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E-Mandi Implementation Based On Gale-Shapely Algorithm for Perishable Goods Supply Chain

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Abstract— **In this paper, we propose to transform the traditional agricultural trading into an electronic exchange between the farmers and consumers in the agricultural supply chain. Preferential evaluations of buyer and supplier satisfactions are mathematically modeled and this preference matrix is given as input to Gale Shapely matching algorithm. The results of m*n matching happens to be a very transparent approach in a bilateral e-trading environment. These results are compared with the results obtained using simple English auction method which produces Pareto-optimal matches. It is found that the proposed method produces stable matching, which is preference-strategy proof and it also reduces the need for number of rounds of allocation.**

I. Introduction

The Indian government has established a large number of public wholesale market yards for agricultural products and regulates these market yards through an Agricultural Produce Market Committees (APMC) Act [1]. It is estimated that there are around 7000 such wholesale markets in India. Typically, the state governments set up marketing boards called APM Committees which frame rules and supervise the wholesale trade of agricultural produce in markets called Mandis. Wholesale trade of agricultural produce in the regulated areas has to happen under the Mandi framework. Trade outside is not permitted. Under this system, the farmers bring the agricultural produce to the Mandi's physical location where it is auctioned and sold to traders, who are registered with the Mandi. The auction format is the classical open-cry ascending price auction (English auction). The traders in turn sell the produce to wholesalers, retailers, or companies.
Mandi's were created with the intention of providing farmers a centralized marketplace to sell their produce, and to ensure that they get fair prices. But over the years, this system has been monopolized by middlemen who dictate the prices. Moreover, the produce has to be transported by the farmers to the Mandi (sometimes for hundreds of kilometers) and the farmers have to wait for their turn of the auction process (for several days during the harvest season). Reports say that about 30% of the perishable commodities are lost due to such inefficiencies in post-harvest processing [2].
Burt [3] coined the term 'structural hole' to denote the separation that exists when two groups of people have no direct contact with each other. In the Mandi network, on one side there is a group of farmers (sellers) and on the other side, there are consumers (buyers). These two groups are not allowed to buy/sell directly with each other and are forced to transact via the Mandi. Therefore there is a structural hole in the network.
Table 1 given in Appendix illustrates the survey of Indian start-ups for facilitating e-agricultural supply chain as listed below. There are no automatic mechanisms being implemented so far as proposed in this paper for matching buyer and supplier with supplier fair play. With the advent of the Internet and the advances in Information and Communication Technologies (ICT), we believe that agricultural trading can be done in an efficient manner which is beneficial to both farmers and consumers, and we present a transparent approach for the same.
A match-making web based system has been developed to match multiple farmers and multiple buyers in a typical trading scenario. A MILP model has been created to match farmers and buyers in a mandi framework in [2], but, it is a typical implementation of English auction, where allocation takes place in multiple rounds. It is solely based on bidding. It does not take into account, the typical satisfaction (in terms of quality, lead time etc.) of buyer/supplier into account while trading in a M*N match-making environment, which is considered in our work. A mathematical model has been developed to assess preferential scores of two distinct players, which is given as input to the Gale Shapely matching algorithm in Section 2. The results are discussed in Section 3. Finally, the conclusion is presented in Section 4.

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II. Mechanism Design for Matching

We assume a set of buyers i = {1,2…,m} and set of set of farmers j = {1,2,…n}. Both trading partners submit the attributes for their product to our web based decision support system (e-DSS) to find an optimal match. For a given product of given quality level and promised lead time, the farmer must submit his true valuation (bid price) to the e-DSS as a private information, along with his expected quality and lead time. The competing bidders will not know the valuation of contending buyers. Similarly, the farmers will submit the ask price for their product of a quality grade in a closed form, along with their promised quality and lead time of supply. The satisfaction level of buyer and farmer is determined as follows:

A. Evaluation of Buyer Satisfaction B_{ij}

Bij={$\sum_{a=1}^{k}$ wia * bija , 0}, bija € (0,1); (1)

wherebija is fitness function for buyer "i" over farmer j for attribute a.

wia is weight given by buyer "i" for attribute "a".

