

# USING SYSTEM DYNAMICS AND 3-DIMENSIONAL VISUALIZATION TO EXPLORE THE DYNAMICS OF FUTURE GLOBAL PROTEIN CONSUMPTION

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## ***Abstract***

*Strategic decision making is particularly difficult relative to research investments, where the uncertainty inherent in research and lengthy time lags requires investments to be made far before outcomes are known. This paper reports upon the development and evaluation of the Protein Consumption Dynamics (PCD) system, a tool created to assist managers to improve their perspective of future protein needs. This research effort was funded by the Illinois Soybean Checkoff Board to aid them in strategic allocation of research funds.*

*The PCD system includes a Powersim model, the output of which is displayed using a 3-dimensional visualization software package, In3D. The system dynamics model component relates population and income growth to regional protein needs and malnutrition. The model tracks estimated consumption annually (for the years 2001 to 2025) of six agricultural commodities that serve as sources of protein for humans in eight regions that encompass the world. The system dynamics model is designed so that alternative scenarios of the future can be examined using population and income projections of the World Bank and the UN's Food and Agricultural Organization.*

*The output of the system dynamics model is displayed using 3-dimensional visualization techniques. The visualization component was developed in collaboration with design experts from the National Center for Supercomputing Applications at the University of Illinois.*

*Through formal experiments with actual manager in the soybean sector, the effects of use of the PCD system are being formally evaluated. This evaluation documents the effects of scenario modeling and visualization on individual and group decision-making processes.*

## **Introduction**

Strategic decision making is particularly difficult relative to research investments, where the uncertainty inherent in research and lengthy time lags requires investments to be made far before outcomes are known. This paper reports upon the development and evaluation of the Protein Consumption Dynamics (PCD) system, a tool created to assist managers to improve their perspective of future protein needs. This research effort was funded by the Illinois Soybean Checkoff Board to aid them in strategic allocation of research funds.

Daellenbach (1994) identifies several factors that contribute to today's complex environment including rapid technological advances, information explosion, and the widening gap between the developed and underdeveloped countries of the world. Nowhere is this more apparent than in the agricultural sector. The seasonal dimension of agriculture means the results of decisions made today regarding planting and chemical applications often take months to materialize. Likewise, decisions related to investments, market development, and agri-chemical research can take years, or even decades, to yield results. Other factors that contribute to complexity in agriculture include demographic issues (poverty, high population growth, and income growth rates), dietary and consumer preference changes, government action, agricultural research, land use, and climatic changes (Pinstrup-Andersen & Pandya-Lorch 1998).

The Illinois soybean industry continually grapples with such complexity. The Illinois Soybean Program Operating Board (ISPOB) is a public sector organization, which invests in soybean research and market development for Illinois soybean producers. As such the Board faces many similar challenges of a private firm regarding technological innovation decisions. However, as a public entity, ISPOB must also answer to the producers (stakeholders) it is designed to serve. This includes educating producers regarding the appropriateness and applicability of ISPOB research and marketing activities. Membership of the ISPOB is elected and voluntary. Thus the group faces problems inherent to any organization in terms of decision making and learning, but the situation is exacerbated by the turnover and pluralism inherent in the organizational structure.

The long-run future of the soybean sector is very promising. However the current actions of the industry's decision makers will determine the nature of that future. Through the use of scenarios, this sophisticated modeling tool assists decision makers to focus on and better anticipate the future. The ultimate goal of the research is to improve decision makers' confidence about where to invest research dollars so as to positively affect future success.

This research focuses on how decision support systems can alter perceptions of the decision making environment in the soybean industry. The research investigates whether group decision making processes, namely those of the ISPOB, can be improved by using computerized decision aids. To do so the study examines the decision makers' cognitive maps (or perceptions) of the decision environment.

A system dynamics model of global human protein consumption dynamics is the basis for the project. The uncertain time paths for consumption of protein from animal and vegetable sources in diets around the world are a cause of decision ambiguity for the soy value chain today. The model allows decision makers to explore how consumption plays out on uncertain futures given alternative scenarios of income and population growth over the span of the simulation. Sophisticated three-dimensional visualization techniques are used to communicate the model output to decision makers.

