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SINGLE OBJECTIVE SUPPLY CHAIN NETWORK OPTIMIZATION AROUND ACRYLONITRILE PLANT

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Abstract

In this study, a profit oriented supply chain network optimization is performed on an acrylonitrile plant. The network consists of three suppliers which provide two necessary raw materials (propylene and ammonia) for the production of acrylonitrile, one production plant and four customers. In the transportation of the raw materials and product, either highway transportation or sea transportation can be preferred with respect to constraints to achieve maximum profit. To investigate the effects of constraints for raw materials purchased from suppliers, product sold to customers, production capacity of the plant and amount of raw materials & product transported by alternative transportation modes on profit maximization, four cases are performed within the framework of this study. In the solution of this single objective optimization problem GAMS, MATLAB and Solver Tool of Excel are used. In MATLAB, "fmincon" solver; in GAMS program "Cplex", "LindoGlobal" and "Baron" solvers are preferred whereas "Simplex" is used in Excel. According to the results obtained in each program, it is seen that maximum achievable profit changes from 3,869,389 to 4,664,841 $/year and amount of acrylonitrile produced is 79,040 tonnes/year (in the first two cases) and 90,000 tonnes/year (in the consecutive two cases).

Keywords: *Supply Chain Network, Optimization, Modeling, Linear Programming, Profit Maximization.*

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Introduction

The concept of supply chain management was appeared in the early 90s (Guillen et. al., 2005) and it has become a crucial and primary subject to companies over the years to design an effective network. A basic supply chain includes suppliers, manufacturers, distribution centers, retailers, customers and service providers as its participant, but the size of the network changes from one to another. Sometimes it includes all these participants but sometimes a few of them (Armay, 2017).

The importance of supply chain management has been growing day by day because of the intensified competition in the local & global markets and increasing demand on the needs of new and cheap resources (Maestika and Cepinskis, 2015; Armay, 2017). Since the primary objectives in supply chain management are to satisfy the customer demands and to improve the performance of an organization, companies pay a lot of importance in building an efficient supply chain network. Each supply chain has its own participants and properties differ from one to another. Due to this reason, companies' short and long-term developments are planned for each unique supply chain by considering their properties. This provides an operational and strategic advantages to organizations in constantly and highly changing global markets (Maestika and Cepinskis, 2015; Armay, 2017).

Satisfying customer's demands, transportation of products/goods from initial to final participant of the chain at the right time and the right quantity, at the right location with a minimum cost and to maximize the overall value generated are the primary objectives of the supply chain management (Cuttimg-Decelle et. al., 2007; Syntetos et. al., 2016; Armay, 2017).

Supply chain networks consist of various components depended on each other which makes it complicated to be modelled. The level of complexity changes with respect to the number of components, objectives and to some other parameters (Armay, 2017). At high level of complexity of a supply chain network, it is difficult to solve the problem manually (Gattorna, 1998). In such cases, using computer programs offers an alternative way to decision makers to solve the problem in a short time with less effort. There are many programs that can be used for this purpose and in this paper, GAMS, MATLAB and Solver Tool of Excel are preferred to be used.

Problem Statement

This is a single objective optimization problem consists of three suppliers, one manufacturer (acrylonitrile plant) and four customers. The participants of the network are presented in Figure 1. According to this figure, there are two echelons: first one is between suppliers and acrylonitrile plant, and the second one is between the plant and customers. In the first echelon, raw materials (propylene and ammonia) are transported from suppliers to plant whereas in the second echelon final product (acrylonitrile) is transported from plant to customers. In the transportation of these raw materials and product, either sea transportation or highway transportation can be preferred.

The objective of this study is to achieve maximum profit for the network. Within the framework of this study it is aimed to investigate the effects of (Armay, 2017; Armay et. al., 2017):

- constraints for the amount of raw materials & product transported by two modes of transportation in the network,
- production capacity constraint of the manufacturer,
- constraint for raw materials supplied,
- and constraints for product sold to customers

on profit maximization. Hence, four different cases are performed by taken into consideration of these constraints.

