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LOCATION AND SIZE OF GRAIN STORAGE FACILITIES IN DEVELOPING AREAS*

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ABSTRACT

Ideal location and size of storage units is examined for three Brazilian areas, considering transport costs and economies of scale in storage construction. A plant location master program is used with a capacitated network subroutine. The results challenge many earlier practices but received support from farmers, cooperatives and planners.

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1. INTRODUCTION

The objective of this paper is to examine the question of size and location of grain storage facilities in less developed countries, in order to provide useful guidelines for planners. This is attained by formulating the problem as a capacitated network plant location model, applying it to three empirical situations, and cross-checking the results with an analysis of institutional factors and practical experiences of storage planners and users.

2. THE PROBLEM OF PLANNING AND MODELLING

The storage and transport systems of LDCs are often deficient in quantitative and qualitative terms, both in countries which lose substantial amounts of stagnant or declining harvests, as well as more optimistic cases such as Brazil and India where production increases have at times overrun the capacity of their transfer facilities. A major policy question is where to locate facilities (in ports, near consumers, on or near farms, or at intermediate locations) and how large they should be. The most prevalent historical tendency has been for official storage agencies and producer groups to propose large projects, such as "superports" and large storage facilities at intermediate locations, often with capacity for 20, 50 or even 260 thousand metric tons in a single unit or location. In Brazil in the 1970's. for example, 40 and 50 thousand ton storage units were often constructed as banks and agencies found that construction costs per ton of static capacity were lower in larger units, and financing tended to be lumped into a few large projects to maximize the impact of storage programs. In Africa, some government marketing boards have adopted a "think big" strategy, with the basic idea apparently being that there are economies of scale in storage and that the concentration of large quantities in "central places" will make subsequent reallocation more efficient. The impact of storage location on transport costs has not normally been considered in these decisions.

Until now there has been no published technical analysis capable of providing planners with guidelines or a description of the impacts of such a strategy on the combined costs of transport and storage. This is understandable, since spatial elements are seldom explicitly considered in economic analysis, the physical characteristics of transport and storage systems often present complexities which make modeling difficult, the problem is dynamic, risk is present and numerous capacity constraints exist. As Liffin and Boehlje observe (p. 457), there are few empirical analyses which combine intertemporal and interregional dimensions in an allocation model. Only recently have agricultural economists began to perceive the advantages of network analysis for what are implicitly plant location problems (Fuller, Randolph and Kingman, 1976).

3. THE MODEL

The size-location problem is formulated using a heuristic master program whose basic element is a capacitated network model. A simplified transport storage problem is represented as a capacitated network in Figure 1. Each arc (i,j) is assigned three parameters (in order): a unit cost C_{ij}; an upper capacity U_{ij}; and a lower limit L_{ij}. The upper capacity of the arc (DO, PR,) from the dummy origem (DO) to the producing region in period 1 (PR_1), indicates that 50 exogeneously estimated units of grain are the region's exportable surplus. The parameters on (PR_1, CR_1) indicate that it costs \$10 per unit to ship grain from the producing region to the consuming region in period 1. The lower limit of 20 on arc (CR_1, DD) indicates that 20 units must be supplied to the consuming region in period 1. A special feature of the model is indicated by the dotted lines which indicate storage. A flow over (PR_1, PR_2), for example, indicates storage in the production region from period 1 to period 2, and storage facilities also have their costs and capacity limits.

