भारत सरकार
इलेक्ट्रॉनिकी और सूचना प्रौद्योगिकी मंत्रालय
राष्ट्रीय सूचना-विज्ञान केन्द्र
ए-ब्लॉक, केन्द्रीय कार्यालय परिसर, लोधी रोड,
नई दिल्ली-110 003

सत्यमेव जयते

Government of India
MINISTRY OF ELECTRONICS & INFORMATION TECHNOLOGY
NATIONAL INFORMATICS CENTRE
A-BLOCK, C.G.O. COMPLEX, LODHI ROAD
NEW DELHI-110 003
ग्राम्स / GRAMS : INCENT HQ
फैक्स / FAX :
ई-मेल / E-mail :

Certificate of Internship

This is to certify that **Yash Vinayvanshi (ROLL NO. 19BCS081)** student of **Bachelor of Technology (Computer Engineering)** 6th Semester at **Faculty of Engineering & Technology, Jamia Millia Islamia, Delhi** has devised and successfully demonstrated an innovative optimization method for transportation problem in the supply chain of Food Corporation of India (FCI) in his thesis titled **"An electrical network based model and solution method for transportation planning in food grain supply chain (Case: Food Corporation of India)"** under my supervision during his research internship at **Food and Public Distribution Division, National Informatics Centre** from 2 May 2022 to 31 May 2022.

Date: 01 June 2022

(Chandan Pandey)

Scientist/Senior Systems Analyst
chandan.pandey@gov.in
011-24305743

चन्दन पाण्डेय / CHANDAN PANDEY
वैज्ञानिक–सी / Scientist - C
भारत सरकार / Govt. of India
राष्ट्रीय सूचना विज्ञान केन्द्र / N. I. C.
इलेक्ट्रॉनिकी और सूचना प्रौद्योगिकी मंत्रालय / MeitY
ए–ब्लाक, सी.जी.ओ. कॉम्प्लेक्स लोधी रोड, नई दिल्ली-03
A-Block CGO Complex, Lodhi Road, New Delhi-03

An electrical network based model and solution method for transportation planning in food grain supply chain.

(Case: Food Corporation of India)

By

YASH VINAYVANSHI
Bachelor of Technology (Computer Engineering) Semester VI
Faculty of Engineering & Technology
Department of Computer Engineering,
Jamia Millia Islamia, New Delhi - 110025
email : yash.vinayvanshi@gmail.com

under guidance of

SHRI CHANDAN PANDEY
SCIENTIST / SENIOR SYSTEMS ANALYST

undertaken during internship at

NATIONAL INFORMATICS CENTRE
GOVT. OF INDIA

from
1 May 2022 to 1 June 2022

ABSTRACT

We model the transportation problem in Food Corporation of India's (FCI) godown network as an electrical circuit and simulate it for producing approximately optimal transportation schedules yielding minimal cost. FCI is central nodal agency which is responsible for procurement, storage, movement and distribution of food grains throughout the nation. FCI operates nearly 2000 godowns all over India and moves food grains to evacuate stocks from surplus regions and meet requirement of deficit regions and also maintains buffer stocks for food security. The problem is, given a system with current stock status of godowns, demands and supplies, and distance graph indicating transportation costs incurred along routes between different godowns, **from where to and how much to transport such that transportation and operation cost is minimised**, with several added constraints of maintaining specified buffers, vehicle capacity and availability.

INTRODUCTON

Government of India (GoI) has an objective of ensuring minimum support price (MSP) to farmers, availability of food grains to the weaker sections at affordable prices and maintaining food security for the nation. Food corporation of India (FCI) is a nodal central agency which, along with state agencies is responsible for handling **procurement, storage, movement, transportation and distribution** of food grains throughout the nation[1]. The food grain supply chain of India is extremely complex and the scales involved are in hundreds of lakh of metric tonnes. Consequently, a vast amount of planning is required to operate the food grain supply chain of India. Optimisation is an invariable part of planning, but optimisation of such a complex process poses two challenges, one is to model various phases of supply chain and their practical constraints accurately and second is to use the model to obtain optimal solution. The optimisation formulations for such problem are NP hard not possible to solve exactly in practical time. Therefore, heuristic methods are employed to obtain approximately optimal solutions. In a scheme of such a large scale, transportation costs accumulate to vast sum of amounts, therefore even slight optimisation in transportation schedules, can save large amounts of public resources.
In this section we describe the supply chain of FCI, the scales involved in it, and the practical challenges faced at various stages.

1. SUPPLY CHAIN OF FCI

1.2. Procurement

To facilitate procurement of food grains, FCI and various State Agencies in consultation with the State Government establish a large number of **purchase centres** at various **mandis** and key points. Coarse grains, especially wheat & paddy are procured under support scheme mainly by state government agencies for **Central Pool** as per the direction issued by Government of India time to time. [1]
Procurement of food grains is done through Centralised Procurement System (CP) and Decentralised Procurement System (DCP). Under CP, the procurement of food grains in Central Pool are undertaken either by FCI directly or State Government agencies procures the food grains and handover the stocks to FCI for storage and subsequent issue against GoI allocations in the same State or movement of surplus stocks to other States. The cost of the food grains procured by State agencies is reimbursed by FCI as soon as the stocks are delivered to FCI as per cost-sheets issued by GoI. The scheme of Decentralised Procurement of food grains was introduced by the Government in 1997 with a view to enhancing the efficiency of procurement and PDS and encouraging local procurement to the maximum extent thereby extending the benefits of MSP to local farmers as well as to save on transit costs. This also enables procurement of food grains more suited to the local taste. Under this scheme, the State Government itself undertakes direct purchase of paddy/rice and wheat and also stores and distributes these food grains under NFSA and other welfare schemes. The Central Government undertakes to meet the entire expenditure incurred by the State Governments on the procurement operations as per the approved costing [2].
Procurement operations are seasonal. **Kharif Marketing Season** (KMS) starts from 1st October and lasts upto 30 September next year. Paddy / Rice and coarse grains like jowar, bajra, ragi & maize are procured during the KMS. The **Rabi Marketing Season** (RMS) starts from 1 April and lasts upto 31 March next year. Mostly, wheat and sometimes barley is procured during RMS. The kharif cropping season is from July–October during the south-west monsoon and the Rabi cropping season is from October-March (winter) [3].

1.3 Storage

FCI has to store stocks to meet the requirements of Public Distribution System and Other Welfare Schemes undertaken by the Government of India. Also, buffer stock is to be maintained for ensuring food security of the nation. Besides having own storage capacity, FCI has hired storage capacities from Central Warehousing Corporation, State Warehousing Corporations, State Agencies and Private Parties [4]. FCI has a network of strategically located storage depots including silos all over India. There is state warehouse corporation (SWC) which maintains godowns owned by states and central warehousing corporation (CWC) which maintains godowns owned by FCI. FCI procures itself, or states do on behalf of it, food grain for central pool. Owner of central pool is FCI, and all the central government schemes are catered by this pool. States can also maintain their state pool for state level schemes. State godowns can are hired by FCI to store either centralised procurement by FCI itself or decentralised procurement for FCI by states. Each fair price shop is mapped to a closest godown for supplies, similarly, each procurement centre is mapped to a closest godown for storage of procured grain.

1.4 Movement / Transportation

Punjab, Haryana and Madhya Pradesh are the surplus States in terms of wheat procurement vis-a-vis their own consumption. Punjab, Haryana, Andhra Pradesh, Telangana, Chhattisgarh and Odisha are surplus States in terms of rice procurement vis-à-vis their own consumption. Surplus stocks of wheat and rice available in these States are moved to deficit States to meet the requirements under NFSA/TPDS and other schemes as well as to create buffer stocks.
FCI undertakes movement of food grains in order to: Evacuate stocks from surplus regions, meet the requirements of deficit regions for NFSA/TPDS and other schemes, create buffer stocks in deficit regions. Movement Plan is prepared on monthly basis keeping in view : quantity available in surplus regions, quantity required by deficit regions, likely procurement, vacant storage capacity both in consuming as well as procuring regions, monthly allotment/ off take of food grains.
Each state has several regions and each region has a set of state warehouses as well as FCI ware houses [6, 7].

1.4.1. Intrastate Model

Instead of FCI procuring from purchase centres and then transferring them to states, FCI allows states to procure food grain for central pool on behalf of FCI, which is called decentralised procurement. In intrastate model, the state uses food grain from central pool kept in state warehouses on behalf of FCI to transport food grains surplus state godowns to deficit state godowns. State surplus godowns are those which have excess stock due to decentralised procurement. If after this movement by state agencies, any state godown with deficit remains, then this requirement is communicated to FCI, which then fulfils this requirement from its own central godowns in the state. If Even FCI central godowns in the state do not have enough stock to meet state deficits, then FCI records it as a matter of intrastate deficit, and seeks to bring food grain from surplus central godowns of other states. Intrastate transport happens majorly by road. In fact in 2020-21, intrastate movement by road was 54 LMT, and by rail was merely 4LMT. The interaction of intra and interstate model is illustrated in fig1. [8, 9]

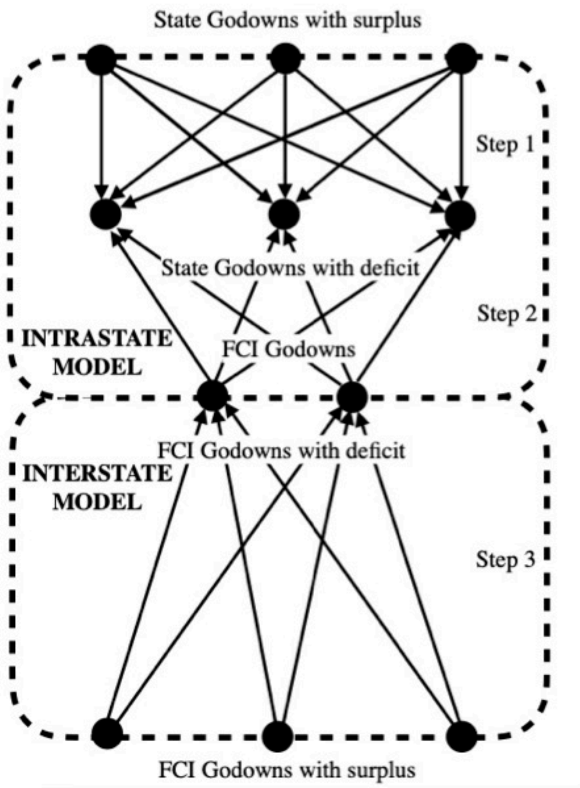


Figure 1 : Intrastate and Interstate model

1.4.2 Interstate Model

FCI plans its interstate movement based on orders from other states. Indian railways then execute the orders from the FCI. This requires efficient rake allocation and rake scheduling systems. Interstate transport occurs mostly by rail and by road to those locations to where there is no rail line. in fact in 2020-21, interstate movement by rail was 473.63 LMT, whole by road was 61.66 LMT. References [7, 8]

1.5 Distribution.

Distribution is from state godowns upto block level and then from a block to delivery points known as fair price shops (FPS) from where food grain is distributed to beneficiaries.