The remainder of this paper addresses the research question, theoretical background, visualization model, data collection experiment, and preliminary results.

## **Research Question**

The primary research question of this study centers on how to assist decision makers to improve strategic decision making. If we are able to broaden their perspective to include a more global and long-term outlook, then the quality of their decision making should be enhanced. Thus, the visualization model that is a part of this research, is designed to impact strategic decision making. Decisions are based on many things, one of which is the decision maker's perception (cognitive map) of the decision environment. A goal of this research is to measure the effectiveness of improved understanding and decision making by exploring how the visualization model changes the cognitive maps of various soy industry decision makers.

## **Theoretical Background**

This research draws on a number of different literature streams. The study of decision making has been central to several fields including economics, anthropology, psychology, computer science and management. Cognitive maps, or perceptions, are an integral part of strategic decision making. Scenarios help decision maker's comprehend the complexity of their environment. Visualization, then, transforms a multitude of data into information that is easily utilized by decision makers. Thus, individual learning can take place through the use of scenarios and visualization. The remainder of the section discusses each of these concepts as they relate to this study.

Psychology and organizational behavior scientists struggle with how to measure the decision making process. One important facet of the process is the decision maker's cognitive map (perception) of their problem environment (Huff 1990). Cognitive maps help decision makers organize the over abundance of information to which they are exposed. The cognitive processes associated with strategy formation (and decision making) are based on maps that individuals have of the world around them. These maps can represent the individual's interpretations about the world (Mintzberg et al, 1998).

Mason (1994) asserts that "[a] critical task of planning is to provide tools that adjust managers' [cognitive maps] to reflect the rapid changes in their competitive environment," (p. 7). Cognitive maps based on outdated information result in bad decision making and focus attention away from important causal relationships. By making cognitive maps explicit, one can identify gaps as well as key variables. Thus cognitive maps help structure and resolve problems, sometimes in a creative manner. This research examines how cognitive maps change as the result of exposure to a visualization model designed to highlight the relationships between key variables and make explicit the complexity of the decision environment.

While system dynamics research professes to change mental models, these changes are generally measured using self-assessment surveys. This type of self-evaluation of cognitive changes can be problematic due to the participant's lack of understanding of how he/she has been influenced. Providing the participant with sufficient detail to understand the experiment, however, may result in subject biases from knowing too much about the studied behavior (Doyle 1997:256). Cognitive psychology offers techniques to accurately measuring these changes. Doyle posits that system dynamics intervention evaluation can gain from the controlled experimentation techniques of cognitive psychology, specifically, the use of "pre- and post-measurements of cognitive processes and mental models," (p. 256). This research uses pre and post questionnaires to assess the changes in mental models of soybean industry decision makers.

Cognitive maps change through learning (Sterman 1994). However, according to Argyris (1994), organizations in and of themselves do not learn. Learning takes place at the individual level. An organization learns either through the learning of its individual members or through acquiring new individuals with knowledge beyond that already within the organization, (Sonka et al 1995 point to Simon). Because of bounded rationality (or limits on cognitive capacity), models and scenarios are needed to help decision makers narrow the scope and therefore better comprehend the complexity of their environment.

Scenario analysis differs from other forecasting in that it is more descriptive, qualitative and contextual; and that it identifies plausible possible futures. “Scenarios also provide a common means for everyone in the company to think about the future that takes into account many uncertain factors (some of which are qualitative) in a flexible, although estimative, way,” (Mason, 1994:66). By focusing on only a small number of potential futures, decision makers will be able to more fully explore the implications of decisions they make today in relationship to these various futures scenarios.

Richardson (1996) identifies several issues for future system dynamics research. Those relevant to this paper include understanding model behavior and widening the base of system thinking in other fields. He suggests the development of computer-based tools that facilitate “understanding the connections between model structure and behavior,” (p. 142).

Visualization enables understanding and communicating research results to other researchers and the general public. It helps shape public policy by improving understanding regarding potential outcomes and the relationships between multiple variables (Orland et al, 1997). “Visualization—combining computer graphics, computation, communication, and interaction—is invaluable for changing data into information, designing products and supporting complex decision making,” (Brown 1997:1; also see Rheingans & Landreth 1995).