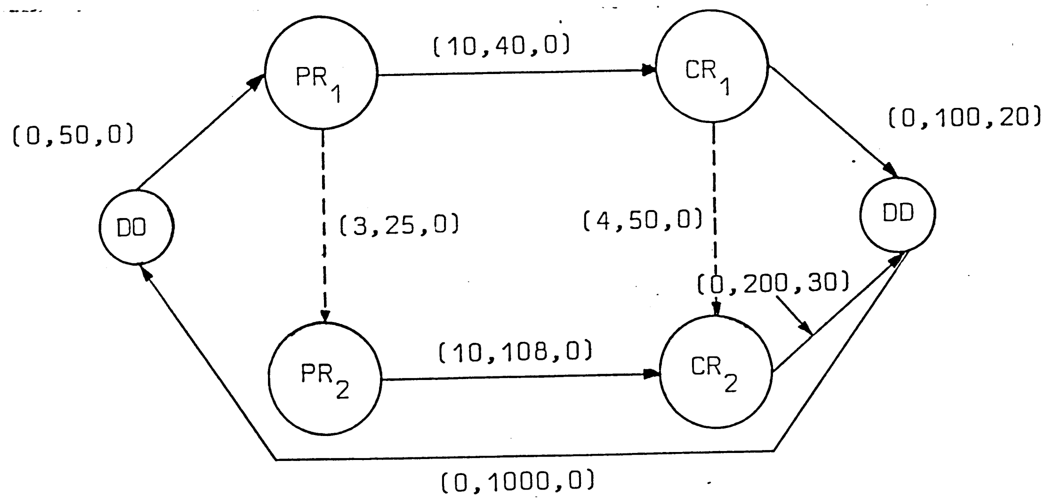


FIGURE 1. A SIMPLE CAPACITATED NETWORK WITH STORAGE

Such a capacitated network is a very flexible and efficient modeling technique and facilitates comunication with non-specialists (Bradley, p. 222) who typically provide many of the inputs and comprise the decision makers who will use results. The essential spatial, physical and economic features of the transfer system are easily represented, and capacity constraints and the dynamic aspects of storage and various time periods are easily incorporated. The use of the Fulkerson's algorithm (OKA) results in the minimization of total costs of all flows X_{ij}, given by

$$(1) \quad \sum_i \sum_j C_{ij} X_{ij}$$

subject to the capacity constraint

$$(2) \quad 0 \leq L_{ij} \leq X_{ij} \leq U_{ij}$$

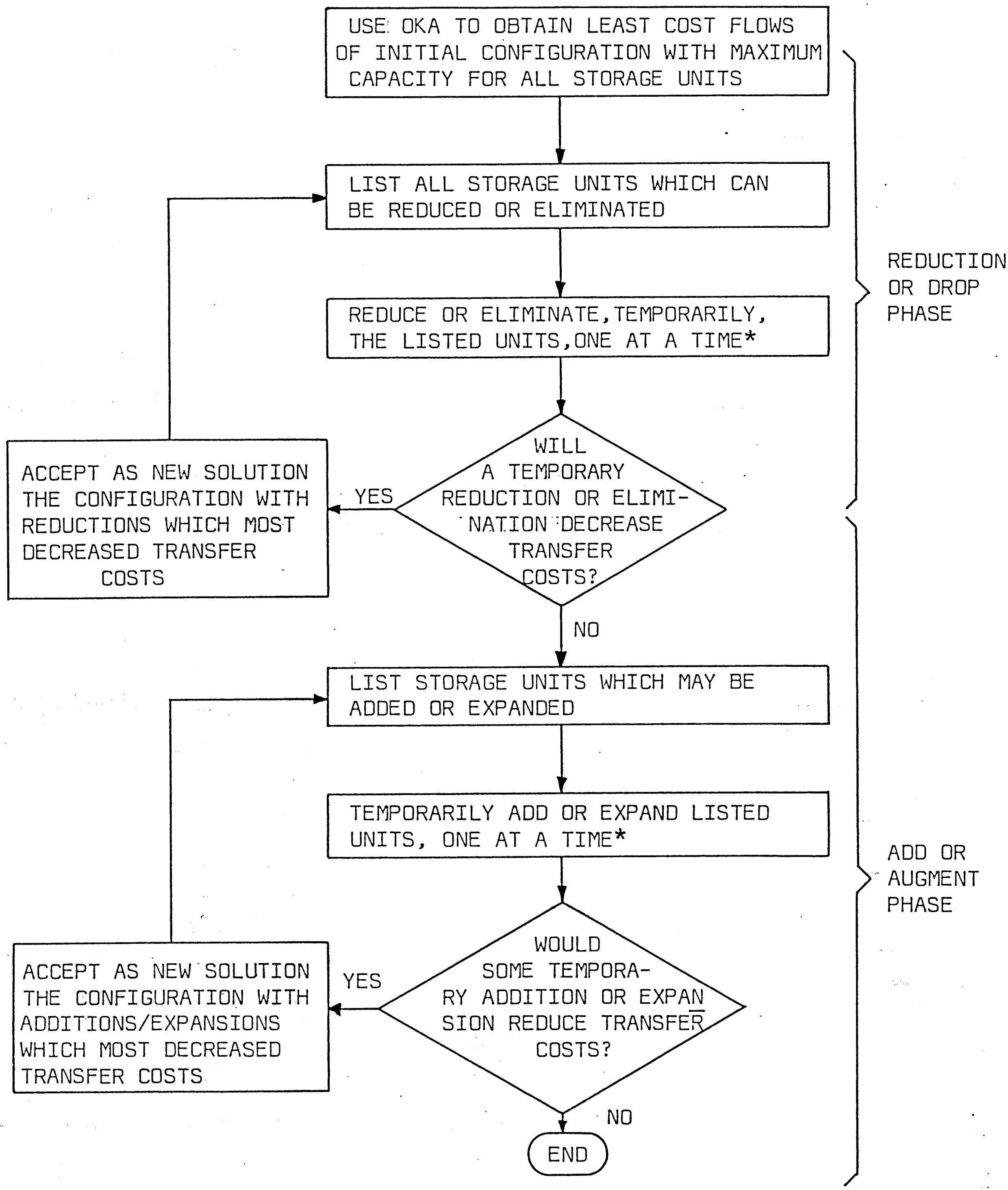
and the circulation principle that no flow be gained or lost at any mode, a problem avoided by the presence of the (DD, DO) arc in Figure 1.