The attributes considered by the buyer are quality of produce, cost and lead time to supply. This demands true valuation of a product in terms of quality, lead time and bid/ask price from the buyer and supplier respectively. This is modeled as follows:

More is better:

$$b_{ij}a = \begin{cases} 1, \ a_{ja} \geq e_{ia} \\ \frac{a_{ja} - e_{iamin}}{e_{ia} - e_{iamin}}, e_{iamin} \leq a_{ja} < e_{ia} \\ 0, \ e_{ia} < e_{iamin} \end{cases} \quad (2)$$

Less is better:

$$b_{ij}a = \begin{cases} 1, \ a_{ja} \leq e_{ia} \\ \frac{e_{iamax} - a_{ja}}{e_{iamax} - e_{ia}} e_{ia} < a_{ja} \leq e_{iamax} \\ 0, \ a_{ja} > e_{iamax} \end{cases} \quad (3)$$

Where,

a_ja = actual value of attribute "a" given by supplier "j", e_ia = expected value of buyer "i" for attribute "a",

eia_{min}= Min expected value of buyer "i" for attribute "a".

eia_{max}= Max expected value of buyer "i" for attribute "a".

Evaluation of Supplier Satisfaction S_{ji}

Supplier satisfies only on the bid cost of buyer.

$$S_{ji} = \begin{cases} 1, p_{bi} > p_{sj} \\ \frac{p_{bi} - p_{sj}}{p_{sj} - p_{sjmin}} \quad , p_{sjmin} \leq p_{bi} < p_{sj} \\ 0, p_{bi} < p_{sjmin} \end{cases} \quad (4)$$

p_{bi} = actual bid of buyer "i",

p_{sj} = expected bid of supplier "j",

p_{sjmin} = Min expected bid of supplier "j".

The calculated preferences Bij and Sji are used for preferential matching using Gale Shapely algorithm. The GS algorithm calculates the profit of matching the registered suppliers and buyers using equation (5).

$$\text{Profit} = \sum_{i,j} (p_i - p_j) * x_{ij} \quad (5)$$

Where,

x_{ij} = quantity of trading between matched buying agent i and selling agent j.

p_i = Bidding price per unit agreed upon in transaction by buying agent i

p_j = Ask price per unit agreed upon by the selling agent j.

The following constraints are used in the mechanism design.

$$\sum_{i}^{m} x_i \leq q_i \quad (6)$$

The total number of units allocated to a buying agent is less than or equal to its demand.

$$\sum_{i}^{n} x_j \leq q_j \quad (7)$$

The total number of units bought from a selling agent is less than or equal to its supply.

$$\sum_{i}^{m} x_i \leq \sum_{j}^{n} x_j \quad (8)$$

The number of units sold does not exceed the number of units procured.

When a buyer is interested in a quality k_i, it is okay if he is allocated a quality better than k_i,. When a seller has an item of quality k_j, , it is okay if his allocation is for a quality lower than k_j if he is getting the same price. (9)

When a buyer intends to receive supply in a lead time of l_i, it is okay if he receives it in a lead time lower than l_i. (10)

III. Matching using Gale Shapely algorithm

Shapley's theory is based on stable matching. In their 1962 paper, Gale and Shapley demonstrated this idea with the stable marriage problem [4]. The stable marriage problem asked how a number of women could be matched to a number of men, considering their respective preferences for each member of the opposite sex. They showed that no matter the preferences, there would always exist a stable allocation. A stable allocation is one whereby no parties can be better off by further exchange. Stability is property as it is seen as an indication of efficiency because further improvement of happiness from exchange is impossible. An implication of the Gale-Shapley algorithm was that the proposing party would secure more favorable matches. In our application of matching farmers and consumers, the farmers were chosen as the proposing party.

Analysis of allocation mechanisms relies on a rather abstract idea. If rational people – who know their best interests and behave accordingly – simply engage in unrestricted mutual trade, then the outcome should be efficient. If it is not, some individuals would devise new trades that made them better off. An allocation where no individuals perceive any gains from further trade is called stable [5]. In this paper, we assume that farmers and consumers are rational individuals who participate to cooperatively choose an allocation. Under our customized GS algorithm, upon registration by a buyer/supplier, they receive the best possible item that is available for procurement/supply respectively based on their reported preference order. Hereafter, buyer/supplier's allocation can never deteriorate. Furthermore, if in the future the allocation can be improved due to either party's cancellation. It follows that for every supplier and buyer truthfully reporting its preference order is a dominant strategy. Hence, our customized GS algorithm is preference strategy-proof.

