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Simulated Model for Cost Effective Paddy Product Distribution in Sri Lanka

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Abstract A simulation model is presented for cost effective paddy product transportation in Sri Lanka. Paddy production in Sri Lanka is assumed to be sufficient to meet the entire requirement of the country, and distributing among the administrative districts is taken to be proportional to their respective populations. This simulation problem is solved by chance constraint stochastic transportation method. Suppliers and consumers are determined by their production and their population by assuming paddy production to be independent and normally distributed.

Keywords: Maha Season, Yala Season, Simulation, Transportation Problem, Stochastic Transportation Problem.

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1. Introduction

Rice is the staple food in Sri Lanka. It is produced from paddy, which is harvested in the two cultivation seasons ‘Maha’ and ‘Yala’, which are agricultural periods based on monsoon rains. Time period of these seasons are from September/October to March/April for the ‘Maha’ season, and from April/May to August/September for the ‘Yala’ season. Total rice requirement for human consumption can be produced in Sri Lanka. However, in some years rice is being imported to meet the demands. For instance in 2003, total rice requirement for human consumption is 1,923 thousand metric tons of which 1,888 thousand metric tons had been supplied from domestic source and, 35 thousand metric tons from imports (www.statistics.gov.lk). Paddy harvests vary highly among the districts of Sri Lanka and consumptions also vary according to the human population of the districts. Because of this unbalanced paddy production and consumption, it is required to transport paddy from higher production areas to low production areas.

However, due to various reasons, price of rice is relatively high and is steadily going up. One of the factors that cause increase in price of rice is ad-hoc transportation. In an earlier work on this matter, de Silva et al. (1979) have solved a simple transportation problem of paddy supplier districts to consumer districts. A new transportation strategy is attempted in this work where instead of ad-hoc or classical transportation method, the problem is solved by using Stochastic Transportation Problem (STP), which is a special class of Stochastic Programming Problem (SPP). There are various classes of SPP such as Single Objective Stochastic Programming Problem (SOSPP), Multi Objective Stochastic Programming Problem (MOSPP) and Stochastic Linear Programming Problem (SLPP), and they are classified according to the treatment of objectives and that of the constraints (Mohan et. al. 1997). A very common approach of chance constraint programming simplifying to deterministic equation is used for this study (Hamdy 1999) due its simplicity and the comparatively less amount of calculations involved.

The sequel of this paper is organized as follows: In the Section 2 we present the methods and materials used in the investigation with deterministic equivalent of stochastic transportation problem that derives model equations. In the third section, results are presented followed by discussion and conclusion.

2. Methods and Materials

The transportation problem deals with commodity shipped from a source to a destination. The objective is to determine the amounts shipped, from each source or supplier district to each destination or consumer district that minimizes the total transportation cost while satisfying both supply limits and the demand requirements (Hamdy 1999a, Harvey 1999b). This model assumes that the transportation cost on a given route is directly proportional to the number of units shipped on that route and is taken to be proportional to the distance between administrative capitals of the districts.

Stochastic paddy transportation problem which aims at finding out cost benefit transportation strategy can be described as below:

If c_{ij} and x_{ij} are transportation cost and number of units to be transported from i^{th} supplier of 'm' number of suppliers to the j^{th} consumer of 'n' number of consumers respectively, then the problem is to minimize the total transportation cost z given by

$$z = \sum_i \sum_j c_{ij} x_{ij} \,, \tag{1}$$

subject to

$$P\left\{ \hat{a}_i \geq \sum_{j=1}^{n} x_{ij} \right\} \geq \alpha_i \quad i = 1,2,\ldots m \text{ , and} \tag{2}$$

$$P\left\{\hat{b}_j \leq \sum_{i=1}^{m} x_{ij}\right\} \geq 1-\beta_j \quad j=1,2,\ldots n\,, \tag{3}$$

where P in the above stands for the *Probability*, $\hat{a}_i$, supply amount, is independent, normally distributed random variable with mean E($\hat{a}_i$) and variance var($\hat{a}_i$) and similarly $\hat{b}_j$, demand amount, is also independent normally distributed with mean E($\hat{b}_j$) and variance var($\hat{b}_j$). The minimum probabilities that satisfy ith supplier constraints and jth demand constraints are α_i and 1- β_j respectively.

Paddy production is uncertain in each season and year due to various reasons as well as climatic conditions. The supply and demand of the paddy production vary from season to season and year to year due to various reasons. For instance, the uncertainty in the weather conditions is one of the obvious ones.

Deterministic Equivalent of Stochastic Transportation Problem

In the stochastic chance constrained transportation problem described above, supply and demand constraints depend on probabilities of at least α_i and $1-\beta_j$ respectively. These chance constraints can be converted to equivalent deterministic form as follows (Hamdy 1999a).

Consider the ith supply constraint,

$$P\left\{\hat{a}_i \geq \sum_{j=1}^{n} x_{ij}\right\} \geq \alpha_i,\ i=1,2,\ldots m\,.$$

Based on the normality assumption, one can easily see that this ith constraint reduces to

$$\Phi\left[\frac{\sum_{j=1}^{n} x_{ij} - E(\hat{a}_i)}{\sqrt{\mathrm{var}(\hat{a}_i)}}\right] \leq \Phi\left(K_{\alpha_i}\right)$$

where $\Phi\left(K_{\alpha_i}\right) = 1 - \alpha_i$ and $\Phi(.)$ is the cumulative distribution function of a standard normal distribution. This gives,

$$\sum_{j=1}^{n} x_{ij} \le K_{\alpha_i} \sqrt{\operatorname{var}(\hat{a}_i)} + E(\hat{a}_i); \quad \mathrm{i} = 1, 2, 3, \ldots \mathrm{m} \tag{4}$$

Similarly the second type of chance constraints (demand chance constraints) can be written as equivalent to the deterministic type as

$$\sum_{i=1}^{m} x_{ij} \ge K_{\beta_j} \sqrt{\operatorname{var}(\hat{b}_j)} + E(\hat{b}_j); \quad \mathrm{j} = 1, 2, 3, \ldots \mathrm{n}\,. \tag{5}$$

In many research, solution approach of SPP is to find its deterministic equivalent. Another way of approaches is fuzzifying approach to cope with vagueness appearing in the cost functions and constraints. In this approach decision maker has specified a fuzzy aspiration level of probability to the stochastic constraints and objective functions and then get the deterministic equivalent of SPP (Mohan 1997). Here, it is adapted the earlier one due to it's simplicity and less interaction of decision maker. After getting deterministic equivalent of SPP, it can be solved first by taking a feasible solution and then by performing iterations. Least-cost first rule is adapted to get feasible solution (Hamdy 1999, Harvey 1999).