The transport-storage problem is thus configured in terms of the alternative storage locations, each with different possible sizes and corresponding costs. The costs are estimated from economic engineering techniques (Black; Sammet and French). The basic alternatives consider expanding existing facilities at their marginal costs or building new facilities. The Master Program (Figure 2) serves two basic purposes: (1) to compare the minimum cost solutions of alternative size and locational configurations; (2) to deal with the scale economies in storage construction through an "equilibrate" routine, so that the storage costs which appear in the final solution are within a defined tolerance what the actual average costs would be for storage units of the size which appear in that solution.

The Master Program is heuristic. It systematically searches for ways to reduce the total costs by reducing the size of storage facilities (or eliminating them) at different locations, and them seeing if adding or expanding facilities will decrease costs (DROP-ADD routine). This is necessary since an exhaustive search for the optimal solution in a problem with only 20 locations where storage units could be built would have 1,048,575 possible solutions, without introducing the size-cost variations considered herein. The heuristic process used, however, is in line with modern programming techniques which in well-behaved systems such as the one studied are expected to reach the optimum solution or one very close to it, and do so with reasonable computer times and costs (Monterosso).

4. *RESULTS AND ANALYSIS*

Three Brazilian areas were studied: the Southwestern and Campo Mourão microregions of Paraná, important soybeans and corn producing areas, and Central-Western Maranhão, where rice is the main crop. The Southwest has the lowest level of tenure inequality (GINI = 0.64), the largest median farm are a (13.1 hectares) and the most dense paved road system (0.045 km/km^2; followed by Campo Mourão (0.71; 8.2; and 0.03) and severely underdeveloped Maranhão (0.90; 1.3; and 0.014). For each case, the OKA algorithm was used to optimize transport/storage flows for the base year (1979) for the existing "collector" storage system . Then eight different scenarios were simulated to find the (heuristically) optimal storage locations and capacities under different assumptions. These scenarios asked:



* Each temporary configuration corresponds to one run of the equilibrate routine in which the OKA subroutine is used iteratively.

FIGURE 2. Master Program: Heuristic Storage Location and Size Procedure

(a) How efficient or inefficient is the present storage system, vis-à-vis total transfer costs?

(b) Given the sunk costs of the existing units, what additions to present units or which new units should be built, if full annual prorated costs of new construction are charged?

(c) What will be least cost locations and sizes of units under future production?

(d) Do variations in the interest rate considered affect location and size?

(e) How do fuel price variations affect location and size?

(f) Which locations and sizes entail the least risk if errors are made regarding future production, fuel prices or other factors?

(g) Should facilities be limited to good all-weather roads?

Representative results used to address such questions are given in Tables 1, 2 and 3 for Campo Mourão, Southwest Paraná and Central Maranhão, respectively. In the first two micro-regions, some short-term excess storage capacity was available, since the 1979 crop was below normal. Even then, a system built from scratch to minimize transfer costs, to address question (a) above, would have been less geographically concentrated, that is, more smaller units would have been built and more evenly spread throughout each micro-region. Columns (1) and (2) of each table reveal that: Campo Mourão would have had facilities in 6 locations where there were none in 1979, while only 2 locations would have lost storage units; Southwest Paraná would have gained 3 and lost one; Central Maranhão would have gained 7 and lost one. Further, in all locations where losses occurred, adequate capacity was located nearby in each model simulation.