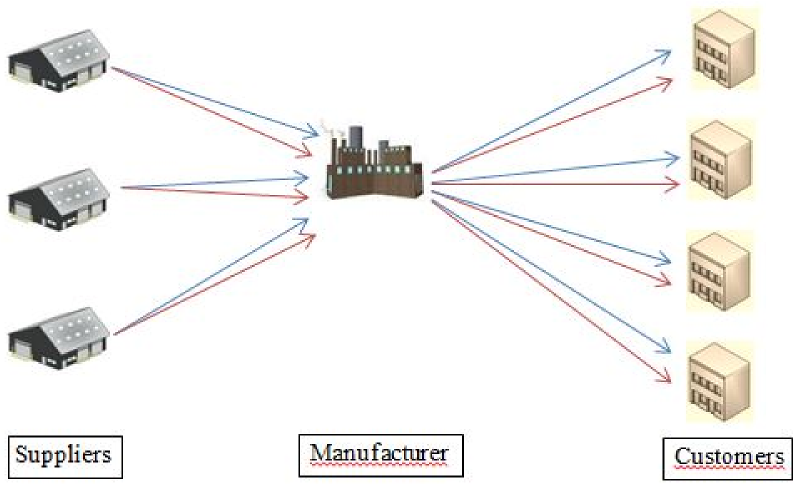

Figure 1. Participants of the supply chain network.

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The objective function, capacity & mass balance constraints of the proposed model are presented as follows:

Objective function:

$$Profit = (Pprod \times Xproduced) - \sum_i \sum_m (CtrSupManNH3_{i,m} \times XsmNH3_{i,m}) - \sum_i \sum_m (CtrSupManProp_{i,m} \times XsmProp_{i,m}) - \sum_i (CrawNH3_i \times Xammonia_i) - \sum_i (CrawProp_i \times Xpropylene_i) - \sum_k \sum_m (CtrManC_{k,m} \times Xmanc_{k,m}) - (Cprod \times Xproduced) \quad (1)$$

Capacity Constraints:

$$Xammonia_i \leq CapSupNH3_i \quad (2)$$

$$Xpropylene_i \leq CapSupProp_i \quad (3)$$

$$\sum_k \sum_m Xmanc_{k,m} \leq CapMan \quad (4)$$

Mass Balance Constraints:

$$Ya = \sum_i \sum_m XsmNH3_{i,m} \quad (5)$$

$$Yp = \sum_i \sum_m XsmProp_{i,m} \quad (6)$$

$$Xproduced = 0.79 \times Yp \quad (7)$$

$$Xproduced = 0.32 \times Ya \quad (8)$$

$$Xproduced = \sum_k \sum_m Xmanc_{k,m} \quad (9)$$

$$Xammonia_i = \sum_m XsmNH3_{i,m} \quad \forall i \quad (10)$$

$$Xpropylene_i = \sum_m XsmProp_{i,m} \quad \forall i \quad (11)$$

$$XsmNH3_{i,m}, XsmProp_{i,m}, Xproduced, Xmanc_k, Xammonia_i, Xpropylene_i, Ya, Yp \geq 0 \quad \forall i,k,m \quad (12)$$

Additional constraints added to the model in each case are given as follows [2]:

- In Case 1, quantity of product produced in the plant should be less than or equal to the capacity of manufacturer.
- In Case 2, some constraints are added to Case 1. These are: amount of product transported from manufacturer to customer 3 with transportation mode 1 (highway) and 2 (sea transportation) should be greater than or equal to 5,000 tonnes per year; to customer 4 with transportation mode 1 should be greater than or equal to 10,000 tonnes per year; to customer 2 with transportation mode 2 should be less than or equal to 50,000 tonnes per year. Also, amount of propylene purchased from supplier 3 and then transported to manufacturer with transportation mode 1 should be greater than or equal to 20,000 tonnes per year. And finally, amount of ammonia purchased from supplier 2 and then transported to manufacturer with transportation mode 1 should be greater than or equal to 25,000 tonnes per year.
- In Case 3, quantity of product produced in the plant should be equal to the capacity of manufacturer.
- In Case 4, additional constraints in Case 2 are added to Case 3.