In this study, a simulation has been used to find out the best transportation strategy for paddy production in Sri Lanka. Since district-wise paddy production is unbalanced, it is needed to transport the paddy production from surplus areas to consumer areas. The paddy production is taken with the reasonable assumption that the total amount would be sufficient to meet the entire requirement of the country.

The total paddy production of a cultivation year is designed to be distributed among administrative districts proportional to the population density. On this basis that each district requirement an amount proportional to its population, certain districts which have surpluses after meeting its own needs were identified as supplier with the amounts of supply and those who are in deficit were identified as consumer along with their requirements. Therefore paddy consumption per person (γ) is defined by considering available data of each district.

$$\gamma = \frac{\sum_i \left\{ \left(\text{Maha Production}\right)_i + \left(\text{Yala Production}\right)_i \right\}}{\sum_i w_i \times \left(\text{District Population}\right)_i}$$

where

$$w_i = \begin{cases} 2 & \text{if data is available in both seasons} \\ 1 & \text{if data is available in one of the seasons} \end{cases}$$

These weights are assigned according to the availability of paddy harvest data in cultivation seasons. Therefore, once there is an absence of data in any cultivation season of a particular district, it is omitted from the transportation problem.

Similarly district-wise paddy consumption per person (γ_i) is taken as a simple ratio of paddy harvest to the population in each season as follows,

$$\gamma_i = \frac{\text{Paddy Production of a Season in District i}}{\text{Population of District i}}.$$

A particular district will be either a supplier or a consumer. Supplier or consumer districts are determined based on the figures γ_i and γ. That is, if γ_i is greater than γ then the district 'i' is considered as a supplier district of that cultivation season and if γ_i is less than γ then the district 'i' is considered as a consumer district of that cultivation season. Thus the supplier or consumer amount of each district for a season is given by

$$(\gamma_i - \gamma) \times (\text{Population of District i}).$$

The calculation procedure is shown in Figure 1.

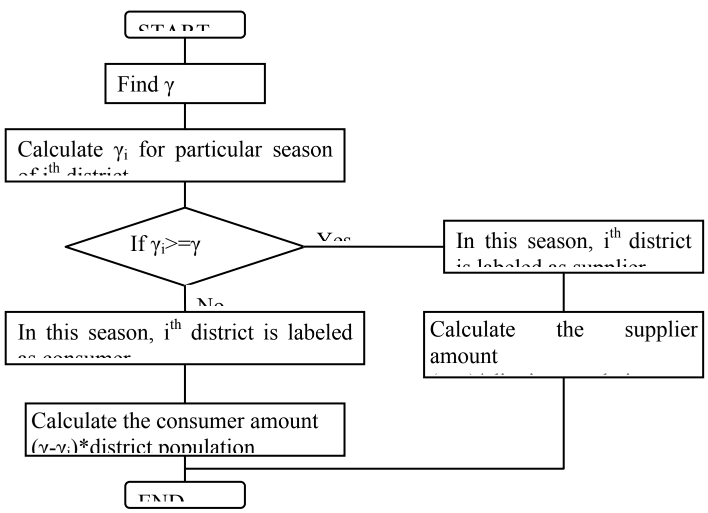

Figure **1**: Flow chart to find out supplier and consumer districts

If a particular district has surplus paddy production in 'Maha' but needs some more paddy to fulfill its requirement in 'Yala', the excess production of 'Maha' will be allocated to be used in the 'Yala' season, instead of transporting to another district. If 'Maha' production is large enough to fulfill 'Yala' requirement, the remaining amount after allocating for 'Yala' seasonal demand, can be transported. Otherwise, if 'Maha' production is not large enough, all the surpluses are allocated for 'Yala' requirement and the rest will be taken from another district. Therefore, if a particular district has a surplus production, it may be transported or not, which is decided by 'Yala' production (Figure 2).

However, if both seasons have an excess production they are transported without any adjustment. Again if both seasons need more paddy to fulfill their requirements they are taken from another supplier district. Moreover, as total supplier amount and consumer amount are not the same, fictitious consumers or fictitious suppliers are introduced to make balance transportation problem.

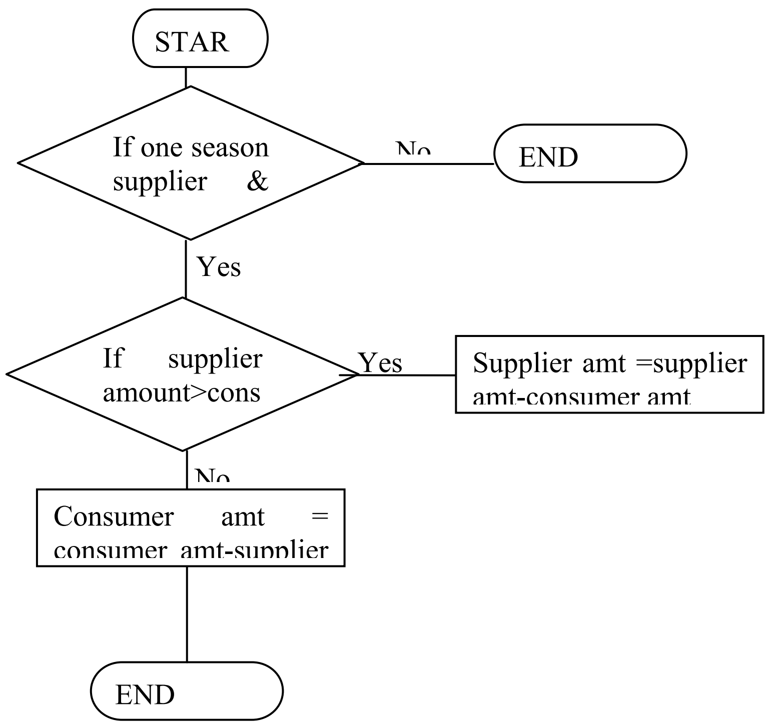

Figure **2**. Rearranging the supply and demand amount according to the 'Maha' and 'Yala' requirement

Supplier and consumer districts are determined based on their average values of concerned period (1989-2003) to construct simulation model. Supplier and consumer amounts of each district for each season is calculated based on right hand side values of deterministic equivalence of chanced constraint equations (equation 4 and 5). Three simulation cases are presented by assuming that the minimum probabilities to hold the supplier constraints (α_i's) are 0.15, 0.05, and 0.01 and the minimum probabilities to hold demand constraints (β_j's) are 0.85, 0.95 and 0.99. These simulated supplier and consumer amount calculating procedure are shown in the following flow chart of figure 3

For this study, data from year 1989 to 2004 from the annual report of the Central Bank Sri Lanka, are considered and the simulated model is presented for the year 2004. Initial transportation tables and optimum tables were prepared using MS EXCEL and MATLAB packages.