Pseudo-code for GS algorithm

```
Start ()
{
//City is passed as a mandatory input to restrict trade outside as per APMC act
Varcnt = Take count( COMMODITY TYPE, COMMODITY NAME, CITY);
For (i=0;i<=cnt;i++)
{
calc_pref_matrix(COMMODITY TYPE, COMMODITY NAME, CITY);
}}
//Calculate preference matrix and give it as input to GS algorithm
calc_pref_matrix(ctype,cname,city,cnt)
{
//Reg_date is a weighing factor included to break the tie in preferential assignment.
For i in (select SUPPLIERS from bid_table where bid_status is AVAILABLE and ctype=ctype,cname=cname , city=city and rownum<= cnt)
//Bid status becomes "CLOSED" only when the matching proposal has been accepted by both parties.
For j in (select BUYERS from bid_table where bid_status is AVAILABLE andctype=ctype,cname=cname, city=city and rownum<= cnt )
 {Calculate preferences b_pref and s_pref using equations (1) and (4);
Calc_gs();
Ensure constraints (6) to (10) are met for the matched proposals.
Calculate profit using (5) for the matched proposals.
}
//Implementation of GS algorithm
Calc_gs()
{ Initialize all buyers "B" and suppliers "S" to free
while free buyer b who still has a supplier s to match to {
s = b's highest ranked such supplier to whom he has not yet proposed
if s is free
(b, s) become engaged
else some pair (b', s) already exists
if s prefers b to b'
(b, s) become engaged
b' becomes free
else
(b', s) remain engaged
}
End()
```

IV. Cheat Proof mechanism in E-Mandi

We run online bidding of various commodities that involve users bidding on entries (usually one bid per user per day). The bid range from hundreds to thousands of units. Over the past years online bidding have encountered a number of ways people try to cheat, and have implemented counter-measures in each case. As it stands, we use the following measures:

Authentication

A user must create an account and authenticate (log in). This rules out anonymous bid stuffing.

Email Confirmation

A user must confirm their email address by clicking a link in a system email to confirm they own and have access to their address. These rules out creating accounts en masse using random (not necessarily valid) email addresses.

Distinct contact information, e-Mails and phone numbers:

If a contact information (door no, street, city, pin and village/block), e-mail address or phone number is already registered, the new registration for same contact, e-mail address or phone number will not be allowed. Even if any-one constraint fails. That slows down potential cheaters.

The contact information is validated as a group (door no, street, city, pin and village/block). If people are from same apartment door no will differ at least, even rests of others are same.

A. *Bidding constraints*

i. Each supplier must register their commodity. Else they cannot post a bid.

ii. A supplier cannot supply commodity other than their registered commodity. If a supplier is registered in "Buyer-Supplier" mode, then he can buy other commodities other than his registered commodity for supply.

iii. A Normal buyer can submit bid to buy any of the available commodity.

iv. Min price and Max price of a commodity will be fixed by the government personnel using admin login console. So that, cheating buyer/supplier cannot bid/Ask for higher prices than specified.

v. If quantity exceeds threshold units of demand/supply (Threshold unit can be fixed by government personnel for normal stock exchange between buyer and supplier in admin login console form) Eg: if it is 250 units per day, if buyer demands for 500 units he should give explanation before submitting a bid.

vi. Options are provided to source from multiple suppliers.

V. Delivery / Acceptance Acknowledgement:

Once goods are supplied by supplier he must acknowledge for his delivery. Similarly, once delivered goods are received by buyer, he must acknowledge for receiving the goods and should submit feedback forms which have fields to tell about seller, about late shipments, deteriorated quality of promised goods, report of wrong quantity and for loss incidents. Based on the feedback we will rate both the buyer and supplier.

Additional Measures:

We routinely audit our signups using programmed internal mechanisms, bidding rosters for strings of email addresses that come from the same private domain. We also look for similar names, usernames, and "local-parts" of email addresses across domains using internal mechanism.

We also show bidding result updates instantly, we collect loyalty feedback from both sides. That way, if someone is trying to cheat, based on feedback questionnaire we evaluate the users, and unless they went big, they won't know for sure if their method was successful. We try to be as much of a "black box" as possible since matching works internally.

VI. EXPERIMENTAL RESULTS

Assume a sample input as given in Table 2. There are 5 BUYERs and 7 SUPPLIERs. Assume for all above records the commodity type as "Fruits", commodity name as "Mango" and city as "CHENNAI".

Take a count of distinct COMMODITY TYPE, COMMODITY NAME, CITY. For above inputs the count will be 1 since all are of same type.