With respect to question (b), simulations not shown in the tables due to space limitations resulted in fewer new locations receiving new or expanded facilities, when compared to model results in item (a). This is natural since no construction costs were charged for existing storage ("sunk costs are sunk costs"), while full prorated costs were charged for new construction. However, there was a distinct tendency for the model to augment capacity at new locations rather than by expanding existing units, even though the latter alternative implied lower construction costs. This confirmed the desirability of the previous pattern of greater geographical dis-

TABLE 1

EXISTING AND SIMULATED STORAGE CAPACITIES, TRANSFER COST AND FREQUENCY OF ADDITIONAL CAPACITY ALLOCATION-CAMPO MOURÃO

LOCATION	EXISTING CAPACITY 1979	OPTIMAL CAPACITY 1979	ADDITIONAL CAPACITY		MODE OF ADD. CAP.
			W/40% PROD. + 100% FUEL PRICE INC.	Nº TIMES CAP. ADDED	
B. Esperança	30,000	-	-	-	-
Campo Mourão	189,900	132,000	-	-	-
Eng. Beltrão	50,570	6,000	-	-	-
Fênix	30,580	12,000	-	-	-
Iretama	-	12,000	12,000	8	12,000
Mamborê	105,290	92,000	-	-	-
Peabiru	14,400	12,000	-	1	2,000
Quinta do Sol	300	2,000	-	4	2,000
Goio-Erê	56,380	60,000	-	-	-
Janiópolis	480	2,000	-	2	8,000
Ubiratã	35,300	40,000	-	-	-
Mariluz	7,200	-	-	-	-
Araruna	-	-	-	3	2,000
Barbosa Ferraz	-	2,000	-	4	8,000
Roncador	-	20,000	12,000	8	12,000
C. Loagoa	-	8,000	2,000	7	10,000
Nova Cantu	-	2,000	2,000	6	2,000
Moreira Sales	-	2,000	-	4	2,000

TOTAIS:

Capacity(t)	520,400	404,000	548,400
Storage cost(Cr$)	99,981,967	103,505,293	15,545,228
Transport cost(Cr$)	720,806,354	688,830,954	1,180,217,978
Total cost (Cr$)	820,788,321	792,336,247	1,195,763,206

TABLE 2

EXISTING AND SIMULATED STORAGE CAPACITIES, TRANSFER COST AND FREQUENCY OF ADDITIONAL CAPACITY ALLOCATION-SOUTHWEST PARANÁ

LOCATION	EXISTING CAPACITY 1979	OPTIMAL CAPACITY 1979	15% PRODUCTION AND 100% FUEL PRICE INCR.	Nº TIMES ADDITIONAL CAPACITY	MODE OF ADD. CAP.
G. Carneiro	240	2,000	-	-	-
Mangueirinha	9,000	32,000	24,000	8	24,000
Chopinzinho	19,016	32,000	-	-	-
F. Beltrão	22,740	40,000	-	-	-
Mariópolis	-	-	-	-	-
Renascença	7,040	2,000	-	-	-
I. D'Oeste	7,240	2,000	-	-	-
São João	5,400	12,000	-	-	-
Verê	4,723	2,000	-	-	-
Marmeleiro	1,620	-	-	-	-
Salto do Lantra	4,134	40,000	-	-	-
S. I. D'Oeste	-	-	-	-	-
Ampere	720	2,000	-	-	-
S. A. Sudoeste	28,077	40,000	-	-	-
P. D'Oeste	6,000	6,000	-	-	-
Clevelândia	-	2,000	2,000	8	2,000
Bituruna	-	-	-	-	-
Vitorino	-	-	-	-	-
S. J.D'Oeste	-	-	-	-	-
Barracão	-	2,000	2,000	6	2,000
Salgado F.	-	-	-	1	2,000
E. Marques	-	-	-	-	-
Planalto	-	24,000	-	2	2,000
Palmas	7,200	2,000	-	-	-
Cel. Vivida	31,140	12,000	-	-	-
Pato Branco	60,652	60,000	-	-	-
D. Vizinhos	20,232	2,000	-	-	-
Realeza	96,750	24,000	-	-	-
Capanema	38,400	20,000	-	-	-