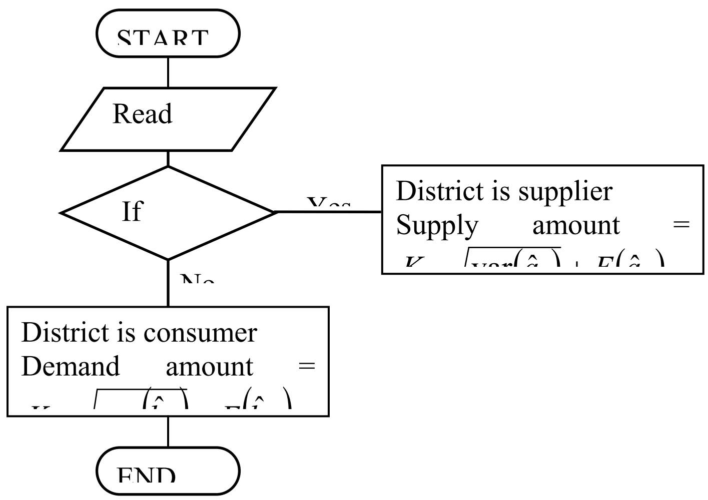

Figure 3: Flow chart for the forecast supply or consumer amount (Where, K_α is found from standard normal table)

As described above, initial transportation tables of the year 2004 of both seasons are presented in Table A.1 (a) – (b). In these tables, supply and demand amounts of supplier and consumer districts are presented by thousands of metric tons of a right most column and a bottom row respectively. The cost of transport from a supplier to a consumer is taken to be proportional to the distance between administrative capitals of district. The relative transportation cost is presented in the initial transportation tables by row and column deduction. Similarly, simulated initial transportation tables of the year 2004 are shown in Table A.2 (a) – (c) and Tables A.3 (a) – (c). The Decision Maker (DM) can decide the probability level required to hold demand and supply constraints (eq. (2) & eq. (3)) and then can decide upon various transportation strategies for the problem. Among those simulated solutions DM can adopt best solution based on decision rules.

3. Results

In both ‘Maha’ and ‘Yala’ seasons, Colombo district is the main consumer district. As the main consumer district the average paddy demands of the Colombo district is 151,180 Mt.(Table 1) and 161,880 Mt.(Table 2) in ‘Maha’ and ‘Yala’ seasons respectively. Polonnaruwa district is recorded as the highest supplier in ‘Maha’ season whilst Ampara district is the highest supplier in ‘Yala’ season with average supply of 261,040 Mt.(Table 1) and 146,120 Mt.(Table 2), respectively. Badulla, Kurunagala, Matale, Monaragala, Mannar, Anuradhapura, Polonnaruwa, Trincomalee, Batticaloa, Ampara and Hambantota districts are the average suppliers whilst Colombo, Kalutara, Galle, Matara, Kegalle, Ratnapura, Kandy, Nuwaraeliya, Puttalum, and Jaffna are the consumer districts in ‘Maha’ seasons. However, in ‘Yala’ season, only few districts function as suppliers namely Polonnaruwa, Trincomalee, Batticaloa, Ampara, and Hambantota and others are consumers (Jaffna district ‘Yala’ data are not available).

According to the paddy transportation strategies for the considered years obtained by solving the classical transportation problems, Kurunagala district is the main supplier for the Colombo for all the years in ‘Maha’ season except for the years 1996, 1999 and 2004. Moreover Kurunagala and Polonnaruwa are the only suppliers of paddy to the Colombo district in Maha season.

The Highest supplier in the ‘Maha’ season is the Polonnaruwa and frequently it supplies to Colombo, Kalutara, Kegalle, Kandy & Jaffna districts and sometimes it supplies to Puttalum, Vauniya & Mannar. Moreover every year Polonnaruwa supplies a large amount of paddy to the fictitious consumer. It means that Polonnaruwa can store a large amount of paddy of its harvest for the ‘Yala’ season, which is comparatively low harvest. Second highest supplier in this season is Ampara district. Ampara district frequently supplies its excess productions to Kandy and Nuwaraeliya and sometime supplies to Ratnapura districts. Every year and season to season, there is a common pattern between suppliers and consumers. Transportation strategies for the year 2004 are shown in Table A.4 and in Table A.5 for ‘Maha’ and ‘Yala’ respectively.

In next season, “Yala” supplies are Polonnaruwa, Trincomalee, Batticaloa Ampara, and Hambantota. Almost all suppliers are from dry zone of Northeast, East and Southeast areas. However the major consumers are Colombo, Kalutara, Galle, Matara, Kegalle, Ratnapura, Kandy and Nuwaraeliya, the same as in the ‘Maha’ season. Again Colombo is the highest consumer and there is not a fixed supplier but most of the time it meets the requirement from the fictitious supplier. However when Polonnaruwa or Kurunagala play as the supplier in this season, Colombo district receives its needy by them. Sometimes it receives paddy from Anuradhapura and Hambantota too.

During the ‘Yala’ season, as it is not much produced like the ‘Maha’ season most of the consumers especially major consumers get their need from fictitious suppliers. Moreover, the amount they receive from fictitious supplier match with the amounts store at fictitious consumers in ‘Maha’ season of the relevant year. Therefore fictitious supplier may be from the same district or a fixed supplier of the ‘Maha’ season.

There is an interesting relationship among the supplier districts and the consumer districts in ‘Maha’ season according to the solutions of transportation problems. That is all major consumers have regular suppliers. Suppliers of Colombo are Polonnaruwa and Kurunagala. Suppliers of Kalutara district are Hambantota and Polonaruwa. Moreover Hambantota district regularly supplies paddy to Galle, Matara and sometimes to Ratnapura districts too. Monaragala district also regularly supplies to the Ratnapura district. Suppliers to Kandy district are Ampara, Matale and Polonnaruwa. Kegalle and Nuwaraeliya get their need from Polonnaruwa, Troncomalee respectively. These observations are same for the year 2004.