The three-dimensional representation of important variables is one way to emphasize the relationship between actions and future consequences, and to illustrate the lack of effects that exogenous factors have on the system. This combination of the power of system dynamics and visualization should aid in understanding the interrelationships of the simulation model variables (Richardson 1996). The three-dimensional representation highlights the relationships between several variables simultaneously. The understanding gained from seeing the interrelationships among variables will enable soybean decision makers to more fully comprehend their environment.

The multidisciplinary nature of this study makes it difficult to know the variables and theories related to the analysis a priori, therefore a qualitative research methodology is used. Qualitative research exhibits the following characteristics:

1. Data source is in a natural setting with the researcher as the key instrument
2. The research is descriptive in nature
3. Process is more important than outcome or product
4. Induction is used to analyze the data
5. Major focus is on meaning or participant perspective (Bogdan & Biklen, 1992)

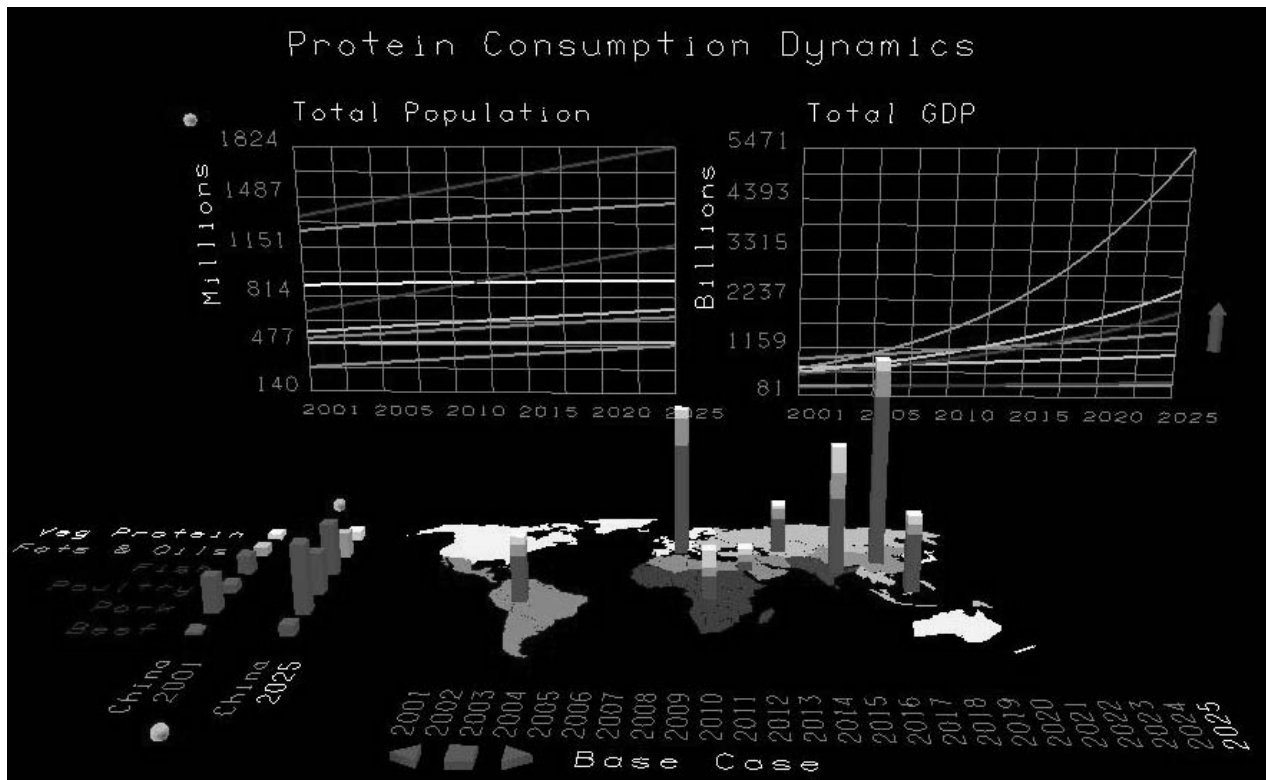
Accordingly, this research describes how the cognitive maps of soy industry decision makers are influenced with the use of sophisticated visualization of information (2). It is concerned with the nature of these decision makers’ perceptions (5), which are captured during interaction with subjects (1). Content analysis (4) is used to evaluate the changes in perceptions (3).