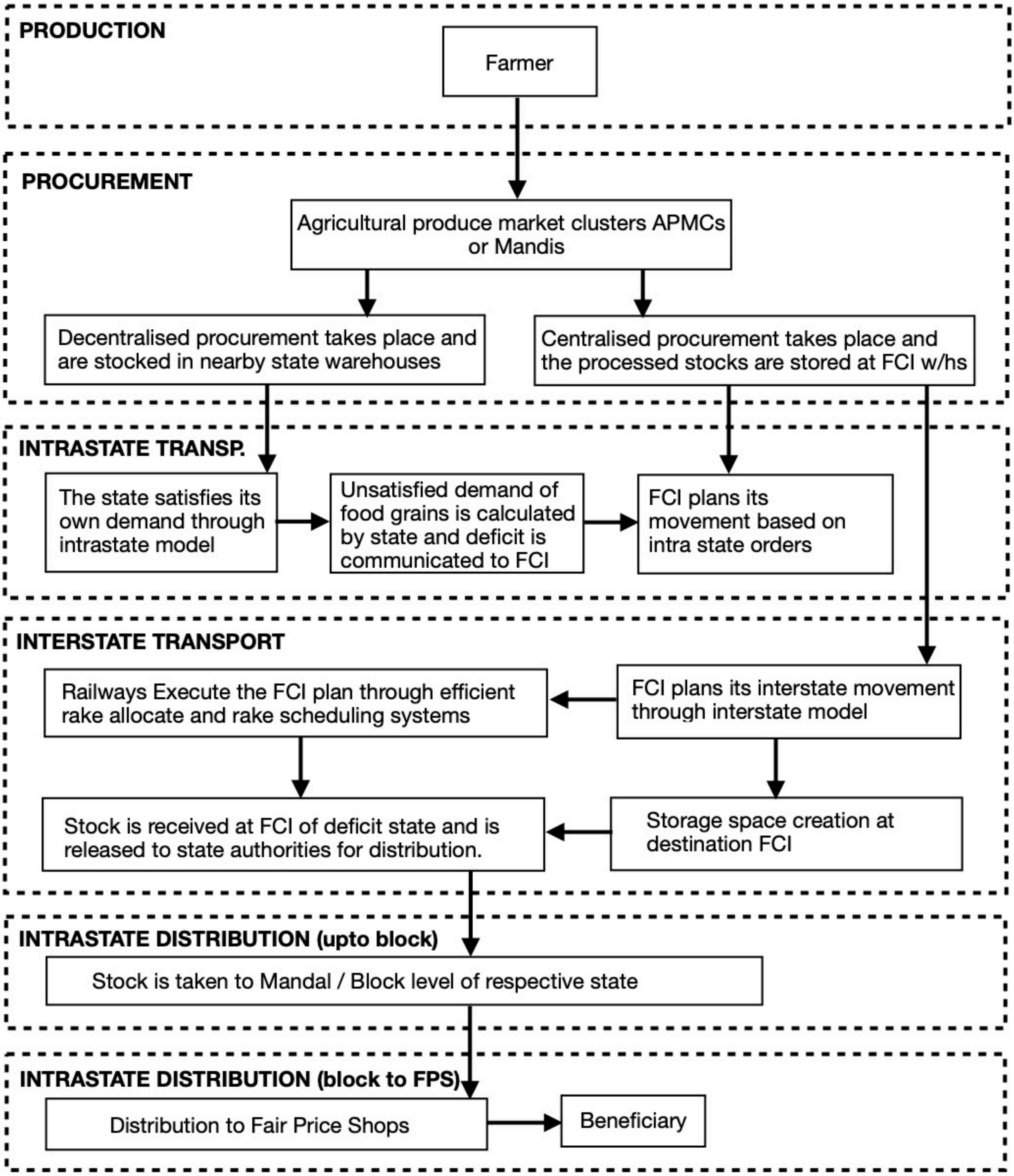


Figure 2 : Supply chain of FCI [7].

The process of transportation has been categorised into two stages, the intrastate transportation stage and the interstate transportation stage. In this paper we will model the general transportation problem and use it cumulatively model the two stages of transportation.The first stage consists of two steps : state's intrastate movement from central pool & FCI's intrastate movement, the second stage consists of one step : FCI's interstate transport.

The nature of the problem is, the demands on a godown are mostly fixed since beneficiaries are mapped to only their local fair price shops which are mapped to fixed godowns for supply. Supplies may change based on yield dependent on weather etcetera. However, with the one nation one ration card, it has been observed in covid 19 pandemic that huge labour migrations happened during which unconventional demands are faced in various regions.

2. SCALE OF THINGS

1. In year 2020-21, FCI, by itself and through state agencies has procured 389.92 Lakh metric tonnes (LMT) of wheat and 601.73 LMT of rice [12, 13].
2. The stock of food grains in central pool as on 1st April 2022 is around 950 (LMTs) against a total 817.96 LMT storage capacity of FCI in state warehousing corporation (SWCs) and central warehousing corporation (CWCs) combined [4,5].
3. For wheat procurement, 21,106 procurement centres in RMS 2021-22 & 74,684 procurement centres for procurement of paddy in KMS 2020-21 were operated.
4. FCI transports on average about 450 LMTs of food grain through a network of 2300 storage depots annually. There is on average a daily transportation of 20 lakh bags, 50 kg each via rail, road or waterways, from producing states to consuming states travelling an average distance of 1500 kms.
5. Above movement incurs annual cost of around ₹8046.8 crores. [11]
6. The total wastage of grain in transportation (manual loading & unloading, sweeping, spillages etc), leakages in PDS, shortage of manpower, underutilisation of existing storage facilities of food grain as of 2016, is around 60 LMT, whose monetary value is estimated to be around ₹50000 crores [14].
7. More than 60% of stocks procured are moved from from surplus regions to deficit regions.
8. More than 80% movement of food grains is undertaken by rail.
9. PDS is having a large network of 5.13 lakh fair price shops (FPS) throughout the country which makes it one of the largest retail system in the world.

3. PROBLEM

We describe several constraints in the transportation scenerio of supply chain described previously.

1. **Overspill** : Every godown has a maximum capacity of storage. Although temporary arrangements are made when surplus exceeds capacity, but in this article we assume that a godown cannot store more than its capacity.
2. **Multimodal Transport** : Intrastate transport happens majorly by road while interstate transport happens majorly by rail. But both has multimodal choices.
3. **Vehicle Availability** : The amount of transportation that can initiate from a node is restricted by how many vehicles are available at that node and their cumulative capacity.
4. **Vehicle Capacity** : The amount of transfer depends on vehicle capacity, in case of transport by rail in interstate model, a transport is initiated when the amount sums up a half or full rake.
5. **Transportation Cost** : The transportation cost charged by logistic agencies like railways decreases per unit weight as the distance increases and it also decreases due to economy of scales, when large consignments are delivered. Moreover railway also provides two-point

combination feature which allows to combine the demand of two destinations and places and place order for a full rake from source to avail the cost discount of ordering dull rake.

6. **Demurrage Cost** : If Rails run on schedule and they are not unloaded on time by FCI, or any delay caused by FCI to railway produces a demurrage cost to be paid by FCI to railways [7].
7. **Detention Cost** : If FCI trucks run on schedules and there is delay in rail arrival, or any delay caused by railway to FCI produces a detention cost to paid by railway to FCI .
8. **Minimum Buffer** : Government instructs to maintain some reserve in each godown, for its food security policy.
9. **Operational Cost** : Storing grains in a godown costs. Which include labour payments, warehouse equipment costs etcetera.
10. **Optimal Utilisation** : The load on godowns should be distributed such that a situation where few godowns are stressed and others godowns lie mostly free should not occur. Although this is a subjective requirement which depends on how well infrastructure is placed corresponding to production and demand.
11. **Shelf Life** : Older grains (within their shelf) are to be supplied first for consumption, to ensure least wastage. Grains out of the shelf life are discarded and used fo animal fodder or ethanol production and other industries.
12. **Planning Horizon** : Interstate transport happens once in a month. Also it reduces costs if the entire outflow of godown is within a specific week, it gives economy of scales cost discounts.
13. **Production topology** : Grain production is region and season specific. In winters, wheat grows in Northern India and the wheat demand of southern states is to be catered by transporting grain from Northern godowns to Southern godowns and so on. Rice production on the other hand is more uniform across the country.

Given the above constraints, which are not exhaustive, and several input parameters, a model is to be devised which produces a transportation schedule such the overall transportation and storage cost is minimised. The transportation schedule describes what amount of grain is to be transported from which godown to which other godown such that above constrains are fulfilled. The challenge is, the optimisation formulations with so many parameters and constraints is NP hard which implies finding exact solution is not possible in reasonable time for even small input spaces. Invariably a heuristic method has to be employed to get close to optimal solution but fast.

In this article, we develop a circuit simulation based model for general transportation problem with various practical constraints and then use it calculate schedules for intra and interstate transportation.

LITERATURE REVIEW

This is a practical version of the transportation problem studied in operations research. A lot of research is carried out for such transportation problem, but there is a gap between theoretical solutions and practical systems. Several non linear programming based solutions are proposed including different practical constraints. But the exact solution to the LPPs is known to be NP-hard and therefore heuristics known for their effectiveness for such problems are used, like ant colony optimisation, chemical reaction optimisation etcetera. The following works have been reported in context of FCI.