In ‘Yala’ season, there is no clearly shown regular supplier to the particular consumer as shown in ‘Maha’ season. However Ampara, Polonnaruwa and Hambantota which are the highest producers in this season have regular consumer districts. Ampara district supplies paddy to Kandy, Nuwaraeliya, Badulla and Monaragala districts while Hambantota supplies to Kalutara and Galle. Sometime Polonnaruwa and Kurunagala play as the suppliers of Colombo district in this season. But in year 2004 Kurunagala has not been the supplier. Further certain amounts of its (Colombo) needs come from fictitious supplier. As in ‘Maha’ season these common observations are shown in year 2004 (Table A.5)

Always ‘Maha’ season has a fictitious consumer to stock its excess product and ‘Yala’ season needed fictitious supplier to fulfill the demand its consumers. In ‘Maha’ season Ampara and Polonnaruwa regularly supply to fictitious consumer. Further sometimes Baticaloa, Matale, Kurunagala Anuradapura and Trincomalee also supply to the fictitious consumer in this season. Therefore these districts can stock paddy harvest to use next ‘Yala’ season and as it is in ‘Yala’ season, most of the consumers such as Colombo, Kalutara, Galle, Matara, Kegalle, Ratnapura receive their needed amounts from fictitious suppliers.

However, in year 2004 ‘Maha’ season actual transportation strategy show that Batticaloa Ampara and Trincomalee are supplied their excess product to the fictitious consumer of 72.38, 65.45, 49.08 thousand meric tons of paddy respectively and in ‘Yala’ season, Galle, Colombo, Puttalam, Ratnapura, Matara, Kalutara are received their needy from fictitious suppliers.

According to the paddy supply and demand statistics, it shows that averagely they are of high variation from year to year as well as season to season. Generally, most of the supplier districts, their supply amounts too are of high variation than the consumer districts. Kurunagala, Anurahapura Polonnaruwa, Trincomalee, Batticaloa and Ampara are the main supplier districts and comparatively variation is higher than the other districts. However in year 2004, 'Maha' season Badulla, Matale, Monaragala, Vauniya, Manar, Anuradhapura, Trincomalee, Baticaloa, Ampara, and Hambantota districts are the suppliers. But in 'Yala' season of this year only Polonnaruwa, Baticaloa, Ampara and Hambantota are the suppliers.

The estimated values of simulated transportation model of the year 2004 are shown in the Table 1 and Table 2 of both seasons. Due to the variations in the paddy supply or consumption amounts, the simulated paddy supply or consumption amounts of those districts are deviated from the actual values. For instance in 'Maha' season, Kurunagala district plays as a consumer actually whereas in the simulated result it shows that it is a supplier. Moreover, the simulated values for Jaffna, Anuradhapura, Ampara and Hambantota are deviated from actual values. All three simulation cases of 'Yala' season, the Anuradhapura district is neither supplier nor consumer whereas actually it supplies 143.38 thousands metric tons of paddy. However, there is a significant deviation of 'Maha' season. In 'Yala' season in the actual case Kurunagalla district plays neither as supplier nor a consumer. However, the simulation shows that it is a supplier. It supplies paddy to Colombo district as same as in the deterministic transportation problem of each and every year. The simulation results of the Kurunagala district are noticeably deviated from the actual values of both seasons. Moreover, suppliers and the consumers of simulation are the same as in deterministic cases.

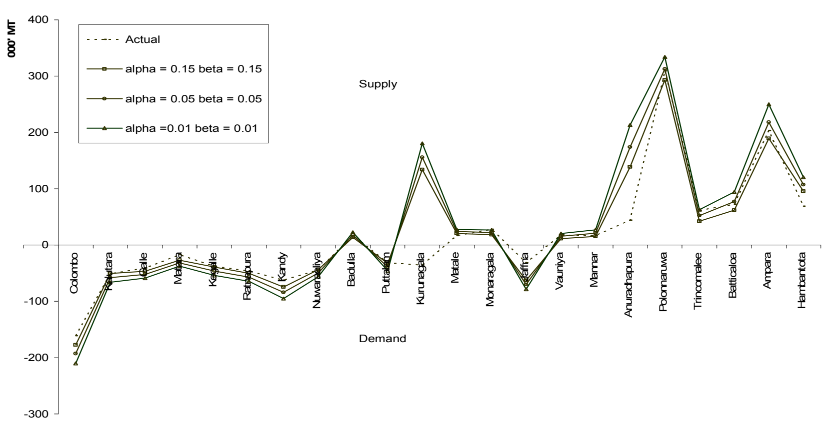

Figure 4. Simulated and actual supply or demand amounts of paddy in year 2004 'Maha'

According to the simulated results, the excess production of Matale, Monaragala, Vauniya, Mannar and Anuradhapura districts in the "Maha' season are stored for the consumption in the 'Yala' season. This is same for all three cases considered in this study. However, excess production of all those districts except Anuradhapura are not enough to completely fulfill the requirement of 'Yala" season. The excess production of Anuradhapura district is sufficient to cover the demand of 'Yala' season and hence the rest is transported.

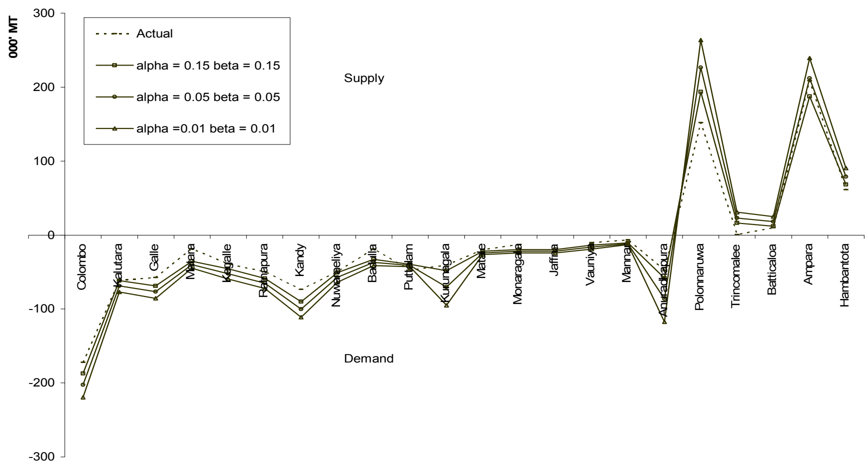

Figure 5. Simulated and actual supply or demand amounts of paddy in year 2004 'Yala'

Table 1: Simulated supply and demand (minus) amounts for "Maha" season of the year 2004. The α and β probabilities are 0.15, 0.05 and 0.01.