## Visualization Model

Visualization provides a sophisticated means of characterizing information to enable decision makers to more easily perceive the interrelationships between the model drivers, and the resulting appetite for the various commodities. The system dynamics model component of this research (the model underlying the visualization) relates population and income growth to regional protein needs and malnutrition. The model tracks estimated human consumption (potential demand) annually from 2001 to 2025, for six agricultural commodities (beef, fish, pork, poultry, fats & oils, and vegetable protein) in eight regions that encompass the world. Population and income growth information are based on secondary data taken from the World Bank and the United Nations Food and Agriculture Organization. The visualization makes it easier to see and understand the interrelationships between the variables in this multitude of information (8 regions x 4 scenarios x 25 years x 6 commodities x income x population). The understanding gained from seeing the interrelationships among variables will enable soybean decision makers to more fully comprehend their environment.<sup>ii</sup>

Figure 1 is a photograph of the visualization model. Regional population and GDP totals are positioned on the back wall of the visualization. Each color-coded region on the floor of the visualization contains a tri-colored bar which represents the (potential) demand for the various commodity groups. As the model animates through time the bars change to reflect how different population and income growth scenarios affect potential demand on a region-by-region basis. The visualization also allows for the commodity groups to be explored in more detail (the area on the left).

Figure 1. Protein Consumption Dynamics Model



## Experimentation

The experimentation using the visualization model is conducted with soy industry decision makers. Following Doyle's suggestion (1998), data are collected through *before* and *after* questionnaires that elicit the strategic issues map from participants. Subjects also engage in a group discussion regarding what they have learned from the exercise. The discussion takes place following the second questionnaire.

Model exposure is a scripted exercise focused on learning from the future that encourages participants to think about the key factors influencing their industry. Content analysis software (Nud\*ist VIVO) is used to evaluate variations between the *before* and *after* questionnaires. The analysis looks at how the individual's maps change, as well as how maps within and between groups change. Transcripts of the group discussions are also analyzed.

Following Creswell (1994), we are more concerned in this study with expert perceptions than in statistical accuracy. Therefore, the experimentation is with a number of hand-selected subjects who have special knowledge of key issues within the soybean industry. The subjects received a treatment that combines the tabular and visualized information.

The *before* questionnaire contains 4 questions. Question 1 asks for questions the respondents have regarding the future of the industry. Question 2 asks for the key issues to be worked on in the industry. In addition, both of these questions contain a part 'b' which asks the respondents to provide a ranking of his/her responses. Question 3 requires the respondent to make an explicit decision regarding research funds allocation, (similar to Wilson, et al's [1989] on-line judgment). Question 4 asks for a self-evaluation of how confident the respondent is about the previous decision. The questionnaires are number identified for internal tracking purposes, with the *before* and *after* questionnaires having the same id number for a given subject.

The *after* questionnaire has the same questions 1, 2 and 3. Question 4 solicits the decision criteria that influenced the previous decision (following Wilson et al, 1989). Question 5 of the *after* questionnaire is identical to Question 4 on the *before* questionnaire. Finally, a few demographics are collected.

Three pretests were conducted—one to test the questionnaire, one to test the exercise methodology, and then a final test of both the methodology and the questionnaire. The first pretest was with the Executive Veterinary Medicine Program, of the University of Illinois, Urbana-Champaign. The 29 subjects were Midwest veterinarians involved in the swine industry. The pretest indicated that there were too many open-ended questions. In addition, the process needed to give something back to participants. The second pretest was conducted with the Illinois Soy Leaders group. The ten subjects were producers, processors, and personnel involved in the soy industry. This pretest looked at the experimental exercise process. While no data were collected via questionnaire, there was positive anecdotal evidence that the subjects benefited from the group discussions of the experimentation process. The final pretest was conducted with three faculty members from the College of Agricultural, Consumer, and Environmental Sciences, University of Illinois, Urbana-Champaign.