Maiyar et al[8], proposed a bilevel model for intrastate transport, A linear model for the first level considering only a single mode of transport by road, and a mixed integer non linear programming model for second level considering multimodal rain-road transportation. The paper also presented two variants of particle swarm optimisation to solve the model.

Mogale et al[14], considered the food transportation-allocation process and modelled both intrastate and interstate transportation using a mixed integer non linear programming to minimise transportation, inventory and operational costs and solved it using chemical reaction optimization heuristic. Later in[] , vehicle capacity constraint is also included in the model.

Anoop et al[15], proposed a model including more practical constraints in interstate transport phase of supply chain which assigns a penalty factors for quantifying demurrage risks in allocating full and half rakes, for capacity utilization of godowns and for quantifying priority of a particular week in a month over others for rake allocation. The two point combination provision by Indian railways was also considered. A multi-period integer non linear programming model was proposed to minimize the sum of these penalty factors and an optimal rake allocation heuristic to solve the model in reasonable time.

ELECTRICAL CIRCUIT BASED MODELLING

Model - 1 : CIRCUIT FOR UNBALANCED TRANSPORTATION PROBLEM

The transportation problem (TP) is, given supply points with their supply amounts and demand centres with their demand amounts and cost of transportation per unit between suppliers and consumers, to find how much grain from which supplier to which consumer should transported such that transportation cost is minimized. In unbalanced version of this problem (UTP), total supply may not be equal to total demand. The linear program formulation for this problem is simple and fast methods exist to find the exact optimal solution for UTP, if it exists. In this section, we model UTP as an electrical circuit and simulate it to find the optimal solution for a real life test case. Later, by comparing circuit simulated results with exact solution, we establish that if an electrical circuit is modelled accurately for an optimization problem, it can be simulated to obtain close to optimal solutions in reasonable time. The transportation problem of FCI is not a straight UTP, there are several other parameters than merely demand, supply and transportation costs, plus there are many more constraints to be imposed. Optimization formulations for such complex models are NP hard, for solving which this circuit simulation approach can be used. Electrical circuits by nature display optimization properties, for instance in a resistive network connecting differently charged capacitors, charge distribution takes place in such a way that potential at each node is same at steady state. And the current flows established during the process of achieving equilibrium are such that power dissipation is minimized among resistors is minimized.

In our circuit design of UTP, godowns are modelled as batteries whose potentials are proportional to their corresponding surpluses or deficits. The average monthly demand to be catered by a godown is provided in input, based on which and the current stock, we can calculate for how much days the stock will last. Suppose we want to transport grains in such a way that each godown holds at least 90 days of stock, in such a case, godowns with more than 90 days of stock will have surplus and godowns with less than 90 days of stock will have deficits. This divides the space of godowns into two mutually exclusive categories, one with surplus, and other with deficits. We can build a complete bipartite graph in which one set contains surplus godown and other contains deficit godowns and flow happens from surplus to deficit godowns. There is no flow between two godowns, both with surplus or both with deficit in this model. The potential of godowns is positive for surplus and negative for deficit and and is calculated as a linear function of surplus stock and amount of stock they are lacking for meeting their days requirement respectively. We initialize these potentials in the circuit and simulate it numerically until steady state is achieved.

During the simulation, currents flow in each arc according to ohm's law. The net charge, that flows through an edge until steady state is achieved, indicates what amount of grain is to be transported through the corresponding path. To simulate this circuit numerically, we define a quanta which is a small amount of charge that flows from higher potential source to lower potential destination, on reaching the destination, it reduces the potential difference between source and destination by a small amount. The size of quanta in an edge is nothing but current which is the rate of flow of charge times a time quanta, which we shall use to simulate the circuit on a digital machine. To simulate the circuit the machine iterates over each edge in a time shared manner, transferring a small quanta each time. This epoch is repeated to simulate the system to precision controlled by the chosen time factor. Broadly, the machine updates the overall system by a differential amount each time by calculating small changes in each edge one by one to accumulate changes in various regions of circuit in parallel.

If the potential of a deficit godown at any stage becomes zero, it implies that its requirement is fulfilled, and the transistor cuts off the godown from global supply system. Similarly, until godown has more stock than the stock it requires for its own days requirement, it participates in the circuit as a surplus godown with positive potential proportional to surplus stock and lends grain to deficit godowns, if it stocks reaches a bare minimum of its own requirement, its surplus becomes zero which means its potential becomes zero, thereby it is cutoff by the transistor to lend off any more in the system. The arms of the bipartite circuit contains resistances which are functions of cost per unit grain per unit distance and distance between two godowns. We have taken resistance as cost multiplied by distance squared, this would scale up the resistance much more with respect to distance and thus discourage movement from surplus godowns that are far away from a deficit godown, because it increases cost. The demand of a deficit godown will be fulfilled at a faster rate by nearer surplus godowns compared to farther surplus godowns, as resistance is much less in transporting grain from nearer godowns. If there is no nearby surplus remaining, then invariably grain will be transported from far away surplus godowns, even though it will happen slower, but at the end when algorithm converges, this does not matter as we are interested only in the net flow. This is nothing but a circuit performing charging and discharging of batteries upto certain limits. The intuition behind optimality of solution from circuit is, the resistance in each arc limits the current in that arc. Suppose we consider a deficit godown D connected to three surplus godowns G1, G2 & G3 with same potentials V1 = V2 = V3 through arcs of resistance R1, R2 & R3, where R1 < R2 < R3. Clearly, G1 will dispense charge toward D at a faster rate than G3 due to lower resistance in between. This is consistent with the requirement that surplus godowns from which transportation cost is minimum to a deficit godown, should lend more to that deficit godown to reduce cost if we assign resistance values proportional to the transportation costs. Similarly, suppose R1 = R2 = R3 and V1 < V2 < V3, in such a case G3 due to higher potential difference will lend more to D than G1. This is consistent with the requirement that godowns should work at good utilisations. Since G3 has larger days of reserve than G1, it is better if G3 reduces its days than G1 so that a more equitable distribution is achieved. Therefore the flow through a branch is dependent on a tradeoff between resistance across that branch and the potential difference across it.

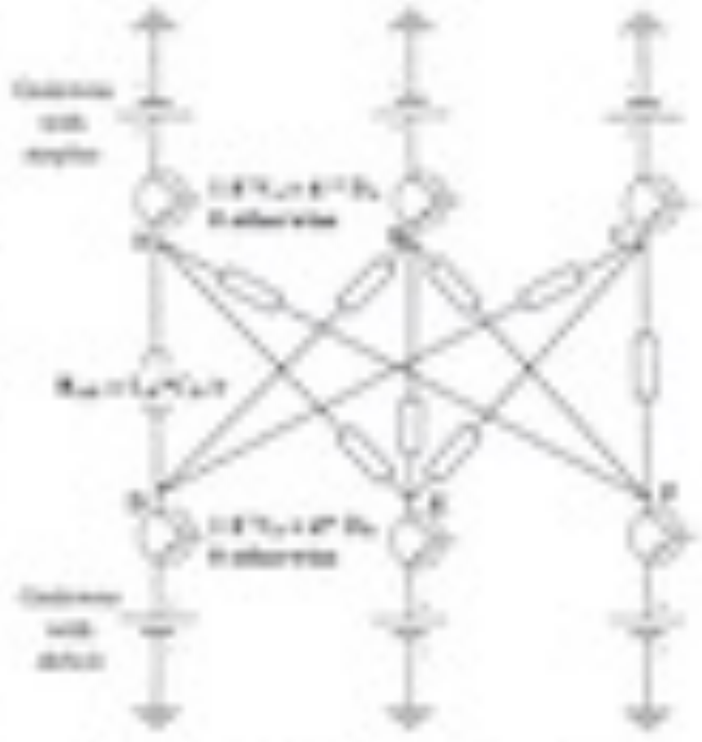


Figure 3 : Circuit for unbalanced transportation problem

ALGORITHM CTPC(n)

Assumptions

Since supply happens within weeks, it is assumed to be already absorbed in the grain stock.

Input

n : number of nodes (godowns)

Vector M[n] : M[i] denotes maximum capacity of a node.

Vector G[n] : G[i] denotes current stock stored in a node.

Matrix L[n, n] : L[i, j] represents distance from node i to j.

Matrix C[n, n] : C[i, j] represents transport cost per unit grain per unit distance on edge <i, j>.

Vector D[n] : D[i] represents average monthly local demand to be fulfilled by godown i.

Vector I[n] : I[i] = 1 if the godown i is taking part in interstate transport, 0 if it is isolated.

Operation :

Vector V[n] : V[i] represents current potential of a node i.

Vector W[n] : W[i] represent the global surplus or demand which node i has.

Matrix R[n, n] : R[i, j] represents resistance offered along an edge <i, j>.

Matrix F[n, n] : F[i, j] records net flow charge (grain) along an edge <i, j>. Initialised to 0.

P : total cost accumulated for entire flow at an instance. Initialised to 0.

Set S : holds godowns with surplus.

Set T : holds godowns with deficits.

Output :

Matrix F at defined steady state, which is the transportation schedule.

Value P which is the total cost incurred.