District	Average Paddy Production '89-'03 ('000 MT)	std dev	Variance	alpha = 0.15	alpha = 0.05	alpha =0.01
				beta = 0.15	beta = 0.05	beta = 0.01
Colombo	-151.18	25.29	639.48	-177.229	-192.782	-210.005
Kalutara	-37.8	12.27	150.62	-50.4381	-57.9842	-66.34
Galle	-36.67	9.5	90.33	-46.455	-52.2975	-58.767
Matara	-18.17	8.35	69.75	-26.7705	-31.9058	-37.5921
Kegalle	-27.43	11.5	132.3	-39.275	-46.3475	-54.179
Ratnapura	-38.27	11.32	128.23	-49.9296	-56.8914	-64.6003
Kandy	-58.28	15.74	247.64	-74.4922	-84.1723	-94.8912
Nuwaraeliya	-33.22	9.93	98.66	-43.4479	-49.5549	-56.3172
Badulla	6.06	7.24	52.47	13.5172	17.9698	22.90024

District		std dev	Variance	alpha = 0.15	alpha = 0.05	alpha =0.01
Puttalam	-22.29	10.12	102.41	-32.7136	-38.9374	-45.8291
Kurunagala	96.74	35.97	1293.89	133.7891	155.9107	180.4062
Matale	14.49	5.69	32.38	20.3507	23.85005	27.72494
Monaragala	11.84	6.32	39.93	18.3496	22.2364	26.54032
Jaffna	-49.85	12.36	152.83	-62.5808	-70.1822	-78.5994
Vauniya	3.87	7.13	50.83	11.2139	15.59885	20.45438
Mannar	6.21	9.06	82.05	15.5418	21.1137	27.28356
Anuradhapura	79.43	57.54	3310.74	138.6962	174.0833	213.268
Polonnaruwa	261.04	31.38	984.55	293.3614	312.6601	334.0299
Trincomalee	25.93	15.96	254.65	42.3688	52.1842	63.05296
Batticaloa	36.27	24.94	622.21	61.9582	77.2963	94.28044
Ampara	141.39	46.62	2173.39	189.4086	218.0799	249.8281
Hambantota	75.39	19.39	375.92	95.3617	107.2866	120.4911

Table 2 Simulated supply and demand (minus) amounts for "Yala" season of the year 2004. The α and β probabilities are 0.15, 0.05 and 0.01.

District	Average Paddy Production '89-'03 ('000 MT)	Std dev	Variance	alpha = 0.15	alpha = 0.05	alpha =0.01
				beta = 0.15	beta = 0.05	beta = 0.01
Colombo	-161.88	24.73	611.66	-187.352	-202.561	-219.402
Kalutara	-49.1	12.02	144.57	-61.4806	-68.8729	-77.0585
Galle	-55.65	12.83	164.54	-68.8649	-76.7554	-85.4926
Matara	-27.93	7.32	53.64	-35.4696	-39.9714	-44.9563
Kegalle	-34.86	10.51	110.36	-45.6853	-52.149	-59.3063
Ratnapura	-48.14	10.26	105.37	-58.7078	-65.0177	-72.0048
Kandy	-73.56	16.17	261.37	-90.2151	-100.16	-111.171
Nuwaraeliya	-40.74	9.93	98.69	-50.9679	-57.0749	-63.8372
Badulla	-26.18	6.56	42.99	-32.9368	-36.9712	-41.4386

District		Std dev	Variance	alpha = 0.15	alpha = 0.05	alpha =0.01
Puttalam	-36.55	2.73	7.46	-39.3619	-41.0409	-42.9
Kurunagala	-10.89	36.19	1309.81	-48.1657	-70.4226	-95.0679
Matale	-18.46	3.41	11.65	-21.9723	-24.0695	-26.3917
Monaragala	-16.17	3.41	11.63	-19.6823	-21.7795	-24.1017
Jaffna				-19.6823	-21.7795	-24.1017
Vauniya	-9.29	4.18	17.49	-13.5954	-16.1661	-19.0127
Mannar	-9.03	1.69	2.85	-10.7707	-11.8101	-12.9609
Anuradhapura	-11.01	45.82	2099.62	-58.2046	-86.3839	-117.587
Polonnaruwa	137.59	54.17	2934.70	193.3851	226.6997	263.5894
Trincomalee	4.87	11.16	124.51	16.3648	23.2282	30.82816
Batticaloa	1.35	10.18	103.63	11.8354	18.0961	25.02868
Ampara	146.12	40.10	1607.83	187.423	212.0845	239.3926
Hambantota	50.83	17.00	289.15	68.34	78.795	90.372

In ‘Maha season Colombo, Kalutara, Galle, Matara, Kegalle, Ratnapura, Kandy, Nuwaraelliya Puttalam and Jaffna districts always be consumer districts in both simulated and actual deterministic transportation strategies. Kurunagala is consumer of actual case but it plays as the largest supplier to Colombo in the simulation. Badulla district does not play as supplier or consumer in both actual and simulated cases of this season. But it has been consumer of the years 1998, 1999 & 2003 and supplier of the year 1989 according to the solutions of transportation problems. When the minimum probability of supply constraint is decreased, the number of suppliers is increased. In this operational study, if the supply minimum probability is reduce from 0.15 to 0.05, the Monaragala district becomes a supplier and if that probability further decreases to 0.01, Matale and Vauniya also become suppliers. In the ‘Maha’ season of the year 2004, the actual transportation strategy shows that Badulla, Matale, and Anuradhapura do not play as supplier nor consumer. However, in simulations sometime Matale plays as supplier while Anuradhapura plays as supplier in all cases.

The major consumer, - the Colombo district obtains all of its requirements from Polonnaruwa and Trincomalee of year 2004 in ‘Maha’ season but in simulation Kurunagala, Polonnaruwa and Batticaloa are the major suppliers for the Colombo district. Moreover, in the actual case, the highest supplier for Colombo is Polonnaruwa whereas the simulation shows that the highest supplier is Kurunagala. In the ‘Yala’ season of year 2004, both actual and simulated cases show that supplier are same and they are Polonnaruwa, Trincomalee, Batticaloa, Ampara &

Hambantota. Moreover, when the minimum probability of demand constraint is increased, the number of consumers is decreased.

Initially, the 'Yala' season of year 2004 Monaragala go away from the consumer list and then Matale and Vauniya are also removed. However, Monaragala and Vauniya are not the consumers in actual transportation strategy but Matale is a consumer. In this season, suppliers are same in both actual and all simulation cases. As there are few suppliers in 'Yala' season, most of the consumers take their needs from fictitious supplier which is stored in 'Maha' season by its suppliers. Both actual and simulated cases show that almost all same consumers receive paddy from fictitious supplier but amounts they received are little deviated. In actual case, the Kalutara and Puttalum receive paddy from fictitious supplier with 0.27 thousand metric tons and 47.39 thousand metric tons respectively but simulation transportation strategy show that these two district requirements are not fulfilled by fictitious supplier; instead they get their requirement from Hambantota & Polonnaruwa respectively. Moreover, Puttalum district receive all of its requirements from fictitious supplier in actual case but simulation transportation strategy shows that all its requirements are fulfilled from the Polonnaruwa district.