As a result of the pretest, the nature of the questions did not change significantly. Two questions were found to be redundant and the wording was changed on the others. A self-confidence evaluation question was added after the pretest. Therefore in place of a second pretest of the questionnaire, it was taken to the Survey Research Institute, University of Illinois, Urbana-Champaign and received positive comments with only a few additional changes. Initial findings from the first pretest show that the results are as anticipated. There was a shift from a

local to a more global focus. In the *before* questionnaire, 55% of the subjects had some mention of a global perspective. In the *after* questionnaire, 100% had a strong global emphasis.

### **Preliminary Analysis<sup>iii</sup>**

Data collection took place from January to March of 2000. Primary data are collected through the use of a *before* and an *after* questionnaire designed to solicit subjects' cognitive maps (or perspectives on the soybean industry). Table 1 describes demographic information related to the subjects in part two of this experiment. The gender mix is heavily male, which is representative of the industry. Most of the subjects have at least some post secondary education, with nearly 65 percent having college degrees. The subjects are spread across a number of sectors including producers, researchers, service providers and agribusiness students (undergraduates and graduates).<sup>iv</sup>

Table 1. Subject Demographics for the Protein Consumption Dynamics Experiments

<b>Demographic Category</b>	<b>Sub-category</b>	<b>Number of Participants</b>
Gender	Male	93
	Female	28
Education	High School	4
	Vocational/Associates	13
	Some College	26
	Bachelor's Degree	23
	Master's Degree	26
	Doctoral Degree	29
Age	Average	38.5
Occupation	Producer	26
	Researcher	28
	Service Provider	33
	Agribusiness Student	34
<b>Total</b>		<b>121</b>

Results show a shift in the research allocation decisions as a result of seeing the visualization model, as seen in Table 2. In the *before* questionnaire, respondents focused more on new product development and developing new markets. In the *after* questionnaire, the group directed even more resources toward developing new markets and shifted away from new product development and genetics research. In the *after* questionnaire, the subjects still recognized the importance of the local issues, but this perspective expanded to include more global and long-term issues.

Table 2. *After* Questionnaire responses to Question 3 on Research Budget Allocation

Area	Average	Change from <i>Before</i> Questionnaire
Production Research	15.99	-0.04
New Product Development	19.28	-2.54
Marketing Research: Strengthen Existing Markets	18.98	+1.07
Marketing Research: Develop New Markets	25.08	+3.33
Genetics Research	16.43	-2.27
Other	4.25	+0.45
Total	100.00	0.00

### Summary

The primary goal of this research is to analyze changes in cognitive maps of soy industry decision makers to determine the effectiveness of using the visualized representation of information from the protein consumption dynamics simulation model. The model uses various scenarios based on income and population growth projections to determine the future appetite for a number of commodities related to the soy industry. Preliminary results indicate that the model is effective in shifting decision makers' perspectives to a more global and long-term focus, thus influencing their budget allocation decisions.

Further work in this study will look at changes in perspectives at the individual, group and across group level. It will also test the differences between using the 3-D model and a tabular representation of the same information. Long-term plans include making the visualization interactive and including more policy variables in the model.

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## Footnotes

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<sup>i</sup> Authors are respectively Director, National Soybean Research Lab and holder of the Soybean Industry Chair in Agricultural Strategy; graduate research assistant; and Associate Professor of Agricultural Management.

<sup>ii</sup> We collaborated with the National Center for Supercomputing Applications at the University of Illinois in developing the 3-D visualization. We used Visible Insights' In3D software, which provides a three-dimensional, dynamic programming environment for data representation.

<sup>iii</sup> The analysis of collected data is still in progress at the time of writing this paper. However, complete results will be reported at the System Dynamics conference, and will be incorporated in a future version of this paper.

<sup>iv</sup> Agribusiness students were included for two reasons. First, many of the students are from farms where soybeans are produced. Second, many of these students will be future decision makers of the industry.