Constants :

Resistance adjustment factor r = 100000

Voltage adjustment factor v = 1000

Number of days to keep stock of , d = 90

Time factor t = 0.01

```
1. for i = 1 to n                                        [calculate resistance matrix]
   1. for j = 1 to n
      1. R[i, j] = C[i, j] * L[i, j]^2 / r               [res. proportional to distance squared]
2. for i = 1 to n
   1. remaining_days = ( G[i] / D[i] ) * 30              [of how many days stock exists]
   2. if remaining_days < d                              [if less than required days - deficit]
      1. W[i] = (remaining_days - d ) * ( D[i] / 30 )    [negative value]
      2. if W[i] > M[i]                                  [if godown cant accommodate its demand]
         1. W[i] = M[i]                                  [storage capped at maximum capacity]
   3. else
      1. W[i] = (d - remaining_days ) * ( D[i] / 30 )    [positive value]
3. for i = 1 to n
   1. if W[i] > 0                                        [is the godown surplus ?]
      1. S = S U {i}
   2. if W[i] < 0
      1. T = T U {i}                                     [is the godown deficit ?]
4. for i = 1 to n                                        [calculate potential based on surplus/def.]
   1. V[i] = W[i] / v
5. while true
   1. if ( |S| = 0 & |T| ≠ 0 )                           [no more surplus left, demand unfulfilled]
      1. return "Surplus not enough", F, P
   2. if ( |S| ≠ 0 & |T| = 0                             [demand fulfilled, still surplus left]
      1. return "Surplus more than enough", F, P
   3. if ( |S| = 0 & |T| = 0                             [rare case : balanced transportation prblm]
```

```
        1.  return "Surplus exactly match Deficit", F, P
   4.  for each i ∈ S                                    {for each surplus godown}
        1.  for each j ∈ T                               {for each deficit godown}
             1.  if I[i] = 1 & I[j] = 1                  {if neither is isolated}
                  1.  Q = ( | V[i] - V[j] | / R[i,j] ) * t   {build charge quantum}
                  2.  W[i] = W[i] - Q                    {flow charge quantum from surplus}
                  3.  W[j] = W[j] + Q                    {to deficit}
                  4.  V[i] = W[i] / c                    {update potential for new state after transfer}
                  5.  V[j] = W[j] / c
                  6.  F[i, j] = F[i, j] + Q              {record flow}
                  7.  P = Q * L[i, j] * C[i, j]          {add cost for charge quantum transfer}
                  8.  if W[i] < 0                        {if surplus of a godown exhausted}
                       1.  S = S - {i}                   {remove it from set of surplus godowns}
                  9.  if W[j] > 0                        {if demand of a godown is met}
                       1.  T = T - {j}                   {remove it from the set of deficit godowns}
5. return F, P                                           {return flow matrix & total cost incurred}
```

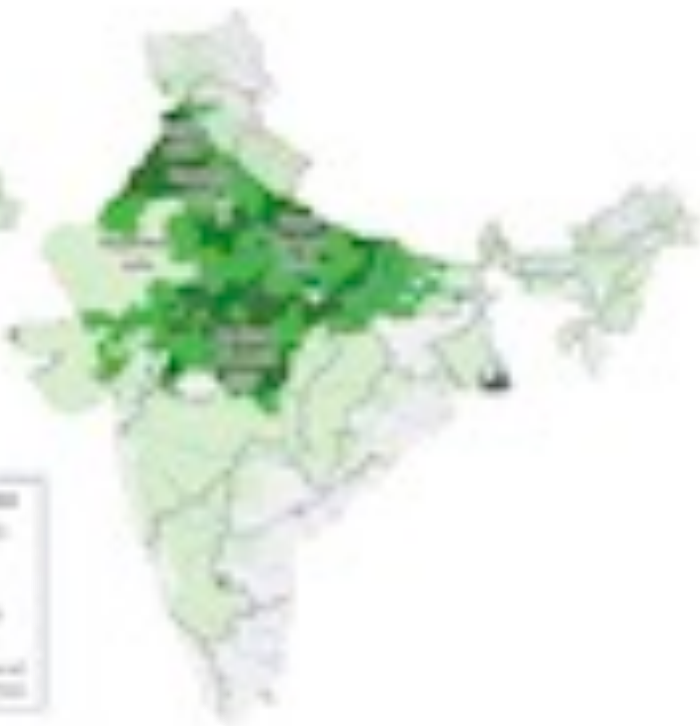
In this model we have that each godown has to reach the same number of days of stock, but this can be easily modified to have different amount to days of stock for different godowns. In such case, an additional vector N[n] will be provided in input in which N[i] describes of how much days ith godown should store stock of. And constant k will be replaced by N[i] everywhere in above pseudocode.

Illustration

In this test case we have assumed 18 godowns in India, and concentrated the capacities and demands of entire states into them for purpose of illustration.Local supply in each node assumed to be 0 as entire supply is accumulated within weeks in the procurement season, and thus the grain stock has already absorbed the entire supply. This test case is good for testing because it has hot rice and wheat test cases, there is more wheat production in Punjab area than entire remaining country, which simulates a system in which one node is extremely productive than others. Rice on the other hand is grown more uniformly allover the country which simulates a uniform distribution case. There is also a godown included in test cases named UDU which can be used to simulate outlying situations and illustrate masking of godowns. In the tests below, it is assumed to have no storage capacity or demand and is used to merely illustrate masking / isolation of godowns in each model.

Map 1 : Railway network between 18 godowns.

India : Kharif Rice production



India : Wheat Production

India : Per capita consumption of rice

India : per capita consumption of wheat

Depot /

n = 18

[illegible]

Distance Matrix (in,n) (Km) (railways)

[illegible]

Cost per tonne per Km Matrix [illegible] (railways)

This cost matrix is calculated based on Indian railways freight price list of grain freight class. Railways charges increasing freight charges per km as the distance increases.[illegible]

		Test case 1) RICE		Test case 2) WHEAT	
godown	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

For both cases : rice & wheat (produced from FCI movement report for quarter Feb - May [illegible])

[illegible]

Isolation vector [illegible] for set of godowns.

Output (for instance1)

[illegible]	[illegible]

Flow chart for Rice produced by above circuit simulation heuristic.
In this schedule, entry at index (i, j) indicates flow from godown i to j in MTs.

Total flow : [illegible]
Total cost : Rs. [illegible]
Number of iterations : [illegible]
Average distance travelled per MT : [illegible] km/MT

Output (for instance2)

[illegible]	[illegible]

Flow chart for Wheat produced by above circuit simulation heuristic.
In this schedule, entry at index (i, j) indicates flow from godown i to j in MTs.

Total flow : [illegible]
Total cost : Rs. [illegible]
Number of iterations : [illegible]
Average distance travelled per MT : [illegible] km/MT

RICE

	(before flow)			(after flow)	
	Monthly Demand	Initial Stock	Days Remain.	Final Stock	Days Remain.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WHEAT

	(before flow)			(after flow)	
	Monthly Demand	Initial Stock	Days Remain.	Final Stock	Days Remain.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Stock position before and after flow.

As we may observe in table 1, the flow has redistributed the stock in such a way that demand for [illegible] days is fulfilled into each godown. The rates can be allocated based on this flow.

Comparison

Index sets

S : Set of surplus nodes (s = 1, 2, ..., S)

D : Set of deficit nodes (d = 1, 2, ..., D)

Cost & Distance parameters

Lij : Fixed Distance from godown i to j

Cij : Fixed Cost per unit per distance from godown i to j

Capacity and Demand variables

Mi : Maximum storage capacity of Deficit node i

Ti : Current stock at godown i

Ri : Demand of deficit node i

Gi : Surplus at surplus node i

Continuous variables

Fij : Amount of grain flow from i to j

$$\text{Minimize } \sum_{i \in S} \sum_{j \in D} L_{ij} C_{ij} F_{ij}$$

subject to constraints

$$\sum_{j \in D} F_{ij} \le G_i \; \forall i \in S \quad \text{(Supply Constraint)}$$

$$\sum_{i \in S} F_{ij} \le R_j \; \forall j \in D \quad \text{(Demand Constraint)}$$

$$T_j + \sum_{i \in S} F_{ij} \le M_j \; \forall j \in D \quad \text{(Maximum capacity constraint)}$$

We see that above LP formulation is of unbalanced transportation problem, for solving which various well known exact methods exist. We can compare the performance of algorithm against exact solution to find the efficacy of circuit based simulation in solving such problem.

[illegible]

Optimal Solution by Simplex Algorithm for rice.

Obtained using simplex LP solver in Microsoft Excel.

```
Total flow : [illegible] MT
Total cost : Rs. [illegible]
Average distance travelled per MT : [illegible] Km/MT
```

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Optimal Solution by Simplex Algorithm for Wheat.
Obtained using simplex LP solver on Microsoft Excel.

```
                        Total Flow  :  [illegible] MT
                        Total cost  :  Rs [illegible]
Average distance travelled per MT   :  [illegible] Km/MT
```

As one may observe the result by circuit simulation is within [illegible]% of the optimal solution. From here we can **establish that if circuit is modelled accurately for a problem, then based on its natural characteristics of optimal current flow to equalize potentials at connected nodes, we can find close to optimal solutions. Moreover, this system is extremely suitable for real time situations, where as a change occurs to a system at steady or even unsteady state, it immediately absorbs the change and performs appropriate activity to achieve equilibrium.**
This simple model was for unbalanced transportation problem for which reasonable time exact solutions exist, but as more constraints are added and LPP gets complex, it may become NP hard for which no fast exact algorithm exists, therefore we resort to heuristics to which circuit simulation model is an addition.

Model - 2 CIRCUIT FOR LOAD DISTRIBUTION PROBLEM

The potentials are built due to storage and therefore an equal distribution is made around the system at equilibrium. All godowns will work at same utilisation, load distributed equally to all godowns proportional to their capacity in the network.

Godowns storing grains are modelled as capacitors storing charge. The network of godowns is modelled as a complete graph, where each vertex is a capacitor grounded one side and connected to node of graph on other side. Each edge <i, j> contains a resistor proportional to the cost incurred in transporting a rake from godown i to godown j. The potential at each vertex i is determined the simple function,

$$V_i = f(Q_i, C_i) = Q_i / C_i$$

where Q_i is the stock held by godown i and C_i is its maximum capacity. As we shall see, more complex functions can be employed to simulate more factors within the network and assert desired conditions. In this model we aim to simulate a simple distribution system driven by potentials based on storage and capacity only. A state where potentials of all vertices become equal there is no further current flow in the network is called the equilibrium or steady state. In a non equilibrium state, the system tends to redistribute charges to achieve the equilibrium state and during this redistribution, currents are established as charges flow from nodes with higher potentials towards nodes with lower potentials. The net charge, that flows

Figure 1 : Load Distribution Circuit for 5 nodes

through an edge until steady state is achieved, indicates what amount of grain is to be transported through the corresponding path. To simulate this circuit numerically, we define a quanta which is a small amount of charge that flows from higher potential source to lower potential destination, on reaching the destination, it reduces the potential difference between source and destination by a small amount. The size of quanta in an edge is nothing but current which is the rate of flow of charge times a time quanta, which we shall use to simulate the circuit on a digital machine. To simulate the circuit the machine iterates over each edge in a time shared manner, transferring a small quanta each time. This epoch is repeated to simulate the system to precision controlled by the chosen time factor. Broadly, the machine updates the overall system by a differential amount each time by calculating small changes in each edge one by one to accumulate changes in various regions of circuit in parallel.

