used 2.85 million bushels out of the 17.8 shipped to Minneapolis [24], [26]. However, the Peavey mill received only about 1.77 million bushels, approximately 10% of the inbound durum, in the time period of interest. The reason for the shortfall and the resulting drop in effective capacity to 40% can be explained in part by a strike at Peavey from July to October 1978. This time period coincided with the harvest period when much of the grain would normally be received. Thus, the allocation coefficients for durum at Minneapolis are: 0.1 to Peavey-Hastings, and 0.9 to all other destinations.

As CERES II is concerned only with wheat actually going to Peavey-Hastings, the coefficients are combined by multiplying the allocation from each region to Minneapolis and from Minneapolis to Peavey-Hastings (Figure 8.2). All other durum, including that going to the other Minneapolis-area mills, now flows to a node labeled "elsewhere."

Data on the rail-truck split in transportation were observed to have a strong seasonal component. While the average rail fraction was 0.502 over the year, data obtained from Peavey showed that rail use reached a low point of 0.15 in February. Furthermore, on the basis of seven monthly data points, it was possible to model the allocation coefficients by sinusoids. If $r(t)$ and $c(t)$ represent the fraction of the commodity transported by rail and truck, respectively, then

$$r(t) = 0.502 + 0.35 \sin(\pi t/6)$$

$$c(t) = 1 - r(t) = 0.498 - 0.35 \sin(\pi t/6)$$

where t is measured in integer units beginning with $t = 1$ for June 1978. It was assumed that all the transportation links to Hastings exhibit the same time-varying behavior.

Figure 8.2. Disappearance, Allocation Coefficients for Durum Movement to Peavey-Hastings Mill, and Distances.

Finally, the distances from the centers of the durum producing regions to Hastings, Minnesota were estimated from road maps and rail atlases. As an approximation, rail and truck distances were assumed to be the same when entering the data in the data base. The numerical values are shown in Figure 8.2. As in CERES I, transportation energy use was calculated by multiplying the quantity transported by each mode by the distance and then by the appropriate transportation energy coefficient:

$$E_r(t) = g^r \frac{r(t)}{12} \sum_i \alpha_i S_i d_i^r$$

$$E_c(t) = g^c \frac{c(t)}{12} \sum_i \alpha_i S_i d_i^c$$

where

E_r : monthly energy use by rail transport

E_c : monthly energy use by truck transport

$c(t)$, $r(t)$: truck and rail allocation coefficient

g^c , g^r : truck and rail transportation energy coefficient

α_i : allocation coefficient from region i to Hastings, Minnesota

S_i : annual feed-corrected disappearance in region i

d_i^r : rail distance from region i to Hastings, Minnesota

d_i^c : truck distance from region i to Hastings, Minnesota

The destination of durum not going to Hastings or the energy used for its transportation were not required for this case study. To preserve material balance in the simplest way, it was assumed that durum for all destinations leaves a region at a constant rate. The allocation from a particular region to the sink node is therefore $1 - \alpha_i$.

8.3 THE PEAVEY-HASTINGS MODEL: MATERIAL FLOW AND ENERGY USE

The Peavey Company mill in Hastings, Minnesota uses two parallel processes for milling durum. One process (designated Milling A) is used to produce semolina, durum flour, and millfeed; the other (designated Milling B) produces only durum flour and millfeed. While the same equipment is used for both processes, fewer break rolls are used in semolina milling.

Before storage, durum grain is cleaned in the elevator section of the mill by a series of sophisticated machines which sort by weight, size, etc. The expected amount of foreign matter in incoming wheat is 4 percent. Typical moisture content for inbound durum ranges from 11.5 to 12%; an average of 11.75% is assumed for the model. During tempering, water is added, typically bringing the moisture up to 14%. The Peavey extraction rate is slightly higher than the national average of 0.783 [38]; this is assumed to apply to cleaned wheat. It

is also assumed that both product and millfeed take up and retain the added moisture at an equal rate.

The allocation coefficients are shown in Figure 8.3. The node at the left represents durum grain entering the mill. It is assumed that durum is milled at a rate matching exactly the rate of input from the agricultural regions; in reality, the elevator acts as a buffer between input and milling. The durum is divided into two streams, Milling A (40%) and Milling B (60%). Then foreign matter is removed and water is added to adjust the moisture to the required level. If the moisture content is increased from $\mu_1 = 11.75\%$ to $\mu_2 = 14\%$, then the coefficient describing the change in weight due to a change in moisture is given by

$$m = \frac{1 - \mu_1}{1 - \mu_2} = 1.026$$

The combined effect of the cleaning coefficient, 0.96, with the moisture change coefficient, 1.026, yields the process coefficient 0.985 shown in Figure 8.3.

Figure 8.3. Allocation Coefficients for Semolina and Durum Flour Milling.

Because of the different number of break rolls used in the two milling processes, the energy coefficients differ, with Milling A having a smaller coefficient than Milling B.

Milling B can produce 5,600 cwt of flour per 24 hour day, or 233.3 cwt per hour; it consumes 4.6 KWh per hundredweight of durum flour produced. Thus, the average power required for flour milling is 1073 KW or 1439 horsepower. Because energy is calculated before the product is separated into flour and millfeed, the energy coefficient has to be multiplied by the extraction rate. The final result, converted into British thermal units, is

$$e_{\ell}^B = 120.3 \text{ Btu/lb}$$

The daily capacity of the Milling A process is 6000 hundredweight or 250 cwt per hour. Because semolina requires less processing, the power requirement is reduced by 200 horsepower. Thus,

$$e_{\ell}^A = 96.65 \text{ Btu/lb}$$

The Peavey-Hastings mill received 1.78 million bushels of durum in 1978-79 at an average rate of 0.148 million bushels per month. The monthly production of semolina and flour was estimated to be

$$\text{Durum Flour: } 4.694 \times 10^6 \text{ lbs/month}$$

$$\text{Semolina: } 2.014 \times 10^6 \text{ lbs/month}$$

A portion of this production is sent to the American Beauty pasta plant in Kansas City, and the rest to the sink nodes. The actual shipments of semolina and flour from Hastings are shown in Figure 8.4. All shipments were by rail, as indicated in Figure 6.2. The effect of the summer strike on production and shipments is clearly evident.

8.4 INPUT TO THE PASTA PLANT

The time series for semolina and flour shipments to the American Beauty Macaroni Co. pasta plant in Kansas City were constructed from monthly production

Figure 8.4. Durum Flour and Semolina Shipments from Hastings to Kansas City.

data. This was possible because the plant processing time is short and the plant has very little storage capacity (Table 8.2).

Monthly shipment data of semolina and durum flour from Hastings to the Kansas City plant were obtained from the mill's records. No data were available on specific shipments from other mills. Information given by Pillsbury staff members identified the other mills supplying American Beauty in Kansas City; they are listed in Table 8.3. Because the pasta plant bought approximately 60% of its durum from the Peavey Company, the Peavey mill in Superior, Wisconsin was allocated this amount less the known amount supplied by the Hastings mill. The remaining 40% was allocated to the other five mills in proportion to their capacity. The one exception was the Pendleton, Oregon mill which supplied only a small amount of flour.

TABLE 8.2 INPUT TO THE PASTA PLANT

MONTH	INPUT	
	SEMOLINA	FLOUR
J	1.805	0.626
J	1.496	0.519
A	1.952	0.677
S	1.782	0.618
O	2.208	0.766
N	2.051	0.712
D	1.915	0.665
J	2.059	0.714
F	2.000	0.694
M	2.694	0.935
A	1.903	0.660
M	1.728	0.599
TOTAL	23.593	8.187

UNITS	Million Pounds

TABLE 8.3 MILLS SUPPLYING AMERICAN BEAUTY PLANT

MILL	CAPACITY	% INPUT TO ABPP	DISTANCE TO ABPP
Peavey - Hastings, MN	5,900	31	563
Peavey - Superior, WI	12,000	29	632
IMF #1 - St. Paul, MN	2,800	4	480
IMF #2 - St. Paul, MN	5,400	7	480
ADM - Minneapolis, MN	12,000	14	490
NDM&EA - Grank Forks, ND	5,000	13	800
General Foods - Pendleton, OR	2,500	2	1784

UNITS	cwt/day		miles

Except in emergencies (strikes, delayed shipments, etc.) all shipments are by rail. Rail cars generally hold 1,000 cwt of durum flour or 1,100 cwt of semolina, although there are some variations. Shipment data are usually available in terms of car loads, with a car being filled either with flour or semolina. The distances between the mills and the pasta plant were calculated along rail lines, assuming reasonable direct routes. Energy use in transporting the plant's input is calculated using the energy coefficients for rail, the distances, and the weight of the shipments.

8.5 THE PASTA PLANT MODEL

8.5.1 Material Flow

The material flow within the plant is determined by the topology of the representation, the allocation coefficients, and the process coefficients; all of these were assumed to be time-invariant for the static annual simulation. The graph of the plant has been shown in Figure 6.2. It should be recalled that three classes of products are manufactured: long goods, short goods, and noodles. A fourth product, dinners, is made by including a packet of sauce, seasoning, or other ingredients with a quantity of long or short goods. All product streams follow essentially the same sequence of steps: unloading and storage in the plant's bins, mixing of semolina or flour with water, extrusion, cutting, drying, and packaging. Long goods require one or two extra cuttings after drying; noodles require the addition of dried eggs in the mixing process. Long and short goods are made with semolina, while flour is used for noodles. All goods were dried using conventional driers; the installation of a microwave drier permits the drying of short goods and noodles by the alternative process.

Process coefficients model the change in weight undergone by the material by the particular process. In the mixing process, the 14% moisture content of semolina is increased to 30%. The corresponding process coefficient is calculated as follows:

$$m_x = \frac{1 - \mu_{\text{semolina}}}{1 - \mu_{\text{dough}}} = 1.2286$$

The wet scraps obtained during cutting are mixed again with the dough; dried cuttings are reground and used again in the dough. Spilled material is considered waste and does not re-enter the process. Noodle scraps are not reground, since they contain eggs. However, since the accidental losses are very small, both extrusion and cutting are represented by process coefficients equal to unity.

Drying reduces the moisture content of the goods down to 11.5%, resulting in a process coefficient given by

$$m_y = \frac{1 - \mu_{\text{dough}}}{1 - \mu_{\text{dry}}} = 0.791$$

Although conventional and microwave driers differ in technology and in energy use, their effect on the material is the same.

Dried dinners made either with long or short goods can be modeled through the addition of externally prepared ingredients. It is assumed that the weight of the packet is approximately one tenth of the weight of the pasta. Hence, the process coefficient is set to unity and a source node is introduced (W2C55) that generates the proper amounts of the other ingredients.

Packaging was assumed to add 5% to the weight of the goods for all products. This is not unrealistic, if it is noted that goods leave the plant in cases and that most of the packaging weight is accounted for by the case's weight. Much of the pasta, e.g., long goods and noodles, is distributed in light-weight cellophane packages.

The noodle stream has the same process coefficients as the semolina stream, except that eggs are added in the mixing process. The eggs are mixed with the flour so that they constitute 5.5% of the dried noodle weight. The resulting process coefficient that also accounts for the change in moisture is

$$m_n = 1.253.$$

Once the process coefficients have been determined, it is possible to estimate the semolina and flour inputs to the plant from production data, as

mentioned in Section 8.4. Given that semolina constituted 74.2% of the input to the plant, with noodles constituting the remaining 25.8%, the time series presented in Table 8.2 can be computed.

8.5.2 The Allocation Coefficients

As in CERES I, the allocation coefficients for the pasta plant were calculated by working backwards from quantity data at the end nodes of the plant's graph. In addition, to resolve indeterminacies, the properties of the flow at coalescence nodes must be known. The procedure followed in the calculation of CERES II allocation coefficients presented some unique problems because of the manner in which Pillsbury kept data and the nature of the data.

Detailed sales data for one month (May 1979) and one year (June 1978 - May 1979) were made available. These coded data indicated product type, quantity, and destination in a highly detailed form suitable for sales analysis. On the basis of substantial computer processing of the data, it was estimated that the total direct sales were only 24.05 million pounds, 7.36 million pounds less than the plant's production. Further analysis and discussions with Pillsbury personnel established that the apparent discrepancy was due to "transshipments," i.e., movement of plant products to other American Beauty Macaroni Co. facilities or Pillsbury distribution warehouses. Since these were intracompany transfers, they were not included in the sales data. Furthermore, it would have been extremely time consuming and costly to try to extract information as to composition and destination of transshipments from warehouse and transportation data. Thus, estimates were made.