4. Discussion and Conclusion

Paddy performance of 'Mahavalli H' region and 'Udawalawe' region which are recorded on Central Bank annual reports are added to their respective district to build up transportation problem based on distances of the AAA road map. Therefore, paddy production of those regions is added to 'Polonnaruwa' and 'Hambantota' districts respectively. Moreover, 'Gampaha', 'Kilinochchi' and 'Mulativu' districts are not considered here as the AAA road map not included those districts to get districts-wise minimum distance systematically.

Transportation costs have been taken to be proportional to the minimum road distance among the districts. However, the other related costs such as loading, unloading, storing and inventory costs are not considered here. Therefore, this model assumes the storage of excess production which is assumed to have no significant cost involvement to be used in the next season instead transporting. Moreover, in this operational study, it is assumed that the total annual production is sufficient for consumption for the entire population. It has not considered export and import situations. This scenario can be included to improve the model by adding as production of the shipped district if it is imported and deducting as consume amount of the shipped district if it is exported.

From this study it is easy to conclude that there is a supply/demand pattern and results are useful in decision making towards cost reduction. Further, if supply and demand constraints hold minimum reasonable probabilities, forecasted amounts of supply or demand and transportation strategy are sufficiently close to actual cost beneficial transportation strategy.

Moreover, it can be concluded that the consumers those who receive their needs from fictitious suppliers in ‘Yala’ season could get their regular supplies in ‘Maha’ season as shown in transportation strategy. For instance, Polonnaruwa supplies large amount of its surplus paddy in ‘Maha’ season to fictitious consumer in every year. Then the Colombo district gets its additional requirement from fictitious supplier in ‘Yala’ season in every year. So this requirement could be met from Polonnaruwa district which is one of the suppliers of Colombo. Moreover, additional requirement of Colombo and Kalutara districts that are taken from fictitious supplier in ‘Yala’ is nearly equal or less than the amount which is fictitious consumer getting from Polonnaruwa district in ‘Maha’ season.

In Maha season, consumer districts are same in both actual and simulated cases but two more supplier districts are added to simulated cases than the actual case. Moreover, the number of supplier districts increased one by one in the second and the third simulated cases. Transportation costs are increased 6%, 51% and 34% of simulated cases than the actual case. In contrast, ‘Yala’ season supplier districts are same in both actual and simulated cases, but two consumer districts are dropped from simulated cases. However, another three more districts are added as consumers to the first simulation case and then the number of consumer districts decrease by one and two from second and third simulation cases respectively. Transportation costs are relatively deviate from actual case however considerable amount of paddy are supplied by fictitious supplier in both actual and simulated case.

It is assumed that both supply and demands are normally distributed. But both paddy production and population densities have upward trends. Therefore, further research could be done trying with some more probability distributions, and extension of this model is possible for specific practical situation.

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Appendix

Table A.1 Initial transportation table of the year 2004 (a) 'Maha' season (b) 'Yala' season (‘000 MT). (Transportation cost, which is proportional to minimum road distance, is indicated after row and column deduction).

(a)

2004 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Kurunagala	Jaffna	Supply
Monaragala	34	0	112	65	95	0	78	0	242	120	335	14.93
Vauniya	33	57	196	288	34	130	52	129	0	34	0	7.17
Mannar	33	57	196	288	34	130	52	129	0	34	19	9.75
Polonnaruwa	0	23	163	255	0	96	18	95	53	0	146	309.1
Trincomalee	0	23	163	255	0	96	18	95	53	0	146	61.73
Baticaloa	0	23	163	255	0	96	18	95	53	0	146	72.38
Ampara	71	36	100	103	7	37	0	37	126	42	269	203.29
Hambantota	67	2	0	0	118	24	168	90	253	166	454	68.99
Demand	-161.25	-50.94	-40.75	-17.41	-37.95	-46.04	-62.4	-44.33	-31.83	-35.82	-31.71	

(b)

2004 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Kurunagala	Matale	Anuradhapura	Supply
Polonnaruwa	0	42	184	276	1	93	26	66	132	0	0	9	0	151.81
Trincomalee	0	42	184	276	1	93	26	66	132	0	0	9	0	0.54
Baticaloa	0	42	184	276	1	93	26	66	132	0	0	9	0	10.02
Ampara	63	47	113	116	0	26	0	0	0	65	34	0	97	208.45
Hambantota	46	0	0	0	98	0	155	40	57	179	145	159	287	61.16
Demand	-172.38	-61.43	-57.52	-18.68	-39.13	-49.53	-73.69	-49.83	-2.25	-47.39	-40.6	-2.87	-3.6	

Table A.2 Simulated initial transportation table of the year 2004 'Maha' season (a) α=0.15, 1-β=0.85 (b) α=0.05, 1-β=0.95 (c) α=0.01, 1-β=0.99(‘000 MT)

(a)

2004E1 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	N'eliya	Puttalam	Jaffna	Supply
Kurunagala	0	0	130	222	0	40	10	50	55	237	85.62
Mannar	66	66	196	288	66	106	52	92	0	0	4.77
Anuradhapura	71	70	201	293	79	119	64	105	0	87	80.49
Polonnaruwa	15	14	145	237	14	54	0	40	35	109	293.36
Trincomalee	15	14	145	237	14	54	0	40	35	109	42.37
Baticaloa	15	14	145	237	14	54	0	40	35	109	61.96
Ampara	104	45	100	103	39	13	0	0	126	250	189.41
Hambantota	100	11	0	0	150	0	168	53	253	435	95.36
Demand	-177.23	-50.44	-46.46	-26.77	-39.28	-49.93	-74.49	-43.45	-32.71	-62.58	

(b)

2004E2 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	N'eliya	Puttalam	Jaffna	Supply
Kurunagala	0	0	130	222	0	64	10	87	55	237	85.49
Monaragala	67	9	112	65	127	0	78	0	242	316	0.46
Mannar	66	66	196	288	66	130	52	129	0	0	9.3
Anuradhapura	71	70	201	293	79	143	64	142	0	87	87.7
Polonnaruwa	15	14	145	237	14	78	0	77	35	109	312.66
Trincomalee	15	14	145	237	14	78	0	77	35	109	52.18
Baticaloa	15	14	145	237	14	78	0	77	35	109	77.3
Ampara	104	45	100	103	39	37	0	37	126	250	218.08
Hambantota	100	11	0	0	150	24	168	90	253	435	107.29
Demand	-192.78	-57.98	-52.3	-31.91	-46.35	-56.89	-84.17	-49.55	-38.94	-70.18	