Consider a godown G at potential V and all its neighbours at potentials lower than V. Since quanta is proportional to the potential difference between source and destination and inversely proportional to resistance along the path, G will dispense grains at a faster rate to godowns which are closer to it and have comparatively lower potential than its neighbours, and similarly, it'd dispense at a slower rate to godowns with potential closer to G and relatively farther away. Thus we can establish rate of dispensation from surplus godowns to deficient godowns based on severity of deficiency and transportation cost tradeoff. From a global perspective, the godowns with highest potentials in system serve the largest number of neighbouring godowns. From the local perspective, a godown sees some godowns with lower potential than its, to which it dispenses, while it receives from godowns with higher potential than its. However, cumulatively, this results in flows which are optimal, or with respect to circuits, the flows which minimizes total power loss in the system, because more power loss implies slower distribution and worse ability to reach equilibrium.

One might observe that in nature, many such optimization systems exists, thunders find the shortest paths to ground, liquid takes shapes such that surface energy is minimized, in a network of capacitors, charge distributes itself such that potential at each capacitor becomes same, in ant colonies, the shortest paths are discovered by larger concentration of pheromones due to more ant traversals per unit time along shorter path.

Such a model can be particularly suitable for a real time system, in which dynamic real time parameters are imposed onto corresponding parameters in circuit, the circuit due to introduction of any change, performs activity again to achieve equilibrium and indicate new optimal solution. This is similar to *dynamic routing algorithms* or ant colonies, which on introduction of change, takes some time for convergence, and at the end lay at optimal solution to the changed environment.

Algorithm LDTS

Input :

n : number of nodes (godowns)

Vector M[n] : M[i] denotes maximum capacity of a node.

Vector S[n] : S[i] denotes current stock stored in a node.

Matrix D[n, n] : D[i, j] represents distance from node i to j.

Matrix C[n, n] : C[i, j] represents transport cost per unit grain per unit distance on edge <i, j>

Vector E[n] : E[i] = 1 if the godown i is taking part in interstate transport, 0 if it is isolated.

Operation :

Vector V[n] : V[i] represents current potential of a node i.

Matrix R[n, n] : R[i, j] represents resistance offered along an edge <i, j>

Matrix F[n, n] : F[i, j] records net flow change (grain) along an edge <i, j>

Output :

Matrix F at defined steady state, which is the transportation schedule.

Value P which is the total cost incurred.

```
1. I = 10000                                        [No. of Iterations]
2. ΔT = 0.01                                        [Time Quanta]
3. c = 100                                          [Resistance adjustment factor]
4. for i = 1 to n
   1. V[i] = S[i] / M[i]                            [Initialize potentials of godowns]
   2. for j = 1 to n
      1. R[i, j] = D[i, j] * C[i, j] / c;           [Initialize resistance matrix]
      2. F[i, j] = 0                                [Initialize net flow through each edge zero]
5. while(I != 0)
   1. for i = 1 to n if S[i] != 0
      1. for j = 1 to n if [illegible]
         1. ΔV = V[i] - V[j]                        [Find potential difference b/w godown i & j]
         2. Q = ( |ΔV| / R[i, j] ) * ΔT             [Determine charge quanta]
         3. if (ΔV > 0)                             [If godown i is at higher potential than j]
            1. src = i, dest = j                    [then flow of charge quanta occurs from i to j]
         4. if ΔV < 0                               [If godown j is at higher potential than i]
            1. src = j, dest = i                    [then flow of charge quanta occurs from j to i]
         5. S[src] = S[src] - Q                     [quanta deducted from source]
         6. S[dest] = S[dest] + Q                   [quanta added to destination]
         7. F[src, dest] = F[src, dest] + Q         [flow of quanta recorded]
         8. V[src] = S[src] / M[src]                [src. potential recalculated (slight decrease)]
         9. V[dest] = S[dest] / M[dest]             [dest. potential recalculated (slight increase)]
   2. I = I - 1
6. for i = 1 to n                                   [calculate net flow in a branch]
   1. for j = 1 to n                                [By adding positive and negative flows]
      1. if F[j, i] >= F[i, j]
         1. F[j, i] = F[j, i] - F[i, j]; F[i, j] = 0
      2. else
         1. F[i, j] = F[i, j] - F[j, i]; F[j, i] = 0

7. P = 0                                            [Initialize total cost incurred to 0]
8. for i = 1 to n
   1. for j = 1 to n
      1. P = P + F[i, j] * D[i, j] * C[i, j]        [cost = amt. of flow * distance * cost/dist/amt.]
   2. return F, P                                   [F holds transport schedule, P holds total cost]
```

In the above illustration, we take a network of 5 godowns as an undirected complete graph and its distance matrix 'M' represents the shortest or preferred railway distance between any pair of godowns in say kilometers. For example M[2, 4] = 100 indicates that distance between godown 2 and 4 is 100kms. Similarly cost matrix C represents the cost of transportation of grain per km per metric tonne. For example, C[2, 4] = 5.1 indicates that the cost of transporting food grain between godown 2 and 4 from path <2, 4> is Rs. 5.1 per km per MT. The distance and cost matrices may or may not be symmetric. The time factor ΔT determines the accuracy of numerical calculations by deciding size of quanta, smaller time factors will simulate the system more accurately, while larger time factors, in fact $\Delta T = 1$ will not simulate the model at all. Recommended ΔT is <= 0.01. The potentials are multiplied by 100, so that a godown holding grain at its full capacity is at potential 100V.

Illustration :

Output (for instance 1 - [illegible])

Time factor = 1

Number of iterations = 1000000

[illegible]

Transportation schedule for rice for making all godown sort of equal utilization.

Total flow : [illegible] MT
Total cost : Rs. [illegible]
Average distance travelled per MT : [illegible] km/MT

Output (for instance 2 - wheat)

Time factor = 1
Number of iterations = 1000000

[illegible]

Transportation schedule for wheat for making all godown sort of equal utilization.

Total flow : [illegible]
Total cost : Rs. [illegible]
Average distance travelled per MT : [illegible] km/MT

		RICE						WHEAT					
		(before flow)			(after flow)			(before flow)			(after flow)		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Stock position before and after flow

One may note that the system distributed grain in such a way that, final potentials of all godowns become nearly equal. This model will be extremely optimal if the storage infrastructure is designed proportional to demand. But in practical cases this is not possible, because infrastructure is planned according to supplies, not demands and regional demands may not be equal to regional supplies. In above example we can observe that godown VJS where demand is much less than the storage capacity, this model will unnecessarily transport grain to godowns where there is not much demand.

We can integrate the model-1 and this model-2 to achieve demand goals as well as good utilisation for all godowns. This model can be used when system is running close to its full capacity, any new input of grain shall be absorbed by the entire system, other wise risking local spillage. Also, this model particularly meets the requirement of utilising all godowns to good percentages.
Moreover the models we have considered are entirely devoted to one grain at a time only, what if rice and wheat are flowing simultaneously in the system and the storage space in godowns is shared by both the grains.

Model - 3 : MODEL FOR INCLUDING VEHICLE CAPACITY & AVAILABILITY

Assumption
Interstate transport takes place using rake only.

Index sets
T : Set of time periods (index t = 1,2,...,T)
S : Set of surplus FCI godown (index s = 1, 2, ..., S)
D : Set of deficit FCI godown (index d = 1,2,...,D)
R : Set of types of rakes (index r = 1, 2,..., R)

Cost & Distance parameters
L_{sd} : Fixed Distance from surplus godown s to deficit godown d via rail.
C_{sd} : Unit shipment per distance from surplus godown s to deficit godown d.
A_{sdr} : Fixed transportation cost on route (s, d) for rake type r.

Capacity and Demand variables
m_d : Maximum storage capacity in MT of Deficit node d.
c_d : Current stock in MT at deficit godown d.
d_d : Demand in MT of deficit node d.
u_{st} : Surplus in MT at surplus node s at time t
o_s : Operation (Loading / Unloading etcetera) cost per MT at surplus godown s.
i_s : Inventory holding cost per MT at surplus godown s.

Vehicle parameters
X_r : Capacity of rake of type r
Q_{rst} : Number of rakes of type r available at surplus node s at time period t
G_{sdrt} : Number of rakes of type r used by surplus node s to transfer grain to deficit node d at time t

Penalty factors

Continuous variables
F_{sdt} : Amount of grain flow from surplus godown s to deficit godown d in time period t

objective function :

Minimise

$$\sum_{t=1}^{T}\sum_{d=1}^{D}\sum_{s=1}^{S}\sum_{r=1}^{R}[(G_{sdrt}A_{sdr}) + (L_{sd}C_{sd}F_{sdt})] + \sum_{t=1}^{T}[\sum_{s=1}^{S}\sum_{d=1}^{D}F_{sdt}]O_s + \sum_{s=1}^{S} I_s$$

subject to constraints

$$\sum_{d=1}^{D}\sum_{t=1}^{T} F_{sdt} \le U_s \ \forall s \in S \text{ (Supply constraint)}$$

$$\sum_{s=1}^{S}\sum_{t=1}^{T} F_{sdt} = R_d \ \forall d \in D \text{ (Demand constraint)}$$

$$\sum_{i=1}^{s} \sum_{v=1}^{V} F_{ijt} \le (M_j - T_j)\ \forall j\ \forall t \text{ (Deficit godown capacity constraint)}$$

$$F_{ijt} \le \sum_{k=1}^{K} G_{ijkt} R_k\ \forall i\ \forall j\ \forall t \text{ (Rakes capacity constraint)}$$

$$\sum_{j=1}^{d} G_{ijkt} \le Q_{ikt}\ \forall i\ \forall k\ \forall t \text{ (Rakes Availability Constraint)}$$

$$F_{ijt} \ge 0\ \forall i\ \forall j\ \forall t \text{ (Flow is positive constraint)}$$

$$s_{it} \ge 0\ \forall i\ \forall t \text{ (Surplus is positive constraint)}$$

The transportation schedule will indicate by which vehicle at which time what amount of grain shall be transported from which godown to which other so that demands are met, no godown overspills and net transportation and operational cost is minimized and risk of delays / demurrage cost is minimized.
In the below implementation, we use the same circuit as model 1, but in its simulation we make a difference. Firstly, no matter what amount of surplus a godown has, it usability in global network is limited by the number of rakes available at that godown. Hence we calculate the effective surplus that a godown has dispensable in global network as min(surplus, transportation capacity available). To simulate transportation in rakes rather than continuum, we use a buffer matrix which holds net flow in continuum in a specific time interval for each branch. We simulate the circuit normally like model 1 and keep recording flow in the buffer matrix. When the net flow in a branch sums up to capacity of rake, we dispatch a rake from corresponding source to supply and record it permanently in the flow matrix. This works like a gravimetric weight dispenser which collects load until it reaches a specific amount, when it does, entire accumulated load is released in one go. In this model we have the transport amounts in discrete domain, but we have not yet implemented the time period based scheduling as described in the previous linear program formulation.