First, the sales data were aggregated into categories specified by the end nodes: long goods, short goods, noodles, and dried dinners, subdivided further according to whether they were retail or institutional sales. Since noodles are a different product made exclusively from flour, the total quantity of noodles produced was computed: 8.48 million pounds. Since the sales data indicated only 4.26 million pounds, it was assumed that the remaining 4.22 million pounds were shipped to Pillsbury facilities as stocks. The remaining transshipments ($7.36 - 4.26 = 3.10$ million pounds) had to be allocated to the three types

of semolina goods: long, short, and dried dinners. On the basis of an estimate provided by the plant manager, it was assumed that dried dinners constitute 6.4% of production; the remaining transshipments were divided between long and short goods in proportion to their relative weight in the sales data. The results are shown in Table 8.4.

TABLE 8.4 PRODUCTION ESTIMATES BY PRODUCT CLASS

MILL	QUANTITY	%
LONG GOODS - Retail	9.678	37
- Institutional	0.932	
- Transshipments	0.967*	
SHORT GOODS - Retail	7.265	30
- Institutional	1.371	
- Transshipments	0.784*	
NOODLES - Retail	3.767	27
- Institutional	0.492	
- Transshipments	4.224*	
DINNERS - Retail	0.455	6
- Institutional	-	
- Transshipments	1.570*	
TOTAL	31.596	100

UNITS	Million Pounds	

* Estimates

A link coalescence occurs where long and short goods are used to package dried dinners. It was assumed that half the dinners were made with long goods

and half with short. Since dinners constitute such a small portion of the plant's production, the possible inaccuracy of the assumption (no data were available) is negligible.

The other coalescence in Figure 6.2 represents the alternative drying technologies. For the baseline case, only conventional drying was allowed. The modeling of the microwave drier is presented in Section 8.6.

On the basis of this information, the allocation coefficients for the pasta plant were unambiguously determined. Several characteristics should be noted. First, the allocations used in the model are time invariant; only the quantity of total production at the American Beauty pasta plant varies over time. Second, the total quantity shown in Table 8.4 is 31.596 million pounds, about 0.6% higher than the actual production figure. This small discrepancy occurs because the weight added in dinner processing was not included in computing the allocation coefficients.

8.5.3 Energy Use: The Electricity Model

In order to assess the impact of alternate technologies on energy use, an energy model of the American Beauty pasta plant was constructed. The use of electricity, natural gas, and oil was disaggregated into production related and overhead components. These were further allocated at the process level so that the effects of using microwave drying in place of conventional drying could be evaluated.

The two component model was constructed by analyzing energy use in the period June 1978 to April 1979, shown in Figure 8.5. In March 1979, a short goods/noodle production line was taken out and in its place a new one consisting of a higher capacity mixer-extruder and a microwave drier was installed. The new line was put in operation in late July 1979, after the period in consideration. Thus, the collected data were appropriate for the baseline case. In anticipation of the loss of production during the change over, unusually high quantities of short goods and noodles were produced in March 1979. The non-typical energy data for March and April may reflect the changes in the plant.

Figure 8.5. Energy Use at American Beauty Pasta Plant..

Although most of the electricity consumption in a pasta plant is for production, a substantial part is used for lighting and for such seasonal needs as summer air conditioning. Both production-related and seasonal consumption can be seen in Figure 8.5: Power requirements also vary according to the type of product made. Electricity use in any given month is modeled as follows:

$$\text{Production-related use: } E_p(t) = k_1 P(t)$$

$$\text{Overhead: } E_o(t) = C + f_1(t)$$

$$\text{Total: } E(t) = E_p(t) + E_o(t)$$

where P denotes the level of production, C is the base load and $f(t)$ represents seasonal demand. Since no information was available regarding variations in product type or efficiencies at different levels of production, a simple

linear relationship between production and energy use was assumed. This is equivalent to linearizing the equations of the plant about an operating point; the linearization is a good representation as long as production at the plant remains at a reasonably high level. Then the coefficient k_1 can be thought of as an average value for all products. In addition to the constant base load C , a seasonal peak for electricity was introduced to reflect increased summer demand. This seasonal demand was modeled by a normal distribution function

$$f_1(t) = \frac{A_1}{\sqrt{2\pi} \sigma_1} \exp \left[-\frac{(t - \bar{t}_1)^2}{2\sigma_1^2} \right]$$

This function is symmetric about $\bar{t}$; the area under the curve is A , and 99.7% of the area is within $\pm 3\sigma$ of $\bar{t}$. If t is set equal to one for June 1978, then

$$\bar{t}_1 = 3.0 \quad ; \quad \sigma_1 = 0.5$$

The value of C was based on a recent study [5], which showed that the typical use of electricity for lighting in a pasta plant is 22%. Furthermore, the energy used for seasonal air conditioning was assumed to be 5% of the total. With those assumptions it is possible to determine the value of k_1 from

$$E = \sum_{t=1}^{12} E(t) = k_1 \sum_{t=1}^{12} P(t) + A_1 + 12C = 4,023,430 \text{ KWh}$$

where

$$A_1 = 0.05E \quad ; \quad 12C = 0.22E$$

Then,

$$k_1 = 0.0891 \text{ KWh/lb packaged product}$$

$$A_1 = 0.2012 \times 10^6 \text{ KWh}$$

$$C = 0.0738 \times 10^6 \text{ KWh}$$

The comparison of electric energy use predicted by the model and actual energy use is shown in Figure 8.6. It is believed that this simple model captures the essential features of electricity use in the plant. To obtain more accurate models, a more detailed analysis would be required which would be based on detailed measurements of electric energy use in the plant.

Figure 8.6. Electric Energy Use at Pasta Plant.

8.5.4 Energy Use: The Natural Gas and Oil Model

The use of natural gas and oil, shown in Figure 8.5, seems to have a large winter peak superimposed on a smaller production related component. This is consistent with the known use of these fuels in the pasta plant. Heat is used extensively in the processing of pasta; in fact, enough is generated also to be the primary source of space heat. However, a great deal of energy is needed in winter to keep the relative humidity high to ensure proper drying.

A model of the same form as that for electricity is assumed, except that the base load term is not required.

$$N(t) = k_2 P(t) + f_2(t)$$

Note that natural gas was the primary fuel used. Fuel oil was used during January, February, and March of 1979 due to a partial curtailment of natural gas; it is not used the rest of the year, as it is more expensive. Since both are used interchangeably to fire boilers, it is reasonable to combine them in modeling fossil fuel use in the plant.

As seen in Figure 8.5, winter heating starts in September, peaks in January, and falls off by May. It is modeled by using the normal distribution with the following values:

$$\bar{t}_2 = 8 \quad ; \quad \sigma_2 = 4/3$$

Total seasonal consumption was determined by first making an estimate of the production-related constant k_2 and then constraining the model to have the same annual natural gas/oil use as the data indicated. The constant k_2 was evaluated by examining the months not included in the winter peak. The total oil and natural gas use is given by:

$$N = \sum_{t=1}^{12} N(t) = k_2 \sum_{t=1}^{12} P(t) + A_2 = 24.04 \times 10^9 \text{ Btu}$$

which yields

$$A_2 = 10.713 \times 10^9 \text{ Btu}$$

for

$$k_2 = 555.7 \text{ Btu/lb of packaged product}$$

A comparison of the model's results and the monthly data for natural gas and oil use at the pasta plant is shown in Figure 8.7. The fit is quite good

except for the March and April data, which are known to have been anomalous points due to the changeover that affected two production lines.

Figure 8.7. Fossil Fuel Consumption at Pasta Plant.

The disaggregation of $N(t)$ into natural gas and oil components, namely,

$$N_g(t) = \alpha(t)N(t)$$

$$N_o(t) = [1 - \alpha(t)]N(t)$$

was based on the assumption that natural gas was preferred, but that curtailments in supply - exogenous events - necessitate the use of oil. Thus, the parameter $\alpha(t)$ was assumed to be an exogenous series. For the baseline year, 1978-79, it was computed from the plant data. The results are shown in Table 8.5.

TABLE 8.5 NATURAL GAS FRACTION

t	MONTH	$\alpha(t)$
1	June '78	1.0
2	July	1.0
3	August	1.0
4	September	1.0
5	October	1.0
6	November	1.0
7	December	1.0
8	January '79	0.3152
9	February	0.1576
10	March	0.9201
11	April	1.0
12	May	1.0

8.5.5 Energy Coefficients

Ideally, energy coefficients should be estimated for each individual operation within the pasta plant and associated with the corresponding link. The degree to which such a disaggregation is made depends on the particular analysis to be carried out and the availability of data. In CERES I, all energy used at Atchison was associated with the one link representing milling. In CERES II, while there are several links modeling the operations in the pasta plant, the data allow the calculation of overall energy coefficients only. Therefore, these coefficients can be associated with any of the links. The most appropriate choice, in view of the simulation algorithm that computes energy use through a backward sweep, was the link denoting product packaging.

For the base case, constructed from the available data, all products were assumed to use the same amount of energy on a per pound basis. The energy coefficients were computed by dividing energy used, by fuel type, each month by

the month's production, i.e.

$$e_{\ell}^e(t) = E(t)/P(t)$$

$$e_{\ell}^g(t) = \alpha(t)N(t)/P(t)$$

$$e_{\ell}^o(t) = [1 - \alpha(t)]N(t)/P(t)$$

Since the energy coefficients are assigned to the packaging links, production is measured in units of gross weight, i.e., product and packaging. The numerical values are given in Table 8.6.

TABLE 8.6 ENERGY COEFFICIENTS FOR PASTA PLANT: BASE CASE

MONTH	ELECTR.	NG	OIL
June '78	403.8	555.7	-
July	459.9	555.7	-
August	597.2	556.8	-
September	434.9	570.0	-
October	385.6	638.4	-
November	391.9	918.7	-
December	398.1	1459.0	-
January '79	391.5	526.2	1143.0
February	394.1	223.9	1197.0
March	370.9	765.6	66.5
April	398.7	651.6	-
May	408.3	570.5	-

UNITS	Btu/lb of Packaged Product

It should be stressed, once again, that the coefficients represent a linearization of the energy use functions $E(t)$ and $N(t)$. This linearization is

consistent with the simulator constructed for the static case, but is not a requirement for ALINET. For example, if allocations are to be determined through an optimization algorithm, the use of energy coefficients leads to Linear Programming formulation, while the use of the energy functions leads to a Nonlinear Programming one.

8.6 ALTERNATE TECHNOLOGY: CONVENTIONAL VS. MICROWAVE DRIER

In the late spring of 1979, American Beauty dismantled one of its production lines and installed a new one which included a microwave drier. It was assumed that one of its advantages would be energy conservation and, consequently, lower operating costs. However, the issue was not straightforward, as it involved changes in the type of energy used and in the level of production. With the agreement of the Pillsbury Company, ALINET was used to analyze this problem.

The new unit is a Model IV60T, Microwave Pasta Drying System for macaroni and noodle products, manufactured by the Microdry Corporation of San Ramon, California. The engineering specifications of this microwave-hot air drier were used to modify the energy coefficients of the plant [51], [52] rather than recorded measurements for two reasons. (a) The microwave drier had been installed and was in operation during the plant visit, but these were intermittent experimental runs rather than continuous production runs. Therefore, neither past data were available, nor would measurements taken from its first month of experimental operation be meaningful. (b) The second and most important reason was the desire to demonstrate how to construct a study in which *potential* energy conservation technologies are assessed. In most cases, the analysis of the type ALINET is capable of providing will be carried out *prior* to the decision to install the alternative technology. Thus, the given specifications will be used in modeling the alternative technology and then variations should be examined that are based on more or less conservative estimates of performance. An indirect benefit of this approach is that it indicates which are the key measurements and system parameters that, in a particular plant environment, affect the overall performance.

One of the problems in evaluating a new technology is that rarely does a simple substitution take place. Often it is accompanied by other plant

modifications, by changes in the production capabilities of the plant, and by changes in policies and procedures. Care must be taken in constructing the alternative models so that the results from the various analyses can be compared correctly. The approach taken for the modeling and analysis of the microwave drier alternative is described in this section. While the emphasis is on quantitative analysis - feasible through the use of ALINET - it is important to consider the qualitative aspects of the methodology used to construct the simulated alternatives.

8.6.1 Material Flow

First, changes in material flow were considered. Both the old and the new arrangement of the American Beauty pasta plant are shown in Table 8.7. The production of long goods was not affected by the installation of the microwave drier. The same three production lines with conventional driers were used before and after the change. Formerly, noodles and short goods were produced on separate lines with conventional driers. The lower capacity noodle line was removed and in its place was installed a high capacity line with a microwave drier. The compact size of the driers allowed the increase in capacity to take place without an increase in plant space. The new microwave line is used to produce short goods only. The line formerly used to produce short goods only, now produces both short goods and all the noodles. Dried dinners are packaged from finished short and long goods and, therefore, do not have a separate production line associated with them; only different packaging lines.