(c)

2004E3 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Jaffna	Supply
Kurunagala	0	0	130	222	0	64	10	87	55	256	85.34
Matale	55	54	184	277	38	119	0	77	128	254	1.33
Monaragala	67	9	112	65	127	0	78	0	242	335	2.44
Vauniya	66	66	196	288	66	130	52	129	0	0	1.44
Mannar	66	66	196	288	66	130	52	129	0	19	14.32
Anuradhapura	71	70	201	293	79	143	64	142	0	106	95.68
Polonnaruwa	15	14	145	237	14	78	0	77	35	128	334.03
Trincomalee	15	14	145	237	14	78	0	77	35	128	63.05
Baticaloa	15	14	145	237	14	78	0	77	35	128	94.28
Ampara	104	45	100	103	39	37	0	37	126	269	249.83
Hambantota	100	11	0	0	150	24	168	90	253	454	120.49
Demand	-210	-66.34	-58.77	-37.59	-54.18	-64.6	-94.89	-56.32	-45.83	-78.6	

Table A.3 Simulated initial transportation table of the year 2004 'Yala' season (a) α=0.15, 1-β=0.85 (b) α=0.05, 1-β=0.95 (c) α=0.01, 1-β=0.99(‘000 MT)

(a)

2004E1Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Matale	Monaragala	Jaffna	Vauniya	Supply
Polonnaruwa	0	3	145	237	0	54	0	0	36	0	0	247	0	0	193.39
Trincomalee	0	3	145	237	0	54	0	0	36	0	0	247	0	0	16.36
Baticaloa	0	3	145	237	0	54	0	0	36	0	0	247	0	0	11.84
Ampara	182	127	193	196	118	106	93	53	23	184	110	0	234	214	187.42
Hambantota	85	0	0	0	136	0	168	13	0	218	189	36	326	325	68.34
Demand	-187.35	-61.48	-68.86	-35.47	-45.69	-58.71	-90.22	-50.97	-19.42	-39.36	-1.62	-1.33	-19.68	-2.38	

(b)

2004E3 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Matale	Jaffna	Vauniya	Supply
Polonnaruwa	0	3	145	237	0	54	0	27	93	0	0	0	0	226.7
Trincomalee	0	3	145	237	0	54	0	27	93	0	0	0	0	23.23
Baticaloa	0	3	145	237	0	54	0	27	93	0	0	0	0	18.1
Ampara	102	47	113	116	38	26	13	0	0	104	30	154	134	212.08
Hambantota	85	0	0	0	136	0	168	40	57	218	189	326	325	78.8
Demand	-202.56	-68.87	-76.76	-39.97	-52.15	-65.02	-100.16	-57.07	-19	-41.04	-0.22	-21.78	-0.57	

(c)

2004E3 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Jaffna	Supply
Polonnaruwa	0	3	145	237	0	54	0	27	93	0	0	263.59
Trincomalee	0	3	145	237	0	54	0	27	93	0	0	30.83
Baticaloa	0	3	145	237	0	54	0	27	93	0	0	25.03
Ampara	102	47	113	116	38	26	13	0	0	104	154	239.39
Hambantota	85	0	0	0	136	0	168	40	57	218	326	90.37
Demand	-219.4	-77.06	-85.49	-44.96	-59.31	-72	-111.17	-63.84	-18.54	-42.9	-24.1	

Table A.4 The amount of paddy to be transported (Optimum Table) for the year 2004 'Maha' seasons (‘000 MT)

2004 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Kurunagala	Jaffna	Fictitous Consumer
Monaragala	0	0	0	0	0	14.93	0	0	0	0	0	0
Vauniya	0	0	0	0	0	0	0	0	0	0	7.17	0
Mannar	0	0	0	0	0	0	0	0	0	0	9.75	0
Polonnaruwa	148.6	40.11	0	0	37.95	0	0	0	31.83	35.82	14.79	0
Trincomalee	12.65	0	0	0	0	0	0	0	0	0	0	49.08
Baticaloa	0	0	0	0	0	0	0	0	0	0	0	72.38
Ampara	0	0	0	0	0	31.11	62.4	44.33	0	0	0	65.45
Hambantota	0	10.83	40.75	17.41	0	0	0	0	0	0	0	0

Table A.5 The amount of paddy to be transported (Optimum Table) for the year 2004 'Yala' seasons (‘000 MT)

2004 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Kurunagala	Matale	Anuradhapura
Polonnaruwa	107.61	0	0	0	0	0	0	0	0	0	40.6	0	3.6
Trincomalee	0.54	0	0	0	0	0	0	0	0	0	0	0	0
Baticaloa	10.02	0	0	0	0	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	39.13	40.68	73.69	49.83	2.25	0	0	2.87	0
Hambantota	0	61.16	0	0	0	0	0	0	0	0	0	0	0
FS	54.21	0.27	57.52	18.68	0	8.85	0	0	0	47.39	0	0	0

Table A.6 Simulated transportation strategy of 'Maha' season of the year 2004 (paddy '000 MT to be transported) (a) α=0.15, 1-β=0.85 (b) α=0.05, 1-β=0.95 (c) α=0.01, 1-β=0.99

(a)

2004E1Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Jaffna	FC
Kurunagala	85.62	0	0	0	0	0	0	0	0	0	0
Mannar	0	0	0	0	0	0	0	0	0	4.77	0
Anuradhapura	0	0	0	0	0	0	0	0	32.71	47.78	0
Polonnaruwa	29.65	47.35	0	0	0	0	0	0	0	10.03	206.33
Trincomalee	0	3.09	0	0	39.28	0	0	0	0	0	0
Batiticaloa	61.96	0	0	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	0	27.8	74.49	43.45	0	0	43.67
Hambantota	0	0	46.46	26.77	0	22.13	0	0	0	0	0

(b)

2004E1Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Jaffna	FC
Kurunagala	85.62	0	0	0	0	0	0	0	0	0	0
Mannar	0	0	0	0	0	0	0	0	0	4.77	0
Anuradhapura	0	0	0	0	0	0	0	0	32.71	47.78	0
Polonnaruwa	29.65	47.35	0	0	0	0	0	0	0	10.03	206.33
Trincomalee	0	3.09	0	0	39.28	0	0	0	0	0	0
Batiticaloa	61.96	0	0	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	0	27.8	74.49	43.45	0	0	43.67
Hambantota	0	0	46.46	26.77	0	22.13	0	0	0	0	0

(c)