Algorithm IIVT

Input :

n : number of nodes (godowns)

Vector M[n] : M[i] denotes maximum capacity of a node.

Vector C[n] : C[i] denotes current stock stored in a node.

Matrix D[n, n] : D[i, j] represents distance from node i to j.

Matrix C[n, n] : C[i, j] represents transport cost per unit grain per unit distance on edge <i, j>.

Vector I[n] : I[i] = 1 if the godown i is taking part in interstate transport, 0 if it is isolated.

Vector Q[n] : Q[i] represent how much days of stock is desired in godown i.

Vector A[n] : A[i] represents number of full rakes available for transport at godown i.

Vector O[n] : O[i] represents operational cost (loading, unloading, ..) per metric tonne at godown i.

Operation :

Vector V[n] : V[i] represents current potential of a node i.

Vector W[n] : W[i] represent the global surplus or demand which node i has.

Vector W'[n] : W'[i] is a temporary variable used for intermediate calculations, initialized to W.

Matrix R[n, n] : R[i, j] represents resistance offered along an edge <i, j>.

Matrix B[n, n] : B[i, j] stores how much charge(grain) did flow through edge<i, j> a specific time interval. Initialized to 0.

Matrix F[n, n] : F[i, j] records net flow charge (grain) along an edge <i, j>. Initialized to 0.

P : total cost accumulated for entire flow at an instance. Initialized to 0.

Set S : holds godowns with surplus.

Set T : holds godowns with deficits.

Output :

Matrix F at defined steady state, which is the transportation schedule.

Value P which is the total cost incurred.

Constants :

v : voltage adjustment factor

r : resistance adjustment factor

f : capacity of a full tube

```
1. for i = 1 to n
   1. for j = 1 to n
      1. R[i, j] = C[i, j] * L[i, j] / r
2. for i = 1 to n
   1. remaining_days = ( G[i] / D[i] ) * 30
   2. if remaining_days < Q[i]
      1. W[i] = (remaining_days - Q[i] ) * ( D[i] / 30 )  (negative value)
      2. if W[i] > M[i]
         1. W[i] = M[i]
   3. else
      1. W[i] = (Q[i] - remaining_days ) * ( D[i] / 30 ) (positive value)
      2. W[i] = min(W[i], A[i]*f)
3. for i = 1 to n
   1. if W[i] > 0
      1. S = S U {i}
   2. if W[i] < 0
      1. T = T U {i}
4. for i = 1 to n
   1. V[i] = W[i] / v
5. while true
   1. if | S | = 0 & | T | ≠ 0
      1. return "Surplus not enough", F, P
   2. if | S | ≠ 0 & | T | = 0
      1. return "Surplus more than enough", F, P
   3. if | S | ≠ 0 & | T | = 0
      1. return "Surplus exactly match Deficit", F, P
   4. for each i ∈ S
      1. for each j ∈ T
         1. if E[i] = 1 & E[j] = 1
            1. Q = ( ( V[i] - V[j] ) / R[i,j] ) * t
            2. W'[i] = W'[i] - Q
            3. W'[j] = W'[j] + Q
            4. R[i, j] = R[i, j] + Q
            5. V[i] = W'[i] / v
            6. V[j] = W'[j] / v
            7. if R[i, j] > f
               1. W[i] = W[i] - f
               2. W[j] = W[j] + f
               3. R[i, j] = R[i, j] - f
               4. W' = W
               5. F[i, j] = F[i, j] + Q
               6. P = ( L[i, j] * C[i, j] + O[i] ) * Q
            8. if W[i] < 0
               1. S = S - {i}
            9. if W[j] > 0
```

5. [illegible]

6. return T, F.

Illustration

Input : Apart from parameters of test case 1, we input several new parameters now including

[illegible]

Days of reserve vector, Number of full rakes available vector, operational cost / MT vector.

Output (for instance1 - rice):

time factor = [illegible]
iterations = [illegible]
c = [illegible]
r = [illegible]
f = [illegible] MT / full rake

[illegible]

Transportation schedule in MT for rice obtained by model : [illegible]

[illegible]

Transportation schedule in number of rakes for rice obtained by model : [illegible]

```
                      total flow  :  [illegible]
                 total rake flow  :  [illegible]
                      total cost  :  Rs. [illegible]
Average distance travelled per MT :  [illegible]
```

[illegible]

Output (for instance2 : wheat)

time_factor = 0.01
iterations = 10000000
r = 1000
r = 1000
f = 5340 MT / full rake

total flow : 5220868.3 MT
total rake flow : 888.8
total cost incurred : Rs. 545,88,22,488.8
Average distance travelled per MT : 1874.6 km

FUTURE WORK

We seek to design circuits incorporating more practical constraints as described in the introduction section.

Experts in field of electronics can use devices with various characteristics to model the problem more accurately by designing better circuits. Machine approaches can be used to learn from previous experiences and adjust factors in such a way that network in a particular environment works best for it. For example, in some countries, it might happen, that entire agricultural input comes from an region only, in which case surplus godowns are few and hence transport is always skewed in few directions. When methods can be developed for agencies to plan future expansions efficiently, the system might suggest from its experience, which godowns work close to full capacity or overflow frequently, such godowns can be upgraded in priority. Also, there can be potential applications in the godown positioning decision, that is, building new godowns at such locations which maximise the serving capacity and minimise the resources for transport etc. for a specific environment.

REFERENCES

[1] https://fci.gov.in/procurements.php

[2] https://dfpd.gov.in/mechanismforProcurement.htm

[3] http://www.arthapedia.in/index.php?Foodgrain_Management_in_India

[4] https://fci.gov.in/storages.php

[5] https://fci.gov.in/app/webroot/upload/Procurement/Quality%20proc.%20(10%20yrs_14.pdf

[6] https://fci.gov.in/movements.php?view=32

[7] https://fci.gov.in/app/webroot/upload/Movement/Movement%20Operations%20in%20FCI.pdf

[8] Lokeshakshu M. Marjan, Swati J. Thakkar, Anjali Awasthi, Manoj Kumar Tiwari, *Development of an Effective Cost Minimization Model for Food Grain Shipments*, IFAC-PapersOnLine, Volume 48, Issue 3, 2015, Pages 881-886, https://doi.org/10.1016/j.ifacol.2015.06.194.

[9] Ajinkya Tanksale, J.K. Jha, (2015) "Implementing National Food Security Act in India : issues and challenges" British Food Journal, Vol.117 Iss 4 pp.1315 - 1335 http://dx.doi.org/10.1108/BFJ-07-2014-0239

[10] CAG (2013) "Storage Management & Movement of food grains in Food Corporation of India", Vol. 3, Available at Union_Performance_Ministry_Consumer_Affairs_Food_Public_Distribution_7_2013.pdf

[11] CAG(2017), "Storage Management & Movement of food grains in Food Corporation of India", Vol. 3, Available at https://cag.gov.in/webroot/uploads/download_audit_report/2017/Report_No.38_of_2017_-_Compliance_audit_Union_Government_Food_Corporation_of_India_Reports_of_Ministry_of_Consumer_Affairs,_Food_and_Public_Distribution.pdf

[12]http://fci.gov.in/app/webroot/upload/Procurement/1Rice%20proc.%20last%2010%20yrs_13.pdf

[13]http://fci.gov.in/app/webroot/upload/Procurement/7wheat%20state%20last%2010%20years%20wise%20_13.pdf

[14] D.G. Mogale, Sri Krishna Kumar, Manoj Kumar Tiwari, *Two Stage Indian Food Grain Supply Chain Network Transportation-Allocation Model*, IFAC-PapersOnLine,Volume 49, Issue 12,2016, Pages 1767-1772, https://doi.org/10.1016/j.ifacol.2016.07.838.

[15] Anoop, K.P., Panicker, V.V., Narayanan, M. *et al.* A mathematical model and solution methods for rail freight transportation planning in an Indian food grain supply chain. *Sādhanā* **43**, 200 (2018). https://doi.org/10.1007/s12046-018-0958-y

[16] https://fci.gov.in/app2/webroot/upload/circulars/MCC_381_eng.pdf

Model - 3 (LOAD DISTRIBUTING INTERSTATE TRANSPORTATION MODEL)
The potentials at nodes are built due to their local demand - supply and its entire grain stock. And load distribution model being the backbone will distribute grains in such a way that godowns work at equal potentials.

A godown in this model has four parameters, local demand, local supply, global demand, global supply. Local demand refers to the consumption of grains by distribution part of supply chain and local supply refers to the procurement which is coming to this godown to be stored. Global demand for a godown comes when its local demand exceeds its current stockpile and local supply. Global supply flows from surplus godowns, whose local demand is less than their current stock and local supply. We assume that local demand from a godown is drainage of charge from a capacitor to ground, and local supply is accumulation of charge by some active device like a battery. The capacitors are connected in parallel with a two controlled voltage supplies V_1 and V_2 through a transistor.