TABLE 8.7 PRODUCTION LINES IN PASTA PLANT

PRODUCT	BASE CASE	NEW CASE
Long Goods	3 lines Conventional Drying	3 lines - unchanged
Noodles	Conventional System #1	Part of Conventional System #2
Short Goods	Conventional System #2	a) Microwave system b) Part of Conventional System #2

The substantial increase in capacity affects both the production related energy use and the overhead. It is important, therefore, to separate at least partly the impact of the microwave technology as an energy conservation method from the effects of increasing overall plant productivity. The separation of the two effects cannot be made perfectly because the introduction of the new technology stimulates additional changes and the intermediate case (in this example: same material flow, new process) never appears on the plant floor. It is a hypothetical construct, a device, created to permit a rational analysis of the energy conservation potential of a technology.

Thus, two alternatives were constructed. In the first one, the hypothetical construct, the material flow remains the same and a microwave drier, operating at the same capacity level, is used to replace a conventional drier in the production line for short goods. This is denoted "Alternative I." In the second case, material flow is increased by 16.8 million pounds and the plant is assumed to operate according to the specifications in Table 8.7. This is "Alternative II." Table 8.8 lists the amount of dry, unpackaged pasta produced by the short goods line for each case, including product later used in dried dinners.

TABLE 8.8 PRODUCTION OF SHORT GOODS

DRIER	BASE CASE	ALT. I	ALT. II
Conventional	10.24	-	4.10
Microwave	-	10.24	22.93
TOTAL	10.24	10.24	27.03

UNITS	Million lbs. (unpackaged)

The production of noodles is kept at the same level as before, but now a larger machine is used; its excess capacity is allocated to short goods. The microwave drier has a much higher production level than the conventional drier.

Its capacity is about twice that of a conventional drier; also, since only 1.5 hours are needed to dry short goods instead of 7.5 hours with the conventional drier, production level is increased by an additional 5%. This is computed on the basis of 128 continuous hours per week (midnight Sunday to 8:00 a.m. Saturday) with 126.5 hours of production with the microwave drier vs. 120.5 hours with the conventional drier. Assuming an average output of 3500 lbs. per hour for the new mixer/extruder and 6552 hours of operation per year, the increase in production is 16.79 million pounds ($24.03 - 10.24 = 16.79$ in Table 8.8). This requires the additional input of 17.78 million pounds of semolina.

8.6.2 Energy Use

The conventional driers use air heated by steam coils to dry pasta in a long and delicate process. The steam is generated by boilers fired by oil or natural gas. The microwave drier uses radiation to drive moisture to the surface where it is carried away by hot air; it is thus a hybrid system using electricity to generate microwaves and boiler to produce steam. New energy functions reflecting this were constructed and applied to the short goods line.

The electricity energy function for the plant was given by

$$E(t) = k_1 P(t) + C + f_1(t)$$

The microwave power unit generates 60 KW. At the rated capacity of 4000 pounds of product per hour, this is equivalent to 51.2 Btu/lb of product. Since this energy use is related to production, the electricity energy function is modified as follows:

$$E'(t) = k'_1 P(t) + C + f_1(t)$$

where

$$k'_1 = \delta_1 k_1$$

The value δ_1 is the ratio of the new production related energy use (microwave)

to the old use (conventional). The numerical value of δ_1 was computed to be 1.1637. Then

$$k'_1 = (1.1637)(0.0891) = 0.1037 \text{ KWh/lb packaged product}$$

Then the energy coefficient is computed from its definition:

$$e_{\lambda}^e = E'/P = 466.7 \text{ Btu/lb packaged (Alternative I)}$$

For the second alternative the production level has increased from P to P' , so that

$$e_{\lambda}^e = E'/P' = 406.2 \text{ Btu/lb packaged (Alternative II)}$$

The reduction in the second coefficient is due to the allocation of the base and seasonal energy use over a much larger production base.

The natural gas and oil use function was given by

$$N(t) = k_2 P(t) + f_2(t)$$

The microwave drier is rated at 2.3 million Btu per hour. This is equivalent to 575 Btu/lb assuming a production rate of 4000 pounds per hour. This figure contains both the estimate of energy used directly at the driers (363.2 Btu/lb), production related losses (57.5 Btu/lb) and non-production related losses (154.3 Btu/lb). The decomposition was based on information about "typical" plants contained in [5]. The first two components yield the revised value of k_2 :

$$k'_2 = 363.2 + 57.5 = 420.7 \text{ Btu/lb}$$

The third component is used to modify the values of $f_2(t)$. For simplicity, a multiplier was introduced; it is the ratio of the new average non-production related fuel use to the old one:

$$\alpha' = (154.3 + 117.5)/(203.9 + 117.5) = 0.857$$

Therefore, the revised natural gas and oil energy function is given by

$$N'(t) = k_2'P(t) + \alpha'f_2(t)$$

The resulting average energy coefficients are presented in Table 8.9.

TABLE 8.9 ENERGY COEFFICIENTS: NATURAL GAS AND OIL

COEFFICIENT	ALTERNATIVE I	ALTERNATIVE II
NG: e_{ℓ}^g	523.9	447.8
OIL: e_{ℓ}^o	169.0	144.5

UNITS	Btu/lb of Packaged Product

The time dependent energy coefficients for Alternative I are presented in Table 8.10. The average values are, of course, those shown in Table 8.9.

As indicated earlier, both Alternative I and II represent hypothetical cases since neither is based on actual measurements. Instead, information from many sources such as the DPRA study [5] which characterized a typical plant, the manufacturer's specifications for the microwave drier, or the plant personnel, led to the construction of the two cases. The numerical values were calibrated to the production levels of the American Beauty pasta plant. Thus, the results of this analysis should be interpreted as demonstrating the use of ALINET in assessing an alternative technology and not as quantitative results that characterize a specific facility. While such an analysis is feasible, it is predicated on data collection at the plant, i.e., taking measurements of many of the systems's variables.

TABLE 8.10 ENERGY COEFFICIENTS FOR PASTA PLANT: ALTERNATIVE I

MONTH	ELECTR.	NG	OIL
June '78	453.6	420.7	-
July	509.6	420.7	-
August	646.9	420.7	-
September	484.6	420.7	-
October	435.4	490.7	-
November	441.6	728.1	-
December	447.8	1186.0	-
January '79	441.3	429.9	933.9
February	443.8	181.8	971.6
March	420.7	602.4	52.3
April	448.4	501.8	-
May	458.0	420.7	-
AVERAGE	466.7	523.9	169.0

UNITS	Btu/lb of Packaged Product

8.7 DISTRIBUTION OF PLANT OUTPUT

The energy used in distributing the plant's production is computed using the transportation energy coefficient g^c since all shipments are by truck. The four product groups (long and short goods, noodles, and dried dinners) are grouped according to whether the packaging is for retail sales or for institutional sales. This results in seven distinct product categories since dinners are sold in retail markets only. For each category, an equivalent distance was computed

$$\bar{d}_j = \sum_i q_{ji} d_i / \sum_i q_{ji}$$

where q_{ji} is the quantity of good j shipped to destination i which is

located d_i miles from Kansas City. The information contained in the detailed sales data was augmented with the locations of the Pillsbury distribution centers, the distances from Kansas City and the fraction of the transshipments to each one. The total energy used in distributing the plant's output is given by:

$$E = \sum_j g^c q_j \bar{d}_j$$

Changes in distribution patterns can be accommodated easily through changes in $\bar{d}_j$. The existence of such large transshipments also indicated the possibility of energy conservation through an improved allocation of production and storage among the plants and warehouses. This could be accomplished with ALINET by solving an optimization problem defined on a network that includes the other American Beauty pasta plants and the storage facilities.

8.8 RESULTS

The procedure used to carry out the simulations for CERES II was similar to the one for CERES I. The material flow was calculated first and then the backward sweep process was used to obtain estimates of energy use. Twelve monthly simulations were made for the period June 1978 to May 1979. Since the material flow was the same for both the baseline case and Alternative I, only the backward sweep was carried out for the microwave alternative. The material flow for Alternative II was different, so adjustments had to be made to the baseline solution. The increased demand for semolina was allocated to the seven durum mills in proportion to their previous sales to American Beauty.

Analysis of direct energy use in the five stages of CERES II provides insight into energy conservation questions. One way of measuring energy use is to consider the energy required to produce one unit of each product class; the results are shown in Table 8.11. In each calculation it is assumed that the energy consumption in transporting wheat to the mill is allocated to the product class in consideration. The processing of semolina and flour into packaged

TABLE 8.11 ENERGY USE BY PRODUCT GROUP
FROM FARM TO CONSUMERS-BASELINE CASE

PRODUCT GROUP	ENERGY PER POUND OF PRODUCT			
	BTU/lb	%		
		MILLING	PASTA MFR	TRANSPORT
LONG GOODS	1978	8	66	26
SHORT GOODS	1981	8	65	27
NOODLES	2036	9	64	27

pasta products accounts for 64-66% of the total energy use. The second major component is transportation, 26-27%. Thus, it is apparent that the most promising area for introducing energy conserving technologies and improving energy productivity is in pasta manufacture. The small difference in the per unit energy use between the three product groups is due in part to the differences in milling semolina and flour and in part to the different destinations.

The two microwave drier alternatives concern the production of short goods only. A comparison of energy use in the plant per pound of packaged short goods is presented in Table 8.12. As expected, there is an increase in electricity use for Alternative I but a slight decrease for Alternative II. This occurs because the overhead component of electricity use is distributed over a much larger production base in Alternative II. The effect is even more pronounced in the case of natural gas which has a substantial overhead component.

Having established energy use on a per unit of product basis, in the pasta plant, it is appropriate to consider whether total energy use is reduced, the ultimate objective in energy conservation. Comparison of the baseline case and Alternative I shows that there is a net energy savings. Electric energy use increased, but direct fossil fuel use was decreased substantially (Table 8.13).

The net amount of energy conserved is 1,315 million Btu. However, the computation is based on the energy value of the various fuels and electricity

TABLE 8.12 ENERGY USE AT THE PLANT: SHORT GOODS

	BASELINE (CONVENTIONAL)	MICROWAVE ALTERNATIVE I	MICROWAVE ALTERNATIVE II
ELECTRICITY	417	467	406
NATURAL GAS	669	524	448
OIL	208	169	145
TOTAL	1,294	1,160	999

UNITS	Btu/lb Packaged Product

TABLE 8.13 ENERGY CONSERVATION AT THE PLANT:
COMPARISON OF BASELINE AND ALTERNATIVE I

	ELECTRICITY 10 ⁶ BTU	NATURAL GAS 10 ⁶ BTU	OIL 10 ⁶ BTU	TOTAL 10 ⁶ BTU
BASELINE	4,081	6,552	2,034	12,667
ALTERNATIVE I	4,569	5,129	1,654	11,352

ENERGY CONSERVATION	+488	-1,423	-380	-1,315

FUEL CONSERVATION	142,802 KWh	-1,423 MCF	-2,715 Gallons

at the plant; no consideration was given to the different efficiencies associated with delivering that energy. For an accurate accounting of resource use an energy conversion model that describes electricity production and oil refining in that

region may be used. Alternatively, efficiency coefficients may be used to account for the losses between the energy resource and energy delivered at the plant for direct use. One such set of efficiency factors is [3]

$$\lambda_1 = 1.14 \quad \text{fossil fuel}$$

$$\lambda_2 = 3.68 \quad \text{electricity}$$

Then the energy used to produce one pound of product at the plant, measured in energy content of the original resources, was estimated to be:

Baseline: 2534 Btu/lb

Alternative I: 2508 Btu/lb

Alternative II: 2170 Btu/lb

These estimates were obtained by multiplying the entries in Table 8.12 by the appropriate efficiency coefficient λ and adding the results. On this basis, conventional drying and microwave drying at low capacity consume approximately the same energy resources, while Alternative II - high capacity drying - is more energy efficient. This effect should be reflected in computing the corresponding costs of energy since the price structure reflects to some extent resource use. Indeed, in Table 8.14, where total energy use - from farm to consumer - per pound of packaged product is shown, the cost of energy is estimated to be approximately 0.83 cents per pound for the baseline case and for Alternative I and 0.77 cents per pound for Alternative II. The computation was done using 1977 prices (see Table 7.10).

In order to obtain an overall perspective of energy use in durum milling and pasta manufacture, total energy use, by fuel type, is presented in Table 8.15. Consumption figures include energy used in transportation, milling, pasta manufacture, and distribution of retail and institutional products.

The values in Table 8.15 are the result of the simulation and do not represent the actual consumption either by the Peavey mill in Hastings or the

TABLE 8.14 ENERGY USE AND COST OF ENERGY FROM
FARM TO CONSUMER: SHORT GOODS

	BASELINE BTU/lb	MICROWAVE I BTU/lb	MICROWAVE II BTU/lb
MILLING	165	165	165
PASTA MANUFACTURE	1,294	1,160	999
TRANSPORT	522	522	522
TOTAL	1,981	1,847	1,686

ENERGY COST ¢/lb	0.83	0.83	0.77

American Beauty Macaroni Company's pasta plant. The cost of the fuels and electricity is also shown on the basis of 1977 prices and estimated 1979 prices (Table 7.10).