TOTAIS:			
Capacity (t)	370,324	360,000	398,324
Storage cost(Cr$)	112,438,925	107,017,148	12,080,319
Transport cost(Cr$)	302,181,699	291,995,117	472,837,332
Total Cost (Cr$)	414,620,624	399,012,265	484,917,651

TABLE 3

EXISTING AND SIMULATED STORAGE CAPACITIES, TRANSFER COSTS AND FREQUENCY OF ADDITIONAL CAPACITY ALLOCATION – MARANHÃO

LOCATION	EXISTING CAPACITY 1979	OPTIMAL CAPACITY 1979	100% FUEL PRICE INCREASE	Nº TIMES ADDITIONAL CAPACITY	MODE OF ADD. CAP.
Altamira M.	–	6,000	6,000	8	6,000
Bacabal	60,193	53,748	60,193	–	–
B.Jardim	–	3,000	6,000	8	6,000
B.Esperança	–	–	3,000	2	3,000
Igarapé G.	–	–	3,000	2	3,000
Imperatriz	9,800	12,000	21,800	3	3,000
Açailândia	2,881	17,881	17,881	8	15,000
J.Lisboa	–	12,000	12,000	8	12,000
Joselândia	–	–	6,000	5	6,000
Lag.Pedra	17,612	17,612	23,612	8	6,000
Cocalino	–	6,000	3,000	6	3,000
Lago Junco	–	3,000	3,000	5	3,000
Lago Verde	–	–	3,000	8	3,000
Lima Campos	3,842	3,842	3,842	–	–
Monção	–	–	3,000	8	3,000
Zé Doca	3,403	12,403	6,403	6	3,000
Montes Altos	–	–	–	2	6,000
Olho D'Água	1,454	1,454	4,454	3	6,000
Paulo Ramos	–	–	–	2	3,000
Pedreiras	54,553	51,155	54,553	–	–
P.Mirim	29,491	13,672	29,491	–	–
Pio XII	3,398	3,000	3,398	1	3,000
Santa Inês	16,289	28,289	16,289	1	6,000
Santa Luzia	5,153	12,998	20,153	8	15,000
Entroncamento	–	12,000	12,000	7	12,000
S.L.Gonzaga	–	–	–	–	–
S.Mateus	3,398	–	3,398	1	3,000
V. Freire	3,000	3,000	3,000	–	–
P.Pedras	2,953	2,953	5,953	5	3,000
S.A.Lopes	4,081	3,683	4,081	1	3,000
Esperant.	–	3,000	6,000	8	6,000
TOTALS:					
Capacity (t)	221,501	282,690	344,501		
Storage cost (Cr$)	37,992,850	58,553,809	51,183,387		
Transport cost (Cr$)	416,337,108	376,413,537	610,563,554		
Total cost (Cr$)	454,329,958	434,967,346	661,746,941		

persion in relation to the actual 1979 system.

The third column of the tables shows the effect of a 100% real fuel price increase, a phenomenon which is becoming reality as the Brazilian government removes its cross-subsidies favoring diesel fuel. The table also shows one production increase exogenously estimated for the ensuing five-year period for the two Paraná microregions, to examine questions (c) and (e) above. The fuel price increase substantially reforces the more even geographical distribution of storage units of the earlier solutions. The interest rate increase - item (d) above and not shown in the tables - of course works in the opposite direction, augmenting the cost of storage construction in relation to transportation. However, varying the real interest rate from 10 to 15% affected the results only marginally.

The last two columns in the tables address the risk question (f). In Campo Mourão, for example, the model allocated new storage space to Iretama and Roncador under all 8 scenarios, against only 1 scenario in Peabiru. Thus, the decision maker can consider Iretama and Roncador as high priority locations in very robust model results - they enter the "optimum" solution whatever happens to the relevant economic variables. To aid in choosing the size of the instalations, the last column of the tables also provides him with the mode of the capacities added in the different solutions.