Table 2: Input table

BID_ID	QUALITY	MIN_PRICE	MAX_PRICE	LEAD_TIME	BID_TYPE	BID_QUANTITY
BS31	1	50	75	3	BUYER	200
BS32	2	65	75	1	BUYER	350
BS33	1	60	80	1	BUYER	235
BS34	1	55	65	1	BUYER	340
BS35	1	60	80	1	BUYER	100
BS36	1	60	80	1	SUPPLIER	150
BS37	2	50	80	2	SUPPLIER	200
BS38	1	65	90	2	SUPPLIER	150
BS39	1	55	80	1	SUPPLIER	300
BS40	1	65	90	2	SUPPLIER	200
BS41	1	62	78	1	SUPPLIER	100
BS42	1	61	82	1	SUPPLIER	120

The results of implementing GS algorithm are shown in Figure 1 below. The profits are calculated iteratively over several rounds until there are either no buyers/ suppliers for trading.

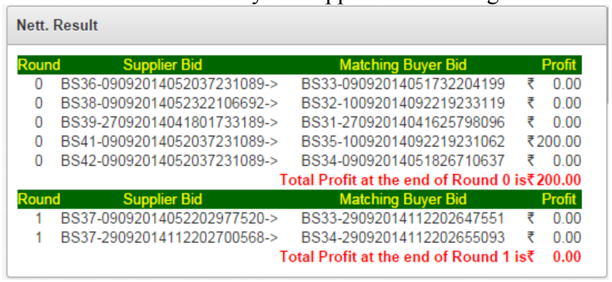

Figure 1: Results of GS algorithm implementation.

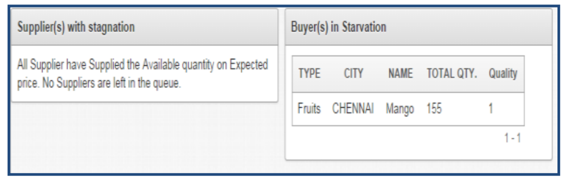

Figure 2: Results showing buyer/supplier stagnation

A) Comparison with English Auction

The proposed algorithm was compared with the mathematical formulation given by [2] for an open-cry auction mechanism for implementing supplier-consumer matching in an e-mandi implementation. Constraints (6) to (10) presented in section 2 are checked for validity. Table 2 is given as input and the results are given in Tables 3 through 7 for various rounds of implementation. After completion of a round, sellers and buyers who have been allocated the items are removed from the system. For the next round, the sellers are given an opportunity to change their asks based on the demand observed in the first round. Similarly, the buyers are given an opportunity to increase their bids, and the next round proceeds. This process continues as long as sellers are present in the system or until the minimum support price for the commodity is reached. Total number of suppliers stagnated at the end of round V is 4.

Table 3 ROUND I ALLOCATION

Criteria	Buyers					Suppliers							Round I Allocation	Profit (Rs)
	BS31	*BS32*	*BS33*	*BS34*	*BS35*	*BS36*	*BS37*	*BS38*	*BS39*	*BS40*	*BS41*	*BS42*		
Quality	1	2	1	1	1	1	2	1	1	1	1	1	nil	0
Quantity	200	350	235	340	100	150	200	150	300	200	100	120		
Price	50	65	60	55	60	80	80	90	80	90	78	82		

Table 4 Round II allocation

Criteria	Buyers					Suppliers							Round II Allocation	Profit (Rs)
	BS31	*BS32*	*BS33*	*BS34*	*BS35*	*BS36*	*BS37*	*BS38*	*BS39*	*BS40*	*BS41*	*BS42*		
Quality	1	2	1	1	1	1	2	1	1	1	1	1	**nil**	**0**
Quantity	200	300	235	340	100	150	250	150	300	200	100	150		
Price	55	70	65	60	65	75	75	85	75	85	73	77		

Table 5 ROUND III ALLOCATION

Criteria	Buyers					Suppliers							Round III Allocation	Profit (Rs)
	BS31	*BS32*	*BS33*	*BS34*	*BS35*	*BS36*	*BS37*	*BS38*	*BS39*	*BS40*	*BS41*	*BS42*		
Quality	1	2	1	1	1	1	2	1	1	1	1	1	BS32&BS37	0
Quantity	200	300	235	300	100	150	300	150	300	200	100	200	BS35&BS41	100
Price	60	71	60	65	71	70	71	80	70	80	70	72		

Table 6 ROUND IV ALLOCATION

Criteria	Buyers			Suppliers					Round IV Allocation	Profit (Rs)
	BS31	*BS33*	*BS34*	*BS36*	*BS38*	*BS39*	*BS40*	*BS42*		
Quality	1	1	1	1	1	1	1	1		
Quantity	200	200	300	200	150	350	200	225	BS34&BS39	0
Price	64	65	69	68	75	69	77	68		