The conclusions that can be drawn from analyzing the results presented in Tables 8.11 to 8.15 can be summarized as follows. Replacement of conventional driers by microwave driers reduces fossil fuel use but increases electric energy use. If the design specifications* of the driers are used in the analysis, then there is a net decrease in energy use. However, because of price differentials between different fuels (when measured in dollars per Btu) the cost of energy remains approximately the same. Whether the substitution of electricity for fossil fuels is desirable depends on local conditions and long term expectations of availability and price.

The introduction of the microwave drier allows for substantial increase in production using the same plant. It is much more compact and allows for higher throughput. Thus, the main contribution of the alternative technology is in

*These specifications are very conservative; they are upper bounds. Substantially lower energy requirements are expected under normal operating conditions in the plant.

TABLE 8.15 DIRECT ENERGY USE FOR ALL PASTA PRODUCTS: FROM FARM TO CONSUMER

	ENERGY-FUELS				ENERGY COSTS - 1977		ENERGY COSTS - 1979	
	ELECTRICITY	NATURAL GAS	OIL	DIESEL	TOTAL	PER POUND	TOTAL	PER POUND
BASELINE* (CONVENTIONAL)	5.09×10^6	21,632	47,971	108,913	253,858	0.781	389,360	1.198
ALTERNATIVE I* (MICROWAVE)	5.25×10^6	20,071	45,000	108,913	255,116	0.785	390,560	1.201
ALTERNATIVE II* (MICROWAVE)	8.01×10^6	27,359	61,743	175,850	387,210	0.772	594,190	1.185

UNITS	KWh	MCF	Gallons	Gallons	\$	c/lb	\$	c/lb

*Production for Baseline and Alternative I is 31.6 million pounds; for Alternative II it is 49.2 million pounds.

increasing the productivity of a given facility - this is the dominant effect. This increase in productivity is feasible because the market for pasta goods is large and can absorb the increase in production. The strength of the pasta market is due not only to population increases, but also to the recent increase in per capita consumption. This is discussed in Section 9.3.

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IX. CONCLUSIONS AND RECOMMENDATIONS

9.1 CONCLUSIONS

ALINET has been developed in three phases. In the first one, the conceptual design and the specifications of the system were made and then presented at a workshop to an advisory group for review and criticism. In the second phase, the computer model was designed and implemented while data and structural information on wheat processing were collected. In the last phase, a pilot project on wheat processing was carried out in cooperation with industry - the Pillsbury Company. Each phase provided a different perspective of the project's objective: the development of a model for analyzing proposed energy conserving technologies in the food processing sector and for identifying opportunities for research and development. Each perspective led in turn to several conclusions on the development of models, on their utilization, and on energy conservation.

On Models

- *A model to be useful in the policy process should be explainable and understandable.*

If a model is to be effective as a decision aid, then its underlying philosophy and its assumptions should be articulated clearly and concisely. Furthermore, the explanation of the model's premises and the limits of its applicability should be understandable not only to other modelers, but - most importantly - to model users. A substantial portion of the effort in developing ALINET was directed to documentation and interaction with potential users. In addition to two workshops that included representation from government, industry, and academia, many presentations were given to industrial and professional organizations.

- *Procedures for using the model should be simple and direct; the interface between the model and the user should be attuned to the concepts and terminology of the application area.*

If a model is to be used, then it should be accessible to persons with diverse backgrounds. Thus, the pre-processor, the input interface between the modeler and the system, and the post-processor, the output interface, should require and present information in terms of parameters, indices, and variables that are drawn from the applications area. In ALINET, some effort was expended in developing algorithms that accepted data in the form collected by plant or corporate management information systems. The output was expressed in terms of variables that are useful in decision making such as cost per unit, total amount of fuel oil required, monthly cost of electricity, etc.

- *A new model should be able to solve efficiently some traditional problems as well as the new classes of problems for which it has been designed.*

This consideration is very important in establishing a model's credibility in terms of workability and reliability. While ALINET has been designed for the assessment of energy conserving technologies, it can also be used as a vehicle for solving a wide variety of traditional operations research problems such as optimum resource allocation, or determination of flows in the network, i.e., determination of optimum allocation coefficients, minimizing transportation costs, etc. The ability to use the model's network structure to formulate and solve such problems - which can be solved with alternative model formulations - enhances the model's usefulness and allows the user to develop confidence in using the model.

On the Analysis of Energy Conservation in the Industrial Sector

- *The method of approach in analyzing energy conservation opportunities should be based on detailed and specific case studies from which general, abstract results could be inferred.*

This is an affirmation of the approach usually referred to as "from bottom up" rather than "from top down." It is appropriate to note that the original approach to the problem was one based on going from the general and abstract to the detailed and specific. The first examples constructed with ALINET were national aggregate network representations of several industries in the food

processing sector. The difficulties that would be encountered with such an approach were first pointed out by the participants in the Phase A workshop. First, a national aggregate representation does not capture the geographic diversity of agricultural production and food processing. Second, conclusions drawn on the basis of typical plants and typical costs are not credible in an industry with such technological diversity and wide variety of products. It is preferable to examine energy conserving technologies in the context of specific facilities and operations and then broaden the basis of the study. Furthermore, the introduction of a new technology in a plant is not an isolated event, but it usually stimulates other changes in production. The case study CERES II is such an example. While a specific technology may conserve energy, the reduction in energy use may not justify the capital investment. However, when it is coupled with plant modernization, or is part of new production facilities, then the resulting increase in plant productivity justifies the investment and leads to energy conservation. Thus, two interrelated conclusions are:

- *Energy conserving technologies should be studied in the context of the changes in production that they may stimulate, and*
- *Energy conserving technologies in the food processing industry should be analyzed in the context of productivity improvement.*

9.2 RECOMMENDATIONS

The main objective of the work thus far has been the development and proof of the concept of ALINET. In the preceding eight sections the overall conceptual framework was described and the software for creating and supporting submodels of the food processing industry were presented. A pilot project was carried out in cooperation with industry in which two case studies were performed. Their purpose was to demonstrate the usefulness of ALINET as a tool in analyzing potential opportunities for energy conservation.

These were essential first steps in the long process of establishing the model's credibility in its use in policy analysis by government agencies or industry. The next steps should be directed mainly toward model utilization and

adoption. The effort should address primarily the last two of the five tests for credibility: workability and reliability [6].

To increase the model's usefulness and increase its applicability to food industry problems, a small set of projects, similar to the one carried out with Pillsbury, should be undertaken. Their purpose will be threefold: (a) to model issues of concern and provide useful quantitative analyses of proposed alternatives - either by industry or by government agencies; (b) to extend the resource base of the system by augmenting the data base and by creating the structural representations - the networks - of various sectors of the food processing industry; and (c) to identify the model's limitation and thus motivate the development of algorithms that solve different classes of problems (e.g., resource allocators, planning algorithms, etc.).

The selection of the specific sectors and technologies would depend on the importance of the sector as an energy user, the existence of potential opportunities or proposed technologies for energy conservation, and the cooperation of one or more firms or industrial institutions. Potential areas in the processing of crops that satisfy some of the above criteria are presented in Section 9.4; in the processing of livestock products in Section 9.5. The listing and brief descriptions are not exhaustive, but rather indicative of the type of projects that could be undertaken. Thus, the first recommendation is:

- *Several projects should be carried out in different sectors of the food processing industry. These projects should be so designed that they expand the data base of ALINET, contribute toward the development of a structural representation of the industry, and provide analyses on specific energy conservation issues.*

In parallel with this work, effort should be directed toward the development of a user oriented version of ALINET. As indicated earlier, ALINET is operational and can be used to carry out selected analyses on aspects of wheat processing. However, in order for the model to become a truly effective tool in the decision process, it must be easily accessible to diverse users and be transferable to different organizations. In addition to reviewing and revising the computer code accordingly, further attention should be given in specifying

inputs and presenting both inputs and outputs in a format that is easily understood by model users. Already some effort has been expended in this direction: quantities are entered in units usually encountered in the industry (bushels, tons, KWh, MCF, gallons, etc.), converted to a consistent set for numerical computations and then reconverted to traditional units.

Another aspect of this activity should be the implementation of a set of routines for presenting results in tabular and graphical format. This approach has already been tested; a commercially available software package was used to generate graphical representations of the network.

While these activities should constitute a small part of the overall effort for further development, implementation, and use, they are essential for establishing ALINET as a credible and useful tool. Therefore, it is recommended that:

- *A user-oriented version of ALINET should be developed from the currently operational version. It should be an easily transferable version and should include input and output processing routines that permit the operation of the model by diverse users.*

The third recommendation concerns the development of the dynamic and adaptive version of ALINET. As mentioned earlier, the current implementation allows for static monthly and annual simulations. The second level, the solution of a sequence of local decision problems to simulate resource allocation, has been studied, but not implemented. The third level, the dynamic and adaptive cases need further research and development. This direction was not pursued more vigorously because it became apparent early in Phase B that the required data to support dynamic simulations were not readily available and could not be developed in the context of this first project. But as the ALINET data base expands through additional case studies, it will become possible to carry out credible dynamic analyses. Thus, it is recommended that

- *Research and development effort should be undertaken to design and implement the dynamic and adaptive versions of ALINET. This effort should be carried out in conjunction with case studies from which the required data will be drawn.*

9.3 FUTURE APPLICATIONS: CROPS

As indicated in the preceding sections, ALINET is adaptable to modeling an entire food commodity sector (e.g., wheat) on the national level; to regionalization on a commodity-specific level by state (e.g., hard wheat processing in Kansas); and to industry and plant-specific modeling of a single product (e.g., durum milling and pasta manufacturing at specific plants). Furthermore, there are no constraints in the model that could limit its applicability to wheat or even to food crops. Before the decision was made to model in detail some parts of the wheat system, the basic model structure and the economics of other leading food commodities were investigated. Preliminary networks for corn, soybeans, rice, dairy products and red meat were constructed during Phase A, although only dairy was implemented on the computer.

A brief overview of several crop and livestock product sectors which could be modeled in detail and incorporated into ALINET is presented below. They were selected on the basis of their importance in terms of energy use and because they have the potential for conservation through technological change.

9.3.1 Other Wheat Processing

In the research effort presented in this report, attention was focused on the detailed modeling of hard wheat and durum. The next logical step would be the modeling and incorporation of soft wheat into the total network. This might include, for example, the manufacture of cookies and crackers and breakfast cereals. Because different geographical areas of production and processing would be involved, the modeling of soft wheat would require not only different engineering processes, but also different regional considerations about energy availability and cost and different modes of transportation.

The hard wheat networks on the national and state level include baking, which is a more energy-intensive industry than milling, for example; detailed models of the baking process could easily be incorporated into the existing network. This inclusion of baking in CERES I and the modeling

of soft wheat milling and the manufacture of breakfast cereals and cookies and crackers will produce a comprehensive model of wheat processing.

9.3.2 Corn

Modeling the corn production and processing network is less complex than modeling wheat. Corn is essentially a uniform commodity, and although some corn is grown throughout the U.S., about two thirds of it is produced in the "Corn Belt", especially Iowa and Illinois. Corn is principally grown for feed; only about 10% of the corn that moves into markets goes for food and industrial uses. Nevertheless, this marketing and processing network is important, as indicated by the rising per-capita consumption of corn products, the popularity of snack and convenience foods, and the rising demand for corn syrup and other products obtained from wet milling. When, because of a poor harvest, total consumption in 1974 dropped by 32% from the previous year, food and industrial use rose nevertheless. Wet milling has grown more rapidly than dry milling, indicating a more favorable market for its end products.

The leading products obtained from corn are shown in Table 9.1. It should be noted that wet milling, according to a recent study [5], ranks second only to sugar beet processing in amount of energy consumed by food industries. With the increasing demand for syrup and starch obtained from wet milling, this is an industry where effecting energy savings would be of great benefit.

TABLE 9.1 CORN PRODUCTS

PROCESS	FOOD PRODUCTS	FEED PRODUCTS
Dry milling	Grits Corn meal Corn flour	Germ meal Hominy feed
Wet milling	Corn starch Corn syrup & syrup solids Dextrose Corn oil	Gluten feed Gluten meal Germ cake
Special Processing	Processed grits Corn flakes Corn bread mixes and products Snack foods Convenience foods (Distilled liquor)	

9.3.3 Soybeans

Soybeans have traditionally been grown in approximately the same area as corn, but the production area has been expanding. However, most of the demand for soybeans is based on oil and meal, rather than whole beans, and after passing through crushing plants, the soybean network splits into two separate and independent flows. Also, the network is especially complicated because of the intricate structure of oil markets in general. The increasing interest in the food use of vegetable protein from soybean meal presents many future possibilities in food technology.

The leading products obtained from soybeans are shown in Table 9.2.