In all three regions, an examination of locations which received additional storage, along with the corresponding flows using detailed maps, revealed that "intermediate" locations with very large storage capacities were seldom chosen by the model under any assumption. Large storage capacities were allocated only to locations which were the centers of intense grain production and which, in addition, were located along the routes from the farms to industrial centers or ports which were considered the "final destinations" in the model (processing or export points). This occurred for two basic reasons: (1) cleaning and drying grain at storage units reduces the dead weight by some 5 or 10%, so that post-storage transport is considerably less expensive per kilometer than the farm-to-storage leg of the journey; and (2) as the area served by a single storage facility grows larger, the average distance traveled to reach the final destination increases, due to indirect routes (e.g., a farmer transports soybeans 30 km westward to the collector storage unit, from which they are sent 250 km eastward for processing. Intermediate units which receive and reship using the same transport mode (i.e., trucks) merely create expensive and unnecessary transshipments and augment total shipping distance. The larger the units are, the worse the second problem becomes, indicating the "think big" strategies referred to earlier are likely to be quite inefficient. These results are also in accord with Wright's analysis (1980) that, on major corridors, the dynamic capacity for receiving grain by truck and loading rail cars is more important than the static storage capacity of such intermediate units and so should not be primarily designed to supplant storage capacity in production areas.

The foregoing reasoning and a joint analysis of the three areas studied also contradicts a widely held premise that collector storage units should be located on good roads (question (g), above). Such a strategy is understandable from the storage owner's point of view if he buys from farmers at a fixed price and farmers pay the transport costs to the storage unit, which in fact occurs in Maranhão where rice is sold often at the government established minimum price. Location on good roads may also be necessary if sales to industries or exporters are subject to demurrage charges if inclement weather makes poorer roads impassable (Wright, 1980), but this situation is being eliminated in Brazil by appropriate cooperation among farmer-associations. However, the efficiency criterion leads to the smallest units and greatest dispersion in Maranhão, with the worst road system and the fewest units located on good roads. This occurred because poor roads increase transport costs just as fuel price rises do, augmenting the cost of inefficient local routes with extra weight before cleaning and drying occurs.

The final phase of this research involved checking to see if crucial qualitative variables would reforce or reject the apparently consistent quantitative results. Federal and state storage planners, farmers and cooperative leaders and extensionists who had aided earlier and expressed interest in the results, were contacted regarding the results. The research team found that the farm-to-storage unit transport problem was perhaps even more crucial than the model indicated. Farmers and cooperatives were engaged in efforts to locate the collector units nearer the farmers, and were begining to get a more receptive hearing from a new generation of storage planners who were themselves somewhat-sceptical of the earlier norms aimed largely at maximizing total storage construction given their budget constraint. Paraná's state storage planners were already experimenting with a "mini poles" program of locating small units close to farmers. In both federal and state cases, the results helped remove doubts that such a response to farmer pressure might not be efficient. Finally, even specific locations chosen by the model coincided with the hindsight of cooperative leaders and storage planners regarding where they would construct units if they could do it over. A further example was given by the Campo Mourão cooperative: as our results rolled off the computer, a telephone contact provided the news that the cooperative had rented makeshift storage units in Iretama and Roncador to bring storage closer to area farmers, and that it had high priority projects to build permanent units there. Those were the only two locations in that micro-region which appeared in all model solutions, and the cooperative subsequently received funding for those facilities.

5. REFERENCES CITED

BLACK, Guy. "Método Sintético de Análise de Custo em Firmas de Comercialização Agrícola". Piracicaba: ESALQ/USP, translation of Giannini Foundation Journal Paper 144 (Berkeley, 1953).

FULLER, Stephen W., Paul Randolph and Darwin Klingman. "Optimizing Subindustry Marketing Organizations: A Network Analysis Approach". Am. J. Agr. Econ. 58(3): 425-36.

MONTEROSSO, Cesar D. B. "Um Método Heurístico Para a Localização e Dimensionamento de Armazéns em Sistemas de Grande Porte Considerando Economias de Escala". Rio de Janeiro: COPPE, 1977.

SAMMET, L. L., and B. C. French. "Métodos de Engenharia Econômica na Pesquisa de Comercialização." Piracicaba: ESALQ/USP, translation of Giannini Foundation Paper 135 (Berkeley, 1953).

WRIGHT, Charles L. "Contribuição à Análise Econômica da Armazenagem de Soja". Revista Brasileira de Armazenamento 5(2): 51-7, 1980.