Table 7 ROUND V ALLOCATION

Criteria	Buyers		Suppliers					Round V Allocation	Profit (Rs)
	BS31	*BS33*	*BS36*	*BS38*	*BS39*	*BS40*	*BS42*		
Quality	1	1	1	1	1	1	1		
Quantity	200	200	200	175	50	300	250	BS33&BS36	200
Price	67	67	66	73	69	77	67	BS31&BS42	0

Table 8: SUPPLIER STAGNATION

Criteria	Suppliers			
	BS38	BS39	BS40	BS42
Quality	1	1	1	1
Quantity	175	50	300	50
Price	70	66	75	65

The comparison results of the proposed modified GS algorithm with preferential inputs were compared with classical open-cry mathematical model proposed by [2] and tabulated in Table 9. It is thus inferred that the proposed model is better in terms of reducing the number of rounds of allocation at the end of all rounds and minimizing the stagnation of suppliers/buyers at the end of allocation. The results produced by English auction are always Pareto-optimal and hence the profit seems to be higher side, but it is a variable and depends on the random bid variation by the traders. Whereas, the minimum guaranteed profit can be arrived in the proposed model. Also, the performance metric is chosen as "Time averaged profit (TAP)". With the assumption that every round of allocation (R) is done at the end of every time period 't', TAP = Net Profit/R. When large number of multiple users updates bids in every round of allocation, system will face insert, update anomalies, whereas our proposed system will not have any such issues.

Table 9: COMPARISON OF RESULTS

Comparison		Classical English auction	Proposed Model
No of rounds of allocation		5	2
Net Profit		Rs.300	Rs.200
Performance Metrics	Time Averaged Profit	60	100
	Buyer/Supplier stagnation	4	1

VII. CONCLUSION

A matching is stable when there does not exist any match (A, B) by which both A and B are individually better off than they would be with the element to which they are currently matched. This is achieved in this bilateral trading scenario of matching buyers and suppliers with individual preferences. If the participating agents, buyers/ sellers are rational and submit their true valuation of a multi unit, single indivisible product to the decision support system (DSS), it is more likely that they get stable matches of allocation. The proposed method allows registered users to submit their bids/asks in the form of [price range, quantity, quality, lead time] instead of the traditional English auction model of submitting bid/ask in the form of [fixed price] in first round, which is then varied every round by the user to find an optimal match. Since, the bids/asks are submitted as a private information to the DSS, it is more likely to make the allocation cheat-proof and produces matches in less number of rounds. Finding the best match solely depends on the true valuation of product by the user. Also, the customized Gale Shapely algorithm has been applied to produce optimal matches in a bilateral trading scenario, which is first of its kind application in an e-trading environment. Compared to many e- supply chain portals, the proposed model seems to be more realistic and transparent to the users in matching supplier and buyer. It is first of its kind implementation to the e-agricultural supply chain.

We further would like to make our e-portal to take the complete governance responsibility and act as the key interface in selecting partners, setup and evaluate performance metrics of the players, maintain accountability of material and services, provide feedback on operational status for the prospective development of its players. The complete governance model of our proposed e-mandi is given in Figure 3.

In this work, we have taken only the boundary values of the submitted bid/ask price to finalize the match. In our future work, we aim to build in Genetic algorithm to vary the ask/bid price from the submitted price range of the supplier/ buyer respectively to maximize the profit.

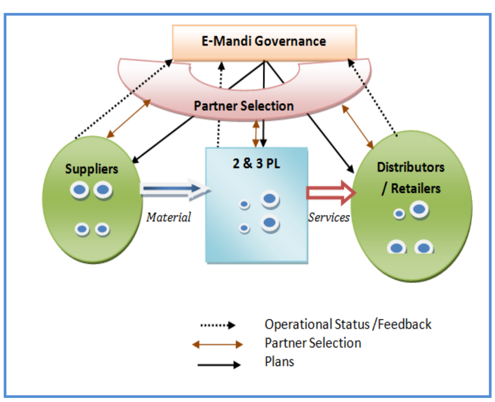

Figure 3: E-Mandi Governance Model

Appendix

Website	Drawbacks
farmer.gov.in/	There is no trading mechanism.
https://www.echoupal.com	It only reaches middle-sized farms. It acts as a mediator by getting list of farmers and their available commodities and gives information about available stock to registered buyers.
http://www.agmarknet.nic.in/	The system only sensitizes and orients farmers to respond to new challenges in agricultural marketing by using ICT as a vehicle of extension.
www.ikisan.com	No additional information.
www.ekrishi.org	There is no automatic mechanism to match farmers and consumers demand and supply.

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