TABLE 9.2. SOYBEANS, SOYBEAN PRODUCTS: FOOD AND FEED USES

PRODUCED FROM	FOOD USE	FEED USE
Whole soybeans	Cereals Flours Snack foods Oriental foods	Beans for feed
Soybean meal	Baked goods Cereals Textured veg. protein foods Food drinks Baby foods Confections High-protein foods	Livestock feed Protein concentrates Fish and pet food
Soybean oil	Margarine Shortening Cooking & salad oils Mayonnaise Desserts Spreads	

The principal uses of soybean oil are for edible oil products such as margarine, salad and cooking oils, and mayonnaise. Soybean meal has been the major high protein ingredient used in feeding livestock and poultry, and the expansion of the livestock and poultry industry has led to an ever increasing demand for it. Export demand for soybean meal has also continued to expand. Traditionally, only a minor percentage of the meal has been processed for human consumption in the United States.

However, the steadily rising cost of food-grade animal proteins derived from meat, poultry, eggs, dairy products, and fish has compelled the food industry to look into the low-cost vegetable sources of protein, principally the oil seeds, as an alternative. At present, the least expensive and most readily available high quality vegetable protein comes from the soybean; soy flour ranks just below animal proteins in nutritional value. Food products derived from soybeans include manufactured meat products of various kinds, dairy-type products such as coffee whiteners and whipped toppings, infant formulas, dried-soup mixes and special dietary items [47]. All indications are that soybeans will continue to play an increasingly prominent role in the U.S. economy and the world food supply.

9.3.4 Sugar and Confections

While most sugar is consumed directly or indirectly as a food, it is also becoming a valuable raw material for a wide variety of products. The potential use of sugar as a source of fuel has aroused considerable interest in its processing.

The U.S. produces around one half of its sugar supply; of the sugar produced domestically, slightly over one half comes from beets, which are grown all over the country. The principal U.S. cane-growing areas are Hawaii, Florida, Louisiana, Texas and the Commonwealth of Puerto Rico (see Table 9.3).

Among the food-processing industries in the U.S., the beet sugar mills were rated in a recent study [5] as first in energy consumption. The cane sugar industry is divided into the raw cane sugar industry and cane sugar refining; the establishments are, generally, totally separate. Cane sugar refining is, like the beet sugar industry, one of the highest in energy use among food processors (over 5 million BTU per ton of raw sugar processed) [5]. The modeling of the sugar network can also be extended to include the confectionary industry.

TABLE 9.3 SUGAR, CANE AND BEET: SOURCE OF SUPPLY*

COUNTRY OR AREA OF SUPPLY	1975	1976	1977
Total foreign countries	3,883	4,658	6,136
Domestic areas:			
Mainland (beet)	3,283	3,822	3,513
Mainland (cane)	1,349	1,592	1,424
Hawaii (cane)	955	985	979
Puerto Rico (cane)	96	203	102
Texas (cane)	81	118	85
Total, domestic areas	5,764	6,720	6,103

UNITS	Thousand Tons (raw value)

* Source: *Agricultural Statistics*, 1978 [14]

9.4 FUTURE APPLICATIONS: LIVESTOCK PRODUCTS

Modeling the processing and distribution networks for various live-stock commodities involves more complex considerations than modeling crop processing. This is so because the supply and prices of livestock products depend on the supply and prices of those crop products used as feed. The modeling of this close interrelationship between the crop and livestock sectors was one of the key features of AGRIMOD [8]. If ALINET is to be used in conjunction with AGRIMOD, then the appropriate information can be generated by the latter to be used in the former. If, however, ALINET is to be used independently, provisions have to be made for introducing consistent exogenous information.

The relative per-capita consumption of crop products and livestock products, as well as the relative consumption of meat, dairy, and poultry, has changed over the past ten years, as shown in Table 9.4 and Figures 9.1 and 9.3. While traditionally meat, especially beef, consumption had been increasing and consumption of food cereals decreasing, the sharp rise

in meat prices in the late 70's partly changed this trend. Chicken consumption has risen steadily; per-capita egg consumption has continued to decline; consumption of fluid milk has decreased, but cheese consumption has increased.

TABLE 9.4 PER-CAPITA CONSUMPTION OF SELECTED FOODS*

FOOD ITEM	1968	1978	% CHANGE
Beef and Veal	84.2	91.7	8.9
Pork	61.4	56.5	-8.0
Fish	11.0	12.9	17.3
Poultry (Chicken and Turkey)	44.6	57.1	28.0
Eggs	40.1	34.6	-13.7
Fluid Milk and Cream	304.0	288.9	-5.0
Cheese	10.6	17.4	64.2
Fats and Oils - Total Fat Content	51.2	56.0	9.4
Fresh Vegetables	93.6	95.2	1.7
Canned Vegetables	50.5	53.0	5.0
Frozen Vegetables	9.6	10.9	13.5
Wheat Flour	112.0	107.6	-3.9
Sugar	99.0	92.7	-6.4

UNITS	LBS.	LBS.	LBS.

*Source: *National Food Review* [48].

Figure 9.1 Per-Capita Food Consumption

Source: National Food Review [48]

9.4.1 The Meat Industry

Several trends have been evident in the meat production and processing industry in recent years. At one time, some 80% of all the cattle, calves and sheep were sold in terminal markets; by 1964 the proportion had declined to 40% and by 1973, to approximately 14% [50]. One of the reasons has been undoubtedly the high cost of transportation and labor. As a result, packing and processing plants have moved closer to livestock-producing areas. Also, more and more processing of meat is being done at the packing plants; rather than shipping whole carcasses, packers cut up and pre-package meats for restaurants and stores.

Figure 9.2 Per-Capita Consumption of Selected Livestock Products.

Source: National Food Review [48].

Both beef and hog processing is done rapidly under sanitary conditions. Though there are many individual steps in the operation, it is continuous from the time the animal is in the holding pen until the carcass is in the cooler, approximately 40-50 minutes later. This involves stunning, bleeding, skinning, eviscerating, splitting in halves and trimming. The carcass is washed at points along the way and again before it is chilled. Some packing plants have a capacity of 250 slaughters per hour for beef. Beef is skinned, as hides are valuable, but hogs usually are not, as there is not as much market for pigskin.

The usable end products, both for beef and pork, can be classified in three groups: (1) usable by-products, including hides, processed blood, and edible offal like liver, heart, and kidneys; (2) fresh meat to be cooked

at restaurants and fresh meat, packaged and labeled, to be purchased at supermarkets for cooking in the home; and (3) canned or processed meats -- sausages, Spam, canned corned beef, etc. While much of the beef consumed is marketed fresh, a large fraction of pork finds its way into processed meats. Hog processing is also highly energy-intensive, and in recent years there have been numerous innovations in hog-processing technology. This is one sector that would have high priority for modeling to identify and analyze opportunities for energy conservation.

9.4.2 Poultry and Eggs

Technical advances in the poultry and egg industry since World War II have made it possible to increase production at substantially reduced cost. Lower prices have brought increasing per-capita consumption of poultry meat, but total consumption of eggs has risen only because of population growth. The demand for poultry is affected, however, by red meat prices; if meat prices fall, fewer chickens are bought. It is evident that, although the food production and processing network can be separated according to food commodities, it is interconnected, through the elasticities of substitution, as the situation in one sector can affect supply, prices, and consumption in another.

The commercial operation of killing, dressing, and transporting chickens has become so rapid and efficient that most chickens today are sold fresh chilled. Technological advances in production have resulted in a highly standardized product. Older chickens, too tough to be sold as broilers, have found utilization in various processed food items, sometimes substituting for red meats -- as in chicken franks, for example. Most poultry and eggs are marketed through retail stores and the channels of distribution between processors and retailers have become more direct and streamlined. The prospects for continued high consumption of poultry are good, and egg consumption has benefited from increased use of processed eggs and the use of eggs as ingredients in other food products.

Both poultry and eggs could be modeled as a separate sector, or according to the processing operations being studied, as one of the ingredients in various processed foods.

9.4.3 The Dairy Industry

All milk is graded as Grade A, or Manufacturing Grade. The major portion of Grade A milk is sold as fluid milk or utilized for fresh milk products such as cream or flavored milk. Because it is marketed fresh and is extremely perishable it requires daily processing and marketing as well as stringent sanitary precautions. The surplus Grade A milk is sold for manufacturing purposes, and, along with Manufacturing Grade milk, is processed into milk products from which much (or all) of the liquid has been removed -- dried milk, cheese, ice cream, etc. While the fresh milk which is to be used for manufactured products must be processed immediately, the end products are considerably less perishable and may be stored for considerable lengths of time. The processing and marketing channels for fluid Grade A milk and for manufactured milk products are almost totally separate; thus, modeling the dairy industry involves constructing two distinct networks.

In modeling the dairy industry, a certain amount of regionalization would be necessary because production and processing patterns vary from state to state. Milk is produced in all 50 states, although the largest volume is produced in Wisconsin, California, New York, Minnesota and Pennsylvania. However, while generally enough Grade A milk is produced everywhere to satisfy local demand, Manufacturing Grade milk is primarily produced in the Midwest and Lake states, as are most manufactured dairy products. Wisconsin and Minnesota lead in production of butter, cheese, and dry milk. California produces a large amount of butter, evaporated milk and dry milk, but relatively little cheese. New York produces a lot of cheese, but relatively little butter and a negligible amount of evaporated milk. Iowa, which is not at the top in total milk production, ranks right after New York in cheese production, while the largest producer of evaporated milk is Ohio.

Dairy products undergo many different processes on their way from farmer to consumer. Fluid milk processing, which was rated in a recent study as the highest energy consumer among dairy industries [5], involves

clarification, homogenization, pasteurization and fortification. Manufacturing dairy products involves numerous distinct processes -- churning, freezing, drying, coagulating, ripening, etc. Alternative technologies exist in a number of processes -- as, for example, traditional and continuous buttermaking.

A preliminary, national-level network of the dairy industry was designed and implemented on the computer during Phase A of the project. The following processes were identified in the dairy sector:

Transportation	Mixing
Handling	Condensing
Retailing	Flavoring
Separation	Fortifying
Grading	Souring
Churning	Instantizing
Clarifying	Cottage Cheese making
Pasteurizing	Curing
Homogenizing	Freezing
Cheesemaking	Sweetening
Drying	Packaging
Culturing	Canning

The same number and type of attributes were required as for wheat.

The preliminary dairy network that has been implemented is an aggregated, national-level one; it contains 85 nodes and 108 links. However, as was the case with wheat, it can be modified to focus on a specific state, region, plant, or process. In the past, much of the technological innovation and interest in new processing methods have revolved around the energy-intensive fluid milk processing industry. This will certainly continue to be an area where potential energy saving technologies should be explored; however, the processing of milk into a wide variety of dairy products deserves further investigation.

9.5 CLOSURE

The development of ALINET, from inception to design and implementation and to its application on two examples of wheat processing, has been documented in this report. The modeling effort achieved many of the originally set objectives. The direct interaction with potential users and the cooperative effort with the Pillsbury Company necessitated some desirable revisions in the specifications. The project team believes that these revisions increased the utility of the model by making it simpler to use, but more detailed and realistic in its representation of segments of the food processing industry. The interest expressed and the advice and constructive criticism received from potential users in government and industry may indicate that ALINET could become a useful tool in the analysis of energy conservation issues in the food processing industry.

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APPENDIX A

DATA SYSTEM EXECUTIVE

The decision to use System 2000, a general purpose data base management system developed by MRI Systems Corporation[45] was based on a variety of considerations. These can be categorized as: (1) the ease with which changes to the data definitions are incorporated, (2) the match between the peripheral functions available and the desirable features of the ALINET Data System, (3) the compatibility between the natural data structure and the particular hierarchical formulation from which System 2000 is derived, and (4) the commercial availability of the system.

A System 2000 data base is defined hierarchically in terms of data elements which contain the values to be stored, and repeating groups which provide both the structural connection between levels of the hierarchy and the framework for storing multiple sets of data values. Data base manipulation is controlled primarily through the interactions between sets of pointers; some which describe the relationships between data sets and some, inverted indices, which indicate the location of the data values. Designation of an element within the data structure as *key* implies that the data base is inverted with respect to that element, thus allowing direct access to a particular value of that element. More importantly, the effective use of relational operators (e.g., EQ, NE, GT, SPANS, EXIST, etc.) allows the efficient processing of complex access criteria before actual data values are retrieved. The trade-off between key and non-key status is one of storage for maintaining the inverted index versus time required to search through the subset of the data within which a non-key value lies [45].

Two additional components are a basic part of the data definition. The first of these is a set of strings which allows the user to denote complex structures and to concatenate frequently used commands. The use of such strings can simplify the input, for example, so that a user who is not a programmer can invoke the string and specify the values. The second is a set of user specified functions which may be any arithmetic function containing element names, constants, symbols, etc. Such functions permit computation upon retrieval for specific queries or reports [46].