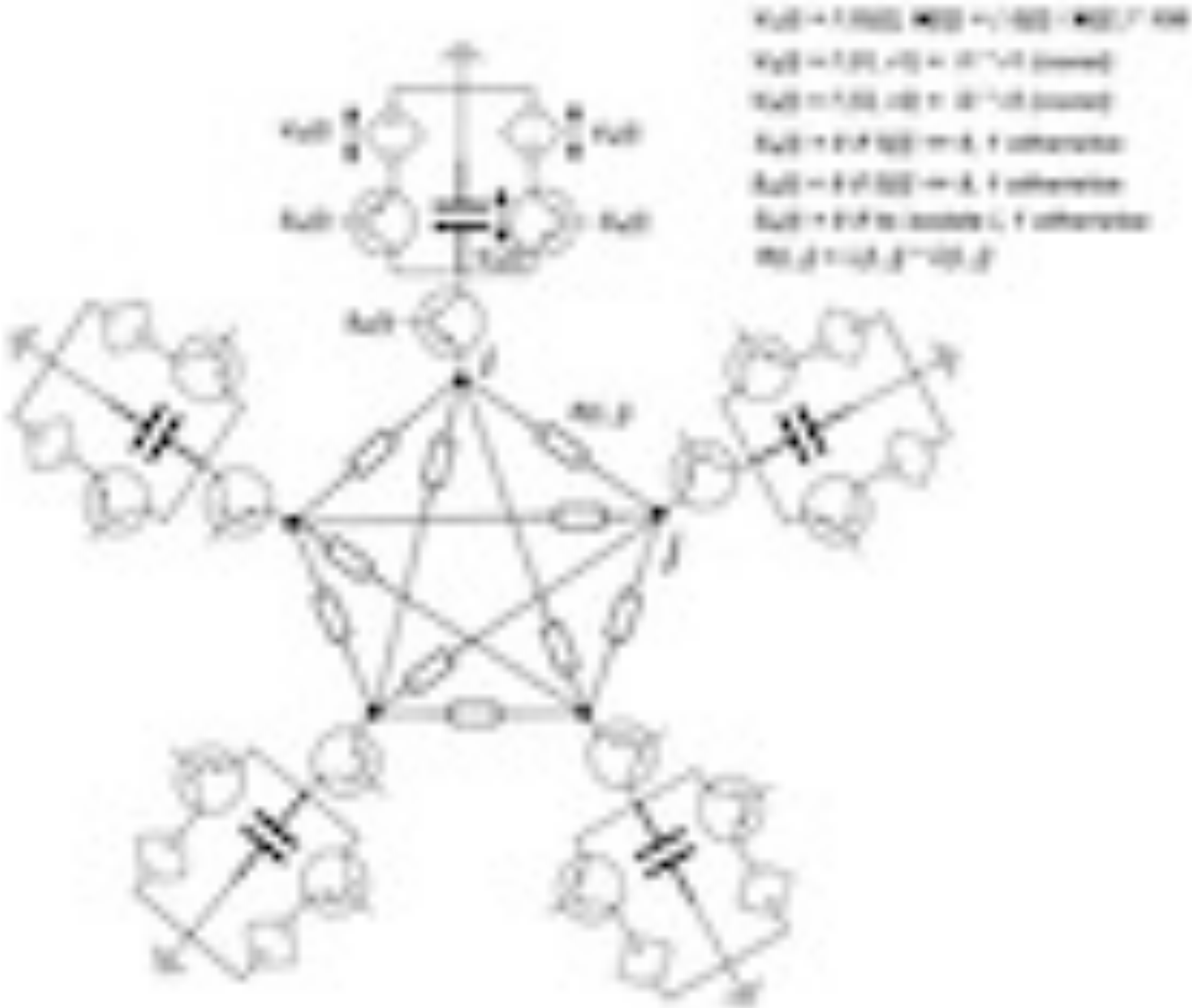


Figure 3 : Load distributing interstate transportation model.

Here we define, $V_2 = f(V_1, const) + V_1 + IR$, where I and R are taken to be constants, I being large and R being small to make large charge quantum per unit time quanta, assuming intrastate transport is much faster than interstate. V_2 also maintains a constant positive potential difference (constant current supply) with respect to capacitor until there is any local supply remaining, this is assuming intrastate transport from the procurement points to godowns is uniform. If there is any supply, V_2 remains at higher potential and capacitor start charging, which simulates a supply being stored into godown. If the supply is exhausted, the transistor turns off the connection between supply source and godown. Similarly, we define $V_3 = f(V_1, const) + V_1 - I'R'$, again I' and R' are constants taken based on transport characteristics from godown to FPSs which register demand, generally assumed to be fast and uniform. V_3 also maintains a constant negative potential difference with respect to capacitor until there is any local demand remaining to be full fulfilled. Whenever there is non zero demand, charge leaks from capacitor to ground simulating consumption from a godown, as demand gets zero, leakage from godown is stopped by the transistor. One can adopt different functions and constants to appropriately simulate the intrastate supply and demand transport characteristics. Another fact to note is, if the total charge stored by all capacitors in the system is T, then local supply and demand affects the value of T while global supply and demand does not. Local demand reduces T as it drains charge to ground while local supply increases T as it adds charge to capacitors. Global supply and demand does not affect T, it only redistributes charges among different capacitors. Also, since local transactions take place daily, and global transaction is done once every month, we isolate the participation of a godown in global network using entry transistors as shown in fig3. The on/off signals to these transistors can be given on custom basis, which can be a pulse monthly, or to conduct global transport between a subset of godowns only, one can mask all other godowns by giving 0 signal to their entry transistors.

Algorithm 1 DETM

Input :

n : number of nodes (godowns)

Vector M[n] : M[i] denotes maximum capacity of a node.

Vector G[n] : S[i] denotes current stock stored in a node.

Matrix L[n, n] : L[i, j] represents distance from node i to j.

Matrix C[n, n] : C[i, j] represents transport cost per unit grain per unit distance on edge <i, j>

Vector D[n] : D[i] represents local demand to be fulfilled by godown i.

Vector S[n] : S[i] represents local supply to godown i.

Operation :

Vector V[n] : V[i] represents current potential of a node i.

Matrix R[n, n] : R[i, j] represents resistance offered along an edge <i, j>

Matrix F[n, n] : F[i, j] records net flow charge (grain) along an edge <i, j>

Output :

Matrix F at defined steady state, which is the transportation schedule.

Value P which is the total cost incurred.

1. *I = 10000* — *[No. of Iterations]*
2. *ΔT = 0.1* — *[Time Quanta]*
3. *γ = 100* — *[Resistance adjustment factor]*
4. *I1 = 50* — *[Local supply current : Assumed constant]*
5. *I2 = 50* — *[Local demand current : Assumed constant]*
6. *for i = 1 to n*
   1. *V[i] = S[i] / M[i]* — *[Initialize potentials of godowns]*
   2. *for j = 1 to n*

```
        1. R[i, j] = D[i, j] * C[i, j] / c        {Initialize resistance matrix }
        2. F[i, j] = 0                            {Initialize net flow through each edge zero}
7. while(t != 0)
    1. for i = 1 to n
        1. for j = 1 to n
            1. ΔV = V[i] - V[j]                   {Find potential difference b/w godown i & j}
            2. Q = ( | ΔV | / R[i, j] ) * ΔT      {Determine charge quanta}
            3. if ( ΔV > 0)                       {if godown i is at higher potential than j}
                1. src = i, dest = j              {then flow of charge quanta occurs from i to j}
            4. if ΔV < 0)                         {if godown j is at higher potential than i}
                1. src = j, dest = i              {then flow of charge quanta occurs from j to i}
            5. S[src] = S[src] - Q                {quanta deducted from source}
            6. S[dest] = S[dest] + Q              {quanta added to destination}
            7. F[src, dest] = F[src, dest] + Q    {flow of quanta recorded}
            8. V[src] = S[src] / M[src]           {src. potential recalculated (slight decrease)}
            9. V[dest] = S[src] / M[src]          {dest. potential recalculated (slight increase)}
    2. t = t - 1
8. for i = 1 to n
    1. Q1 = l1 * ΔT                               {local supply quanta}
    2. Q2 = l2 * ΔT                               {local demand quanta}
    3. G[i] = G[i] + Q1                           {small local supply accumulated}
    4. G[i] = G[i] - Q2                           {small local demand dispersed}
    5. S[i] = S[i] - Q1                           {local supply reduces by a small amount}
    6. D[i] = D[i] - Q2                           {local demand reduces by a small amount}
    7. V[i] = G[i] / M[i]                         {node potential recalculated}
9. for i = 1 to n                                 {calculate net flow in a branch}
    1. for j = 1 to n                             {by adding positive and negative flows}
        1. if F[j, i] >= F[i, j]
            1. F[j, i] = F[j, i] - F[i, j], F[i, j] = 0
        2. else
            1. F[i][j] = F[i, j] - F[j, i], F[j, i] = 0
10. P = 0                                         {initialize total cost incurred to 0}
11. for i = 1 to n
    1. for j = 1 to n
        1. P = P + F[i, j] * L[i, j] * C[i, j]    {cost = amt. of flow * distance * corridor.amt.}
    2. return F, P                                {F holds transport schedule. P holds total cost}
```

Output (for Rice) :

[illegible]

Flow matrix (M?)