2004E3 Maha	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Puttalam	Jaffna	FC
Kurunagala	85.34	0	0	0	0	0	0	0	0	0	0
Matale	0	0	0	0	0	0	0	0	0	0	1.33
Monaragala	0	0	0	0	0	2.44	0	0	0	0	0
Vauniya	0	0	0	0	0	0	0	0	0	1.44	0
Mannar	0	0	0	0	0	0	0	0	0	14.32	0
Anuradhapura	0	0	0	0	0	0	0	0	45.83	49.85	0
Polonnaruwa	84.56	3.29	0	0	0	0	0	0	0	12.99	233.19
Trincomalee	0	63.05	0	0	0	0	0	0	0	0	0
Batiticaloa	40.1	0	0	0	54.18	0	0	0	0	0	0
Ampara	0	0	0	0	0	38.03	94.89	56.32	0	0	60.59
Hambantota	0	0	58.77	37.59	0	24.13	0	0	0	0	0

Table A.7 Simulated transportation strategy of ‘Yala’ season of the year 2004 (paddy ‘000 MT to be transported) (a) α=0.15, 1-β=0.85 (b) α=0.05, 1-β=0.95 (c) α=0.01, 1-β=0.99

(a)

2004E1Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Matale	Monaragala	Jaffna	Vauniya
Polonnaruwa	130.35	0	0	0	0	0	0	0	0	39.36	1.62	0	19.68	2.38
Trincomalee	16.36	0	0	0	0	0	0	0	0	0	0	0	0	0
Batiticaloa	11.84	0	0	0	0	0	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	0	25.48	90.22	50.97	19.42	0	0	1.33	0	0
Hambantota	0	61.48	6.86	0	0	0	0	0	0	0	0	0	0	0
FS	28.8	0	62	35.47	45.69	33.23	0	0	0	0	0	0	0	0

(b)

2004E3 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Matale	Jaffna	Vauniya
Polonnaruwa	152.27	0	0	0	10.82	0	0	0	0	41.04	0.22	21.78	0.57
Trincomalee	0	0	0	0	23.23	0	0	0	0	0	0	0	0
Batiticaloa	0	0	0	0	18.1	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	0	35.85	100.16	57.07	19	0	0	0	0
Hambantota	0	68.87	9.93	0	0	0	0	0	0	0	0	0	0
FS	50.29	0	66.83	39.97	0	29.17	0	0	0	0	0	0	0

(c)

2004E3 Yala	Colombo	Kalutara	Galle	Matara	Kegalle	Ratnapura	Kandy	Nuwaraeliya	Badulla	Puttalam	Jaffna
Polonnaruwa	168.11	0	0	0	28.48	0	0	0	0	42.9	24.1
Trincomalee	0	0	0	0	30.83	0	0	0	0	0	0
Batiticaloa	25.03	0	0	0	0	0	0	0	0	0	0
Ampara	0	0	0	0	0	45.84	111.17	63.84	18.54	0	0
Hambantota	0	77.06	13.31	0	0	0	0	0	0	0	0
FS	26.26	0	72.18	44.96	0	26.16	0	0	0	0	0

Table A.8 Data sheet for the year 2004, S: Supplier district, D: Consumer District

Year	Production(MT)			Popula-tion ('000)	Gamma		Supplier/ Consumer		Amount ('000)		Adjusted amount ('000)	
	Maha	Yala	Total		Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
					74.58291	74.58291						
Colombo	13421	2301	15722	2342	5.73	0.98	D	D	-161.25	-172.38	-161.25	-172.38
Kalutara	29983	19494	49477	1085	27.63	17.97	D	D	-50.94	-61.43	-50.94	-61.43
Galle	35318	18556	53874	1020	34.63	18.19	D	D	-40.75	-57.52	-40.75	-57.52
Matara	41359	40097	81456	788	52.49	50.88	D	D	-17.41	-18.68	-17.41	-18.68
Kegalle	21051	19868	40919	791	26.61	25.12	D	D	-37.95	-39.13	-37.95	-39.13
Ratnapura	32194	28712	60906	1049	30.69	27.37	D	D	-46.04	-49.53	-46.04	-49.53
Kandy	36423	25133	61556	1325	27.49	18.97	D	D	-62.4	-73.69	-62.4	-73.69
Nuwaraeliya	9520	4018	13538	722	13.19	5.57	D	D	-44.33	-49.83	-44.33	-49.83
Badulla	77246	41778	119024	813	95.01	51.39	S	D	16.61	-18.86	0	-2.25
Puttalam	22468	6898	29366	728	30.86	9.48	D	D	-31.83	-47.39	-31.83	-47.39
Kurunagala	75011	70229	145240	1486	50.48	47.26	D	D	-35.82	-40.6	-35.82	-40.6
Matale	50863	14732	65595	459	110.81	32.1	S	D	16.63	-19.5	0	-2.87
Monaragala	58360	17733	76093	410	142.34	43.25	S	D	27.78	-12.85	14.93	0
Jaffna	12734		12734	596	21.37		D		-31.71		-31.71	
Vauniya	27926	432	28358	142	196.66	3.04	S	D	17.33	-10.16	7.17	0
Mannar	23683	539	24222	97	244.15	5.56	S	D	16.45	-6.7	9.75	0
Anurad-hapura	101782	9917	111699	773	131.67	12.83	S	D	44.13	-47.73	0	-3.6
Polonnaruwa	336844	179557	516401	372	905.49	482.68	S	S	309.1	151.81	309.1	151.81
Trincomalee	90300	29107	119407	383	235.77	76	S	S	61.73	0.54	61.73	0.54
Batiticaloa	112951	50592	163543	544	207.63	93	S	S	72.38	10.02	72.38	10.02
Ampara	249004	254170	503174	613	406.21	414.63	S	S	203.29	208.45	203.29	208.45
Hambantota	109113	101287	210400	538	202.81	188.27	S	S	68.99	61.16	68.99	61.16

References

De Silva G T F, Ahlip R A. (Dec. 1979). Rice Transportation Strategy for Sri Lanka. *SLAAS Annual Session*.

Mohan,C. and Nguyen, H. T. (1997). A Fuzzifying Approach to Stochastic Programming. *Opsearch* 34, 2: 73-96

Hamdy A Taha. (1999). Operations Research an Introduction. Pp.165-208, 807-809, *Prentice Hall of India*.

Harvey M Wagner (1999). Principles of Operations Research with Applications to Managerial Decisions. *Prentice Hall of India, New Delhi*.

Central Bank of Sri Lanka (1989-2004). Annual Report. *Central Bank of Sri Lanka Colombo*

Supply of Rice, Wheat and Sugar for Human Consumption by Source of Supply and Rate of Self Suffficiency. http://www.statistics.gov.lk/agriculture/RiceProductionandImports.pdf.