Simple procedures are invoked for translating the structural definition, sets of strings, and functions into a data base definition. Once the definition has been made, modification to the structure can be specified through a set of simple commands even after data have been loaded into the data base. Changes to the structure include reorganization, change from key to non-key or vice versa, and changes to the data format (e.g., decimal to integer, decimal to "money", etc.). Since certain of these commands imply a reorganization of the data base, the cost of such decisions is proportional to the quantity of data already in the data base which must be unloaded and reloaded. However, such a cost is considered minimal when compared to cost over time of an inefficient structure or the addition of any programming effort [46].

Four basic methods of interacting with the data base for retrieval and updating are described in Table A.1. Each has its own set of "people readable" commands, easily mastered conventions, and appropriate uses. The procedural language interface, for example, allows large data files acquired from other sources to be processed and loaded directly into the data base, thus providing a powerful auxiliary capability [45].

TABLE A.1 SYSTEM 2000 CAPABILITIES *

ACCESS MODE	RETRIEVAL	UPDATING
Queue Access	• Information production runs • Post-processor input • Sequential processing • Standard queries	• Data base creation • Maintenance • High volume (batch) updating • Update functions
Immediate Access	• Standard and ad hoc queries • Interactive browsing • System and user-specified functions • Non-related queries • Positional retrieval • On-line with multiple terminals	• Single and multiple element updates • Ad hoc updating • Positional updating • Small batch updates • On-line maintenance
Report Writer	• Standard reports • Ad hoc, one time reports	• Changing of report format specifications
Procedural Language Interface	Opens data bases to procedural programs for retrieval, updating, merging and manipulating.	

*Source: System 2000: *Information Manual* [45].

Study of the salient features of each as outlined in Table A.1 indicates the flexibility of the system for meeting the diverse needs of the user, as well as allowing efficient use of the system by the analytical models through the procedural language interface. Precise techniques for manipulating the data, defining complex strings of logical instructions, system functions, and concatenating commands, as well as providing for data base security, are described in the basic system manual [46].

APPENDIX B

CONSTRUCTION OF THE GRAPH

The choice of state level sectors as the basic unit implies that a flow-graph representation will be created many times as portions of sector are examined and elements refined. The underlying assumption in the choice has been that computer efficient algorithms could be developed for the graph generation procedure. The efficiency of the implementation of these algorithms depends on the ability a) to minimize the searching and sorting required in defining the network structure and b) to reduce the interactions and manipulations of the major data base through the Data System.

In order to understand both the algorithms and the implementation in this context, the sequence of operations required to construct and test the graph is presented using a simple example. Tables B.1 and B.2 contain the structural data for selected elements in the data base from which the example is drawn. Colors have been assigned as node names in order to focus attention on the abstract graph rather than on specific commodities within the food processing and distribution system.

The first requirement for the specification of the graph is graph initiation or the definition of the graph boundaries. Such boundaries are defined automatically for the basic flow graph unit through the selection of a sector which includes all relevant elements from the wholesale to the retail level. Subgraphs, with a smaller focus than a total sector, require a more detailed boundary definition for specification. Several degrees of partitioning are permissible, ranging in scope from the specification of modifications to an existing graph in terms of particular elements, added or removed, to the generation of the graph of a sector between any two levels. The flow graph in this example is a subgraph whose boundaries are indicated in terms of a single source node, GRAY. This implies that all processes following GRAY are to be included by logical association until all dead ends corresponding to the right hand edge of the graph are accounted for.

TABLE B.1 SELECTED NODE DATA FROM THE DATA BASE

NAME	SECTOR	LEVEL
BLACK	1	Dark
GRAY	1	
BLUE	1	
SILVER	2	
GREEN	1	
VIOLET	1	
PURPLE	1	Dark
RED	1	
LT. GRAY	1	
ORANGE	1	
WHITE	1	
LT. GREEN	1	
GOLD	2	
YELLOW	1	
BROWN	1	Dark
LT. BLUE	1	

The initial step in building the list of elements is to initialize a list of nodes to be considered (a *consideration* list) with the source node(s); in this case, node GRAY. For each node on this list, the set of links emanating from this point is determined. Since both the origin and destination node names are *key* values as defined in the data structure for the link specification, the location of the elements which satisfy this criterion is made directly through pointers in the data base and does not require extensive searching over the set of all possible links. This set contains the elements L2, L3, and L9, which are examined in order.

Temporary core resident sequential files are defined to contain the information extracted from the data base. The positions of the elements within these files are used for cross referencing and direct data access. The relative order is also used as a temporary flag, entered in the system data base as each element is included.

TABLE B.2 SELECTED LINK DATA FROM THE DATA BASE

NAME	ORIGIN	DESTINATION
L1	RED	SILVER
L2	GRAY	RED
L3	GRAY	BLUE
L4	GOLD	ORANGE
L5	PURPLE	LT. GREEN
L6	LT. GRAY	GRAY
L7	BLUE	GREEN
L8	RED	YELLOW
L9	GRAY	VIOLET
L10	VIOLET	LT. BLUE
L11	ORANGE	BLACK
L12	BLACK	WHITE
L13	BLACK	LT. GREEN
L14	LT. BLUE	BROWN
L15	GREEN	VIOLET
L16	VIOLET	YELLOW
L17	VIOLET	PURPLE
L18	BROWN	LT. GREEN
L19	YELLOW	ORANGE
L20	ORANGE	PURPLE

The examination of link L2 places node RED on the consideration list, since the link and the node pass the test for inclusion, i.e., the outbound link does not cross sector bounds (RED is in Sector 1) and the inclusion flag for RED has not been set in the data base, thus indicating that no previous path to RED has been considered. Links L3 and L9 are examined in turn, adding BLUE and VIOLET to the list. Since the examination of outgoing links only would fail to include outlying sources, incoming links are also processed and the link file expanded to incorporate those whose inclusion flags have not been set. At the end of this first step, the consideration list contains nodes GRAY, RED, BLUE, and VIOLET, and the information is stored in the temporary files is given by Tables B.3a and B.3b.

Although an incoming link is available in the data base for node GRAY, the declaration of GRAY as the source of the subgraph prevents its inclusion.

TABLE B.3a NODE FILE AFTER ONE CYCLE

ORDER	NODE NAME	INCOMING LINKS *	OUTGOING LINKS *
1	GRAY	-	1,2,3
2	RED	1	-
3	BLUE	2	-
4	VIOLET	3,4	-

*Link numbers are pointers to elements in the link file.

TABLE B.3b LINK FILE AFTER ONE CYCLE

ORDER	LINK NAME	ORIGIN		DESTINATION	
		NO. *	NAME	NO. *	NAME
1	L2	1	GRAY	2	RED
2	L3	1	GRAY	3	BLUE
3	L9	1	GRAY	4	VIOLET
4	L15	-	GREEN	4	VIOLET

*Node numbers are pointers to the node file.

Node LT. GRAY and link L6, therefore, indicated in Tables B.1 and B.2, will not appear in the final flow graph. Link L15 was included as an incoming link to VIOLET, although the source node, GREEN, for this link has not yet appeared as the destination node of an outgoing link. Since GREEN is not yet part of the node file, a pointer for cross reference cannot be added to the link file, leaving this entry temporarily blank.

The consideration list is processed in order, with RED providing the next focus for the examination of outgoing links. Although two links are identified, L1 and L8, L1 is disqualified since the destination node, SILVER, lies outside the sector boundaries. When the entire cycle is complete, the composition of the ordered lists is given in Tables B.4 and B.5.

TABLE B.4 NODE FILE

ORDER	NODE NAME	INCOMING LINKS	OUTGOING LINKS
1	GRAY	-	1,2,3
2	RED	1	5
3	BLUE	2	7
4	VIOLET	3,4	6,8,9
5	YELLOW	5,6	11
6	GREEN	7	4
7	LT. BLUE	8	13
8	PURPLE	9,10	14
9	ORANGE	11,12	10,17
10	BROWN	13	18
11	LT. GREEN	14,15,16	-
12	BLACK	17	15,18
13	WHITE	18	-

TABLE B.5 LINK FILE

ORDER	LINK NAME	ORIGIN		DESTINATION	
		NO.	NAME	NO.	NAME
1	L2	1	GRAY	2	RED
2	L3	1	GRAY	3	BLUE
3	L9	1	GRAY	4	VIOLET
4	L15	6	GREEN	4	VIOLET
5	L0	2	RED	5	YELLOW
6	L16	4	VIOLET	5	YELLOW
7	L7	3	BLUE	6	GREEN
8	L10	4	VIOLET	7	LT. BLUE
9	L17	4	VIOLET	8	PURPLE
10	L20	9	ORANGE	8	PURPLE
11	L19	5	YELLOW	9	ORANGE
12	L4	-	GOLD	9	ORANGE
13	L14	7	LT. BLUE	10	BROWN
14	L5	8	PURPLE	11	LT. GREEN
15	L13	12	BLACK	11	LT. GREEN
16	L18	10	BROWN	11	LT. GREEN
17	L11	9	ORANGE	12	BLACK
18	L12	12	BLACK	13	WHITE

Examination of the node file depicted in Table B.4 indicates the presence of end points, nodes LT. GREEN and WHITE, from which no outgoing links emanate. In reality, these may be either sinks (e.g., waste disposal or insignificant by-products) or retail market points.

Study of the link file reveals a single link, L4, for which the table is not complete. The absence of a node file pointer for the origin node, GOLD, indicates that it cannot be reached by forward logic traced from source GRAY. It is assumed, therefore, to be an outlying source which may be either an interconnection point between sectors, or an implied decomposition of the sub-graph from the remaining sector elements. The node, GOLD, is included as an element in the node file and identified as a source with no input links. The link file is then completed.

Once the element set has been identified, the simultaneous procedure of structuring the graph and evaluating it for structural inconsistencies can be initiated. An important consideration in the implementation of these algorithms is the desire to determine the logical level assignment for each node without reliance on trial and error. For cases in which there exist multiple paths between nodes, the strict enforcement of precedence results in links which cross varying numbers of levels. A procedure for level assignment is sought which is independent of the order in which paths are traversed and thus avoids the need for tentative assignments.

A second consideration list is initiated which, upon completion, will be compared with the first. The source nodes, including node GOLD, are placed on this list and arbitrarily assigned to level 1. This is the only temporary assignment since, at the completion of the graph procedure, the outlying sources (in this case GOLD) will be assigned to a level immediately preceding their first connection point. The algorithm proceeds in much the same manner as that for element identification with an important difference. A running count is kept for each node. A node is not formally placed on the consideration list for further processing until all incoming links, as evidenced by the value of the count, are accounted for. Placement of a node on the consideration list constitutes a level assignment, with levels advancing as required to fulfill

the left to right progression of processes. Nodes which have been pre-assigned to the same level are withheld from assignment until all nodes in the group meet the condition for placement. The pre-assigned level is automatically placed in its proper order and processing continues.

Structural errors can be detected in a number of ways. The most straightforward occurs through the comparison of the two consideration lists. If the total number of nodes identified in the node file can be assigned to levels according to the procedure indicated above, it is clear that no cycles exist. Any discrepancy results from unresolvable conflicts of the type: A precedes B and B precedes A ; or A precedes B, B precedes C for the situation in which A and C have been pre-assigned to the same level. Conflicts may arise from such errors as the reversal of origin and destination nodes in a links specification, or the misassociation of nodes with a common pre-assigned level. The detection of an error halts the forward propagation along the path containing the error. All other paths are examined until the possibilities are exhausted, thus permitting error detection in multiple directions. In the event that additional errors are introduced in elements occurring beyond the initial loop within each path, such errors would go undetected in the initial pass.

The decision to adopt this implementation was made on the basis of the speed of the single sweep algorithm, which combines the functions of structural representation and error detection into a single process. For the majority of cases involving simple changes in the structure or the introduction of alternative processes, the single pass is sufficient. One may be tempted, in the event that multiple passes are required, to consider alternative formulations. It was felt, however, that in many cases the initial error may create spurious additional loop conditions, and thus, it is appropriate to display the status of the graph and the element set for examination by the user before proceeding. At the unsuccessful termination of the algorithm, the list of the nodes which have been candidates for assignment, but for which no assignment has been made, indicates the components of the loops.

The element set defined in Tables B.4 and B.5 results in a successful graph in which all nodes are assigned. The resulting structure is depicted in Figure B.1.

Figure B.1 Subgraph Emanating From GRAY

The effect of the pre-assigned level, Dark, can be seen in the placement of node BROWN. The natural position of BROWN would have been one level removed from LT. BLUE on the same level with ORANGE. However, its association through attribute identification with a pre-assigned level, Dark, alters the structure of the network. The assignment of GOLD to the level preceding ORANGE represents the only change in the initial level assignments.