Constants used : Iterations = 100000, ΔT = 1e-3, l=

```
Total Flow : [illegible] MT
Total Cost : Rs. [illegible]
Initial potentials
[illegible]
Final potentials
[illegible]
```

Output (for Wheat) :

[illegible]

```
Total Flow : [illegible] MT
Total Cost : Rs. [illegible]
```

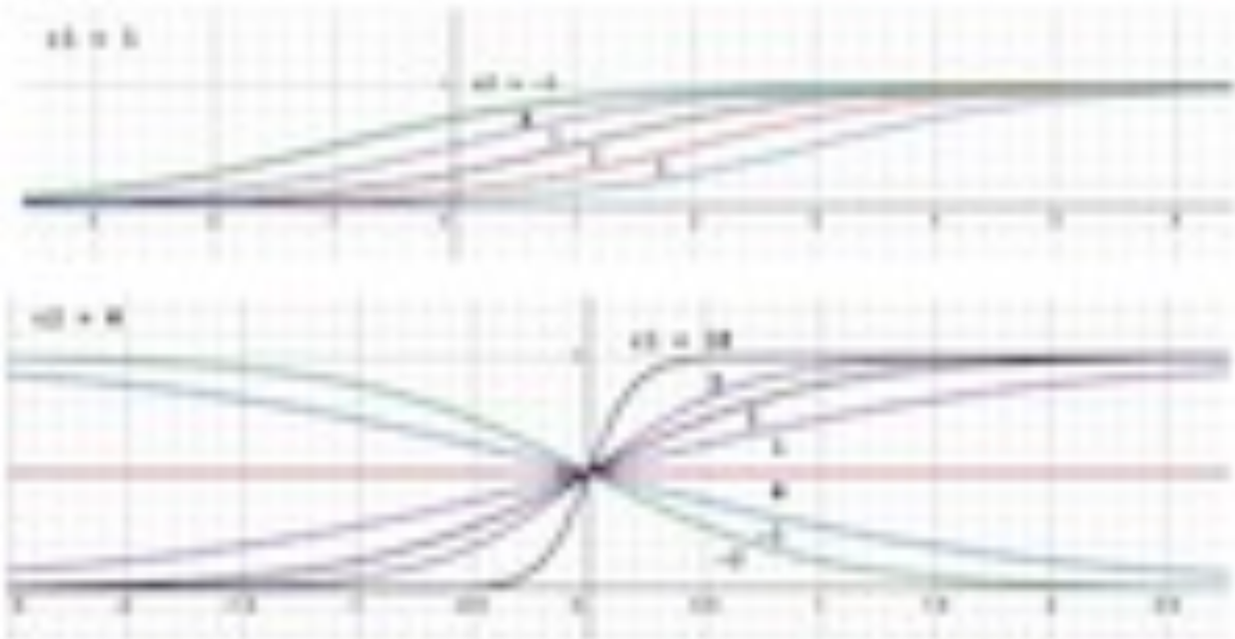
	RICE				WHEAT		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

But as we will see, this model incurs high cost for equal distribution of grain, in fact with respect to the next model, for the same example it costs as much as ten times more.

Model : 4 (REAL TIME PARTIAL LOAD DISTRIBUTING TRANSPORT MODEL) :
In such a case non equal distribution will be caused, some godowns will work at higher capacity, some other at lower capacities based on their local supplies and demands. Transit happen only based on demand supply and when a godown is about to overflow.

The problem with model 3 is, the local supplies on each node are distributed all amongst the entire system, proportional to capacities of nodes. But this causes a lot of transportation overhead, and such a model is not applicable in a general practical scenario. Whenever local supplies appear at a node, we dont want to immediately distribute them to the entire network, that is, we dont want all godowns to run at same utilisation, rather we want that they can run at different utilisations if it saves transportation cost and still meets local supplies and demands. This is a practical scenario for which we produce model 5. The circuit system works by each node achieving equal potentials at the steady state, after which no flow happens. In such a scenario, to implement the feature that different godowns can run at different utilisations, we can mask the grain holdings and assign potentials based on some fraction of grain holding the we deem is available for global lending. Here we employ a sigmoid function with two parameters to determine this fraction.

$$f(x) = \frac{1}{1 + e^{-c1(x - c2)}}$$



Constant *c1* determines how fast to increase or decrease the fraction of stock available for global lending as supply surpasses demand, or demand surpasses supply. If demand is too much and supply does not match, then we need to reserve more of the stocked grain for local demand meeting purpose and less for global lending, and similarly as the local demand reduces and supply increase, one is more sure in meeting local demand and can open the stock more to global lending. Constant *c2* decides how much fraction of stock to be kept open when supply matches demand. if *c2* = 0, it implies we devote only half of the current stock to help global deficits, when there is no effective demand to be catered by the godown.

Object Godown

i/p L[n] : L[i] denotes length of path from this godown to jth godown
i/p C[n] : C[i] represents transport cost / unit grain / unit distance from this to jth godown
i/p M : Maximum capacity of this godown
i/p T : represents the current stock in this godown
i/p D : represents local demand to this godown
i/p S : represents local supply to this godown
i/p B : represents minimum buffer for this godown
i/p H : H = 1 => this godown is isolated from global network.
H = 0 => this godown takes part in global distribution network
V : Potential of this godown in global distribution network
R[n] : R[i] represents resistance offered by path from this godown to jth godown
o/p F[n] : F[i] represents how much good is to be transported from this godown to jth godown .

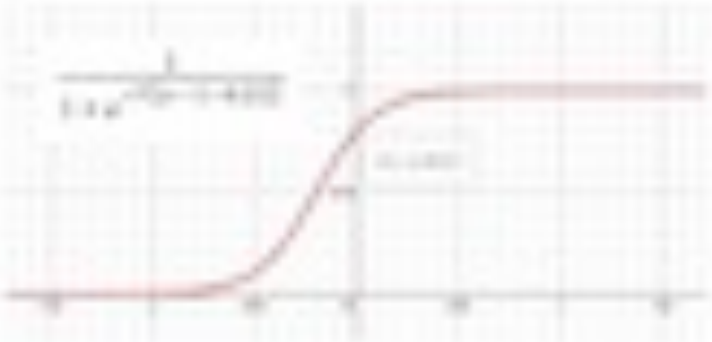
```
CALCULATE_POTENTIAL(Godown Gi)
[A : represents fraction of stock chosen to be lend to global network.]
1. if T > M then A ← T
2. if T < B then A ← 0
3. X ← (S - D) / T
4. A ← 1 / (1 + e^(-c(X+c))) * P
5. return ( A / M ) * 100

ALGORITHM PLDSTM
1. I ← 10000
2. ΔT ← 0.01
3. for i ← 1 to n
   1. CALCULATE_POTENTIAL(Gi)
   2. for j ← 1 to n
      1. Gi.R[j] ← Gi.L[j] * Gi.C[j]
4. while I ← I - 1
   1. for i ← 1 to n
      1. for j ← 1 to n
         1. if Gi.R == 0 & Gj.R == 0
         2. ΔV ← Gi.V - Gj.V
         3. Q ← ( ΔV / Gi.R[j] ) * ΔT
         4. if ΔV < 0
            1. src ← Gi
            2. dest ← Gj
         5. else
            1. src ← Gj
            2. dest ← Gi
         6. src.T ← src.T + Q
         7. dest.T ← dest.T - Q
         8. src.V ← CALCULATE_POTENTIAL(src)
         9. dest.V ← CALCULATE_POTENTIAL(dest)
         10. src.F[dest] ← src.F[dest] + Q
   2. if Gi.S > 0
      1. Q ← s
      2. Gi.T ← Gi.T + Q
      3. Gi.S ← Gi.S - Q
      4. CALCULATE_POTENTIAL(Gi)
   3. Gi.D > 0
      1. Q ← d
      2. Gi.T ← Gi.T - Q
      3. Gi.D ← Gi.D - Q
      4. CALCULATE_POTENTIAL(Gi)
5. F ← 0
6. for i ← 1 to n
   1. for j ← 1 to n
      1. F ← F + F[i,j] * L[i,j] * C[i,j]
7. return F, F
```

The calculate potential method above does the following: If grain stock of a godown is exceeding its capacity we open the entire stock to catering global deficit regions, with a potential even greater than 100%. If the stock in a godown falls beneath its minimum buffer, the godown completely closes its contribution in global supply, and its potential drops to 0%. If it is neither of the above cases, then the fraction of stock that a godown keeps open for global supply depends on difference between demand and supply. X is dependent on how much is supply demand gap with respect to current grain stock. If demand supply gap is low with respect to stock, then stock gains or depletes slowly, in such a case we can assume that stock is going to be consistent and we can safely devote a larger fraction of it to help global deficits. On the other hand, if demand supply gap is high with respect to stock and supply is larger than demand, it means stock is filling, and thus we can devote more to global as we have less local demand to cater to. Also, if demand supply gap is high with respect to stock and demand is larger than supply, then the stock is depleting and so the godown has to cut down the fraction of stock open to global supply. For example,

C1 = 7, C2 = -0.2

T = 10000 MT

Demand	Supply	Fraction of stock open for global potential calc.
2000	2000	80.2
1000	2000	89.1
2000	1000	64.8
3000	5000	98.3
5000	1000	19.8
1000	8000	99.3
8000	1000	99.8



One may notice that in contrast, the fraction deciding function in model 2 was a constant, in which entire grain stock was assumed to be open for global redistribution, ie, it was always 1. In model 2 although there is perfect redistribution, the transportation overhead was large, in this model, it varies as a function of demand and supply, ie only partial stock is available for global redistribution, although final distribution is not even, different godowns are working at different utilizations, transport cost is much low.

Input : the 19 godown test case used in model 2.

Assumptions :

The minimum buffer is kept at 5 percent of maximum capacity.

Constants used :

Output (for Rice) :

[illegible]	[illegible]

Total Flow : [illegible] MT

Total Cost : Rs. [illegible]

C1	C2	Total Flow	Total cost
[illegible]	-0.1	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

The schedules with larger flow resulted in more even distribution around the system, that is, the utilization percentages of godowns varied less, while in schedules with lower flow, utilization percentages varies more, but cost is reduced. Thus, apart from fulfilling demands, there is a cost to uniform distribution tradeoff.

Output (for Wheat) :

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Total Flow : [illegible]
Total Cost : Rs. [illegible]

This is a simple model, we can use more and more complex functions to simulate even more features, more accurately. We can adopt different models for different situations, in war time situation where the stocks may have a regional bias, or in a calamity situation, where a region experiences a sudden large scarcity. The constants can be adjusted by learning from past experience to cater to a specific environment as optimally as possible. Moreover the constants can be adjusted in direction reduction in cost to achieve a local and possibly global minima.

CASE STUDY

		RICE			WHEAT		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

But since supplies come for few days in a year, after this month, the system will reach the equilibrium in such a way that if the next month same demands come, it'd subsequently cost much less. the equilibrium of the system is disturbed vastly over some occasions only.
(graph on cost at this disruptive month and then slowly it being smoothened)

the point is in making the current quanta equal to a half value.