APPENDIX C

GRAPHICAL DISPLAY

The Flow Graph Generator functions as a pre-processor for the actual simulation in which the material flows are determined and the energy conserving technologies evaluated. The Simulation Scheduler may require only that the particular representation of the physical system under study be expressed as a network with a clear indication of the order of processing through the system and the relative location of nodes and interconnecting links by which the network is traversed. However, information structured in a convenient way for the computer may not meet the needs of the user. Since the flow graphs are drawn from a data base of information either input directly or derived through aggregation, it is difficult for the user to feel confident that the network which has been created accurately reflects his intention. The importance of a visual network as an aid to the user in data verification has been stressed as one of the key motivations in the augmentation of the Flow Graph Generator to include a graphical display [10]. An additional benefit is the potential use of such a representation for analysis of the structural impact of the introduction of new technologies.

The graphics package selected is called DISSPLA (Display Integrated Software System and Plotting Language [30], which is a proprietary software product of Integrated Software Systems Corporation (ISSCO). DISSPLA is a system of interrelated FORTRAN subroutines which, from the point of view of the user, is largely machine independent. It was selected because of its flexibility in terms of graphical output devices to be used (i.e., CRT, paper plotter, microfilm, etc.), sizing of the graph and manipulation of the axes, specification of vectors, rotation of titles, selection and creation of symbols, and choice of alphabets for printed information. The communication between ALINET and the graphics package to obtain vectors with arrow heads to denote directed links, rectangles within which the six character node labels can be printed, and the upper and lower case alphabet for labels and titles is accomplished with a simple set of instructions.

Software has been created which permits the drawing of two graphs from the same network representation, designated for convenience "first pass" and "second pass". The first step in both cases is the assignment of the same value on the

abscissa to all nodes on a given level, advancing from left to right in the order determined by the Flow Graph Generator. Within each level, the nodes assigned to it are evenly spaced, thus creating node locations along a sequence on vertical lines. Depending on the relative position of the nodes on a given level, as well as the absolute position of nodes within the graph, lines may cross as the lines connecting two nodes are drawn. The simple procedures implemented as part of the original graphics software to reduce crossings and possible confusion of link labels have been described previously in [10]; only the current, augmented techniques will be presented in the sections that follow.

Once the first pass, using uniform spacing, has been completed, the graph can be studied by the user. Such a display meets the needs for determining the accuracy of the network representation and therefore no further action may be taken. However, viewed in this form, the desired visual structure and symmetries of the network may not be immediately evident and the aesthetic appearance of the graph may not be satisfactory to the user as a permanent record. It may then be appropriate to make a second pass using simple adjustments to alter the spacing of the graph, thus allowing the desired visual structure to emerge. Algorithms may be developed to reposition the nodes based on criteria of minimizing the angles and the number of link crossings. However, such algorithms require considerable development effort to implement and computer resources to execute for a complex sector. It was determined, therefore, that the most effective technique for achieving the desired spacing was to allow the intervention of the user. Using simple instructions, he may be permitted both the shifting of groups of nodes in terms of percentage of vertical line to be spanned by the group as well as simple adjustments to the order of nodes within a given level. A portion of the computer generated graph of a highly aggregated flow graph of the Dairy Sector is depicted in Figure C.1 to indicate the capabilities of the system as originally envisioned [10].

As the development of the ALINET computer system continued, a departure from the angular link representation as depicted, for example in link LD33 labeled "mixing" (from D23, manufacturing grade, pasteurized milk at the plant, to D31, manufacturing grade, ice cream mixture at the plant) was indicated.

THE DAIRY INDUSTRY

Figure C.1 Part of the Dairy Sector

The nature of the more complex networks under study, with an arbitrary number of alternative technologies (or links between any two nodes) and the complex interconnections between subgraphs representing the interstate transfer of materials, provided the guidelines for the modification to the graphical algorithms.

The original notion of uniform spacing for node levels along the abscissa was retained. However, the angular representation for the link vectors was replaced by a representation with a horizontal segment containing the link label designed to improve legibility. The general format is illustrated by a segment abstracted from the national durum graph depicting the blending of various durum and hard wheat flours at the pasta plant into flour suitable for pasta manufacture (Figure C.2). This segment illustrates the simplest example in which single links provide the interconnection between two nodes and span only a single level.

The positions of the nodes and link segments are determined, in general, by considering the entire physical graph to be superimposed upon a grid of evenly spaced slots, both for nodes and links along the vertical level lines, and for links traversing the space between levels. The slots assigned to nodes initially, then, are those which most closely retain the desired spacing; the remaining slots can be allocated to links crossing multiple levels. Once the node positions have been determined, either according to the uniform spacing rule, or the revised spacing requested by the user, the determination of the positions of the links is made.

The first step is to identify all instances of alternative processes (multiple links between two nodes) existing within the graph. These are then grouped together and treated as a block with single vectors providing the connections between the edges of the block and the origin and destination nodes. The use of such a block depicting the five alternative transportation processes for transporting durum grain from the terminal elevator (W17) to the mill (W23) is presented in Figure C.3 (a segment of the national durum graph). The advantages of this representation are apparent in that

Figure C.2 Portion of the National Durum Graph
Depicting Links Spanning Single Level.

Figure C.3 Alternative Processes Between Two Nodes.

it not only permits the easy visual association of these alternatives, but also eliminates the lines which would otherwise be required to represent the continuation of these individual links on either side of the block.

The positions of the blocks within the graph are determined before any single links are considered, regardless of how long such single links might be. The algorithm for allocating slots on the graph for links within link blocks begins with the following simple rules. All blocks are placed to the extent possible, between the level on which the origin node is drawn and the one immediately following it, regardless of the level assigned to the destination node. A desired location for the center of the rectangular block is halfway between the node end points:

$$y_{\text{desired}} = .5(y_{\text{origin}} + y_{\text{destination}})$$

The list of blocks to be drawn between any two levels is then sorted in descending order according to y_{desired} ; subject to the condition that if the same location is desired for several blocks an additional sort is performed on the number of links in a block (also in descending order). The ordered list acts as a set of requests for link slots to be allocated within a particular interlevel space. The allocation algorithm begins with a check for feasibility by comparing the total number of slots requested, plus an inter-block gap of three slots, against the total number available. Since the number of available slots is large, this test is considered a formality. Initial assignments are then made, beginning with the bottom of the request list (the block with the smallest value of y_{desired}). The assignments are made upward through the list, as close as possible to the slot corresponding to y_{desired} , constrained by previous assignments and the inter-block gap.

For example, a measure of the visual impact of a given allocation could be constructed as follows:

$$M = \sum \left| (y_{\text{desired}_i} - y_{\text{assigned}_i}) \right|$$

$i = 1, \text{ number of blocks}$

with a good visual impact postulated to result from the allocation with the smallest value of M . In the event that the initial allocation does not satisfy all requests ($M = \infty$), a simple search procedure is instituted which perturbs the allocation by 1 slot, first for each block individually (no effect for the first iteration after the initial allocation), then for pairs of blocks, to see if the value of M can be reduced.

The results of such an allocation can be seen in the segment abstracted from the hard wheat graph depicting the movement of hard red spring and winter wheat grain (nodes W170 and W171) to subterminal elevators (nodes W172 and W173) (Figure C.4).

Once a desired allocation for all blocks has been determined, the allocation of slots for the remaining single links can begin from the left hand edge of the flow graph. Of the links remaining, those connecting nodes on two consecutive levels are positioned first. The desired location for the link is computed in the same fashion as the center of a block. An expanding search is made first below, then above y_{desired} until a vacant slot is located for the link. Links crossing multiple levels, including those that may be introduced from the right hand edge of a block to the destination node, are treated in a similar manner. Processing proceeds from left to right with each link creating a desired allocation from source to destination nodes across multiple levels. Three search areas are defined, one centered with the same y_{desired} as a single $y_{\text{desired}} = y_{\text{destination}}$. Each search results in a list of tentative positions for the link segments, indicating the sequence of slots desired from origin to destination. A single sequence of slots is selected which, if connected, is closest to a straight line. The final allocation, including node positions and link block locations is converted to a sequence of vectors, rectangles and labels for transmission to the graphics package which draws the actual plots.

Figure C.4 Assignment of Multiple Blocks.
(Hard Wheat National Graph)

APPENDIX D

FACILITY DATA DEFINITION

The first step in establishing a set of tools for manipulating the facility level data and integrating it into the ALINET Data System was the design of a general data structure in an appropriate format. The items considered significant for future use in dealing with both mills and elevators were specified and are depicted in the data structure presented in Figure D.1. At the top of this structure are those data items that take on a single value for each facility (e.g. qualifier = durum, facility type = mill). A second structural level is reserved for expandable lists of services, transportation modes, storage and throughput capacity types, etc. in which multiple entries may be required to characterize a single facility. Reference specifications are included at this second level, since it is anticipated that secondary references may be required to document the full facility description. The incorporation of and requirement for documentation codes as part of the computerized data bank establishes a framework for insuring the credibility of data developed from the raw information and for tracing seemingly unexpected conclusions.

The entry of a given facility into the data base is supported by completion of a specially designed facility form. The forms contain information deemed appropriate for each individual facility type, and provide both a reference number by which a particular facility may be identified in the future and a permanent record of any modifications made to the data as published, the date of the information, as well as its source. The top half of the form allows for comments, copies of published data and miscellaneous notes for clarification, while the bottom half of the form is structured in such a way as to permit direct data entry into the computer. Sample forms for a wheat flour mill in Kansas appear as Table D.1 and a Missouri terminal elevator in Table D.2. The facility ID is a six character alphanumeric code, created according to the general specification Mxxxxx for Mills Exxxxx for elevators. Modifications to this format (e.g., BMxxxx for bulgur mills; PExxxx for port elevators) are also acceptable. Qualifiers for the two facility types implemented thus far are given in Table D.3. In preparing the mill form, the primary storage capacity and other storage capacity are given directly as shown, converted to million bushels and entered in the appropriate location on the mill form. The mill throughput capacity is a derived

Figure D.1. Facility Data Structure.

TABLE D.1 FACILITY FORM FOR A WHEAT FLOUR MILL IN KANSAS

Facility Form - Mills

ID	NAME	CITY	STATE
M63	ROSS INDUSTRIES, INC.	WICHITA	KS

RAW DATA:

COMMENTS:

Note: Modification to
1977 form

*ROSS INDUSTRIES, INC.
(Department of Cargill, Inc.)
715 E. 13th St. P.O. Box 2696. Zip 67201. Phone (316)
267-6281.
Superintendent—Donald N. King
Elevator superintendent—Al Scholl
Capacity: wheat flour 18,000 cwt; storage 2,500,000
bus; other storage 8,000,000 bus.
Brands: see corporate listing.

PROCESSING NOTES:

FOOTNOTES: [Manager]: Grain may be received from North Dakota or Minnesota to provide a winter/spring blend with the Kansas Hard Red Winter. Grain is not received from the south (Texas etc.)
In 1977, 4800 cwt SWF capacity was indicated out of a total of 15060 cwt. [ ] stated that, currently, no soft wheat is milled.

ID M63	# 1	NAME ROSS INDUSTRIES, INC		CITY WICHITA	STATE KS	YEAR OF DATA 78	CHANGE FLAG 1
ID M63	2	QUALIFIER WHEAT FLOUR	FACILITY TYPE MILL	PRIMARY CAPACITY 2.5	OTHER CAPACITY 8.	UNITS OF CAPACITY MBU	
ID M63	3	THROUGHPUT				UNITS CWT/DAY	
		WHOLE GRAIN	FLOUR 18000.	SOFT	SOFT/HARD		
		HARD/WHOLE	SOFT/WHOLE	HARD/DURUM	HARD/SOFT DURUM		
ID M63	4	TECHNOLOGY	DATE	REFERENCE JM03	PAGE 33		
			PHASE IN	PHASE OUT			

TABLE D.2 FACILITY FORM FOR A TERMINAL ELEVATOR IN MISSOURI

Facility Form - Elevator

ID	NAME	CITY	STATE
E213	Fowles Grain Co.	St. Louis	Mo.

RAW DATA:

COMMENTS:

FOWLES GRAIN CO.
(Missouri Pacific Elevator)
7900 Van Duren, Zip 63111. Phone (314)
638-1447.

President—Jerry W. Fowles
Superintendent—Timothy Armistead
General Manager—PAUL BOETTCHER
Storage capacity: 4,000,000 bus upright. Li-
cense: Federal. Railroad service: MP. Re-
ceiving: Rail, truck, barge. Loading: Rail,
truck, barge. Services: Drying, cleaning.

PROCESSING NOTES:

FOOTNOTES: Contact: [ ] indicates barge receipts are from
Minneapolis area. Terminal acts as holding storage for large
milling companies who bring grain down the Mississippi River
while the upper river area is navigable. Rail and truck shipments
are received from country elevators.

ID	#	NAME	CITY	STATE	YEAR OF DATA	CHANGE FLAG				
E213	1	FOWLES GRAIN Co	ST. LOUIS	MO	77					
ID	2	QUALIFIER	FACILITY TYPE	CAPACITY- UPRIGHT	CAPACITY- HORIZONTAL	UNIT OF CAPACITY				
E213		TERM	EL	4.		MBU				
ID	3	RECEIVING				LOADING				
E213		RAIL	TRUCK	BARGE	LAKE	RAIL	TRUCK	BARGE	LAKE	OCEAN
		X	X	X		X	X	X		
		SERVICE								
		SAMPLING	SCALPING	DRYING	CLEANING	BAGGING	FUMIGATING			
				X	X					
ID	4	DATE			REFERENCE	PAGE				
E213		PHASE IN			PHASE OUT	JM02	180			

quantity subject to the following definitions: "whole grain" capacity is reserved for whole wheat grind or, when appropriate, for rye, soy, buckwheat, or dry corn processing. "Flour" refers to capacity for milling either hard wheat flour or durum products, while "soft" denotes soft wheat flour production. Many mills can use the facilities for different grinds depending on the demand or economic conditions, thus the indications of alternating capacity - soft/hard, hard/whole, soft/whole, hard/durum, hard/soft/durum - reflect the published combinations. In general, the capacity given in cwt/day can be interpreted as follows.* A published capacity as "wheat flour 1700 cwts (includes 800 cwt SWF and 100 cwt WWF)" for Southeastern mills in Georgia is interpreted to be 100 cwt whole grain, 800 hard wheat flour, and 800 soft wheat flour. The technology indicator is reserved for the process technology name (e.g., "impact") when available and phase in/phase out dates are provided to indicate construction of new capacity or retiring of old.

TABLE D.3 FACILITY QUALIFIERS

MILLS	ELEVATORS
Wheat Flour	Terminal
Bulgur	Port
Durum	
Rye	
Soy	
Buckwheat	
Dry Corn	

Elevator forms are prepared in a similar manner, with the distinction made between upright and horizontal storage capacity. Since the grain transportation network is of interest, modes of receiving (e.g., rail, truck, barge and lake) and shipping (e.g., rail, truck, barge, lake, and ocean) are maintained as separate lists. Indication of the services provided by each facility was also considered important and thus included explicitly. To date, six have been identified from the available data - sampling, scalping, drying, cleaning, bagging and

* Personal Communication, *Milling and Baking News* (Gordon Davidson, 10/78)

fumigating.

Once the information has been prepared for the computer, it can be passed through routines which expand the indications of transportation and services (shown with an "X") into descriptive terms ("BARGE", "RAIL", etc.) and, at the same time, associate capacity types with the appropriate descriptors before checking the data for completeness and entering the data in the data base. Additional verification can be performed using simple data access and tally commands directly from the System 2000 data management software to count data items, and display them according to various criteria.

APPENDIX E DATA CONSISTENCY

As indicated in Section IV, one of the consistency checks that results from the aggregation procedure is the identification of unsupported aggregate nodes. The results of such a request executed in the process of maintaining the ALINET data base is depicted in Table E.1. The annotations indicate the action to be taken (i.e., retain or delete) with respect to maintenance of the data base. Eleven of the twelve soft wheat nodes are retained for convenience. Their relevance will be monitored as the soft wheat networks are developed. Other soft wheat nodes, already included as required during the development of the hard wheat networks (i.e., soft wheat flours for blends) have been justified for inclusion in the national aggregate graph. Those remaining relate primarily to specific soft wheat activities - the milling of soft wheat and production of cakes and cake flour. Two other set of nodes

TABLE E.1 AGGREGATE NODES NO LONGER JUSTIFIABLE FROM EXISTING STATE NODES *

NODES WITH THE FOLLOWING DEFINITIONS CANNOT BE SUBSTANTIATED FROM THE EXISTING DATA BASE							
NODE NAME	TYPE	COMMOD	QUALI	FORM	LOCAT	ENDUSE	ACTION TAKEN
W1	SOFT	W	UNDRD3	---	FARMS	---	Retain
W164	---	W	PKGD3	GERM4	DSTRB5	OWHT6	Retain
W75	---	W	PKGD3	GERM4	PROCS5	OWHT6	Retain
W161	---	W	PKCSD3	GERM4	PROCS5	OWHT6	Retain
W160	---	W	- NA -	GERM4	PROCS5	OWHT6	Retain
W180	HARD	W	- NA -	BLGR4	RETLR5	OWHT6	Retain
W179	HARD	W	SACK3	BLGR4	DSTRB5	OWHT6	Retain
W93	---	W	PKGD3	GERM4	RETLR5	OWHT6	Retain
W85	SOFT	W	PKGD3	CAKES4	RETLR5	OWHT6	Retain
W84	SOFT	W	PKGD3	CKFLR4	RETLR5	OWHT6	Retain
W80	SOFT	W	SACK3	ROLLD4	PORT5	EXPRT6	Delete
W66	SOFT	W	PKGD3	CAKES4	BKRY5	OWHT6	Retain
W65	SOFT	W	PKGD3	CKFLR4	MILL5	OWHT6	Retain
W52	SOFT	W	---	CAKES4	BKRY5	OWHT6	Retain
W46	SOFT	W	BAKER3	CKFLR4	BKRY5	OWHT6	Retain
W36	SOFT	W	BAKER3	CKFLR4	MILL5	OWHT6	Retain
W35	SOFT	W	---	CKFLR4	MILL5	OWHT6	Retain
W19	SOFT	W	MKTGD3	---	MILL5	DOMST6	Retain
W15	SOFT	W	MKTGD3	---	---	DOMST6	Retain

*Computer Generated, ALINET Data System.

indicate that certain small portions of the network have yet to be established within specific states - the processing and packaging of wheat germ by the processor (W161, and W75, respectively), its shipment to the distributor (W164) and from there to the retailer (W93). The existence of a second small portion of the overall network, yet to be established, is inferred from the list - the transfer of processed bulgur beyond the mill to the distributor (W179) or retailer. These nodes are retained in this list since it is conjectured that these functions are performed - even though precise identification of the appropriate channels has not yet been made. Node W80 has been deleted, since it is unlikely that the export of sacked, rolled wheat made exclusively from soft wheat will be considered.

As the number of state level nodes in the data base increases, the chances of introducing a legitimate new node type into the aggregate picture with the definition of additional state graphs becomes smaller. Therefore, as the aggregate graphs become more complete, the list of new nodes created in response to entries in the justification set is also smaller. It becomes easier to illustrate the use of these lists as a data validation aid with the following small set of nodes created and depicted in Table E.2. In each case, the intention had been to define a node with similar attributes to nodes in surrounding states. These individual state nodes, due to errors in specification, appeared in a different justification set than intended, and thereby created a national node with almost the same characteristics as another. Node W188T represents the only legitimate node created within this aggregation run, as is apparent from the long list of states in the justification set. The node identifier is changed accordingly from W188T to W188 as it becomes a permanent part of the data base. At first, the format of these tables may seem awkward for the user. His natural preference for the more readable expanded form of the node definition as depicted in Table 4.10 (i.e., WMN3: Wheat, Durum--undried Grain at the farm in Minnesota for unspecified use) is understandable. However, for purposes of data verification, the usefulness of the encoded format in permitting a quick comparison between similar definitions is apparent.

Consider the two aggregate node definitions as shown in Table E.3 - the first taken from the list of nodes already justified by state data, and the

other from the list of new nodes created and presented in Table E.2. Both definitions represent patent flour at the mill made from hard wheat; however, they are differentiated by the specification of the end use. The designation of the end use "for bread" (which denotes domestic consumption only) for node W110T, derived from the Kansas node definition, was determined to be too restrictive. Such a definition would have prevented the export of patent flour, for example. The definition of the Kansas node was modified to reflect an unspecified use, which eliminated node W110T and grouped Kansas in the justification set for node W110.

TABLE E.2 AGGREGATE NODES DEFINED ON THE BASIS OF NEW ENTRIES OF STATE DATA

NODES WITH THE FOLLOWING DEFINITIONS HAVE BEEN CREATED FROM STATE DATA *							
NODE NAME	TYPE	COMMOD	QUALI	FORM	LOCAT	ENDUSE	STATES
W31 T	DURUM	W	- NA -	FLOUR4	MILLS	DOMST6	ND
W108 T	HARD	W	- NA -	FLOUR4	MILLS	---	MO
W47 T	SOHD	W	- NA -	PRPMX4	BKRY5	OWHT6	MN
W98 T	HARD	W	DRIED3	---	MILLS	WASTE6	NE
W21 T	HARD	W	MKTGD3	---	MILLS	DOMST6	MO
W110 T	HARD	W	- NA -	PTFLR4	MILLS	BREAD6	KS
W140 T	DURUM	W	- NA -	SEMOL4	MILLS	DOMST6	ND
W141 T	DURUM	W	- NA -	GRANL4	MILLS	DOMST6	ND
W188 T	HARD	W	PKCD3	WWBRD4	BKRY5	BREAD6	MN IA NE ND MO KS SD

*Computer Generated, ALINET Data System.

TABLE E.3 ATTRIBUTES AND JUSTIFICATION SET FOR TWO SIMILAR AGGREGATE NODES

CODE NAME	TYPE	COMMODITY	QUALIFIER	FORM	LOCATION	ENDUSE	STATE
W110	HARD	W	- NA -	PTFLR4	MILLS	---	ND MN IA MO NE SD
W110T	HARD	W	- NA -	PTFLR4	MILLS	BREAD6	KS

TABLE E.4 LINKS CREATED ON THE BASIS OF STATE LINKS

LINKS	STRUCTURE	ATTRIBUTES						STATE LINKS
		TYPE	COMMOD	QUALIF	FORM	LOCAT	END USE	
L1 TRUCKING	FROM W71 TO W191	HARD HARD	W W	PKGD3 PKGD3	APFLR4 APFLR4	FFPP5 DSTRB5	BREAD6 BREAD6	LW816
L2 RAIL, BARGE	FROM W60 TO W79	HARD HARD	W W	SACK3 SACK3	BLGR4 BLGR4	BLGM5 PORT5	--- EXPRT6	LWR55
L3 BAKING	FROM W127 TO W189	HARD HARD	W W	-NA- PKGD3	WWFLR4 WWBRD4	BKRY5 PETLR5	BREAD6 BREAD6	LW3123
L4 TRUCKING	FROM W72 TO W190	HARD HARD	W W	PKGD3 PKGD3	WWFLR4 WWFLR4	FFPP5 DSTRB5	BREAD6 BREAD6	LW811
L5 BARGING	FROM W170 TO W172	HRS HRS	W W	SOLD3 MKTGD3	---	COELV5 SUBEL5	---	LW2720
L6 RAIL TRANSF	FROM W171 TO W22	HRW HARD	W W	SOLD3 MKTGD3	---	COELV5 CRMNF5	---	LW1137
L7 TRUCKING	FROM W171 TO W22	HRW HARD	W W	SOLD3 MKTGD3	---	COELV5 CRMNF5	---	LW1136
L8 BARGING	FROM W171 TO W173	HRW HRW	W W	SOLD3 MKTGD3	---	COELV5 SUBEL5	---	LW2733
L9 DRY CLEANING	FROM W100 TO W182	HARD HARD	W W	BLEND3 -NA-	---	MILL5 WGRD5	---	LW1342
L10 MOVING	FROM W17 TO W23	DURUM DURUM	W W	SOLD3 MKTGD3	---	TRMEL5 MILL5	---	LW917
L11 MOVING	FROM W176 TO W21	HARD HARD	W W	SOLD3 MKTGD3	---	TRMEL5 MILL5	---	LW2514
L12 RAIL, BARGE	FROM W176 TO W78	HARD HARD	W W	SOLD3 MKTGD3	---	TRMEL5 PORT5	---	LW1025
L13 RAIL, BARGE	FROM W176 TO W78	HARD HARD	W W	SOLD3 MKTGD3	---	TRMEL5 PORT5	---	LW722

*Source, ALINET Data System

Similar corrections result from the examination of the link aggregation output. Examples of the most common errors are seen in this list which is presented as Table E.4. Link 9, transforming "blended hard wheat grain at the mill for unspecified use" (node W100) to "hard whole wheat middlings at whole grain reduction rolls for bread" (node W182) via the process of dry cleaning, is clearly inconsistent. The proper result of this transformation which cleans and separates waste from the grain should have resulted in one of two states - "hard wheat dry cleaned grain at the mill for unspecified use" (node W101) or "hard wheat fine impurities at the mill for waste" (W102). Examination of the data indicated that the aggregate end point of link LW1342, which caused the generation of Link 9, should have been node WMN102 - a node with the attributes of node W102 as described above. Similar results are

seen from the specification of inconsistent process names. Consideration of Link 12, with process identifier "RAIL BARGE", and Link 13 with identifier "RAIL, BARGE", reveals the deviation from the more standard format by which this transportation process is referenced - "BARGE, RAIL". A single link replaces these two when the process identifiers of Links LW1025 and LW722 (the links in the justification sets for Links 9 and 10) are modified.