The estimated values of necessary data, sets of indices, variables & parameters used in the problem are presented in Tables 1 to 6.

Table 1. Purchase price of raw materials ($/tonne) and capacity of suppliers (tonne/year).

Supplier	**Ammonia**		**Propylene**	
	CrawNH3	CapSupNH3	CrawProp	CapSupProp
1	500	126,000	900	120,000
2	450	112,000	850	105,000
3	470	135,000	800	118,000

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Table 2. Unit transportation cost of raw materials according to different transportation modes ($/tonne).

Supplier	Ammonia		Propylene	
	Transportation mode		Transportation mode	
	1	2	1	2
1	8.30	7.00	6.90	6.00
2	8.60	8.00	6.85	5.00
3	7.80	6.00	6.30	5.00

Table 3. Unit transportation cost of product according to different transportation modes ($/tonne).

Customer	Transportation mode	
	1	2
1	8.0	6.0
2	7.2	5.0
3	7.4	7.0
4	6.8	6.0

Table 4. Price and unit production cost of acrylonitrile ($/tonne) and capacity of plant (tonne/year).

Pprod	2,650
Cprod	105
CapMan	90,000

Table 5. Sets of indices used in the problem.

$i \in I$	Suppliers
$k \in K$	Customers
$m \in M$	Transportation mode

Table 6. Variables and parameters used in the problem.

CapMan	Capacity of plant (tonne/year)
$CapSupNH3_i$	Capacity of supplier i to supply ammonia (tonne/year)
$CapSupProp_i$	Capacity of supplier i to supply propylene (tonne/year)
Cprod	Unit production cost of product ($/tonne)
$CrawNH3_i$	Unit purchase price of ammonia at supplier i ($/tonne)
$CrawProp_i$	Unit purchase price of propylene at supplier i ($/tonne)
$CtrManC_{k,m}$	Unit transportation cost of product from plant to customer k by transportation mode of m ($/tonne)
$CtrSupManNH3_{i,m}$	Unit transportation cost of ammonia from supplier i to plant by transportation mode of m ($/tonne)
$CtrSupManProp_{i,m}$	Unit transportation cost of propylene from supplier i to plant by transportation mode of m($/tonne)
Pprod	Price of product ($/tonne)
$Xammonia_i$	Total amount of ammonia purchased from each supplier and transported to plant (tonne/year)
$Xmanc_{k,m}$	Total amount of product transported from plant to customer k by transportation mode of m (tonne/year)
Xproduced	Total amount of product produced at plant (tonne/year)
$Xpropylene_i$	Total amount of propylene purchased from each supplier and transported to plant (tonne/year)
$XsmNH3_{i,m}$	Amount of ammonia transported from supplier i to plant by transportation mode of m (tonne/year)
$XsmProp_{i,m}$	Amount of propylene transported from supplier i to plant by transportation mode of m (tonne/year)
Ya	Total amount of ammonia purchased from all suppliers (tonne/year)
Yp	Total amount of propylene purchased from all suppliers (tonne/year)

In the solution of this profit oriented single objective supply chain network optimization problem Solver Tool of Excel, GAMS and

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MATLAB programs were used. In GAMS program “Cplex”, “Lindoglobal” and “Baron” solvers were selected whereas in MATLAB, “fmincon” solver was preferred. In Excel, “Simplex” was used.

Findings

In this linear programming optimization problem, each four cases include 29 positive variables and 11 equality constraints. On the other hand, number of boundaries in each case differ from one to another. There are 7, 13, 6 and 12 boundaries in Case 1 to 4, respectively.

The results obtained in each program with using five different solvers are presented for each case in Tables 7 to 10.

Table 7. Results obtained in each program for Case 1.

	CASE 1					
	GAMS			***EXCEL***	***MATLAB***	
	CPLEX	*LINDO-GLOBAL*	*BARON*	*Simplex*	*fmincon*	
Profit	4,664,841	4,664,841	4,664,841	4,664,841	4,664,835.75	$/year
Xproduced	79,040	79,040	79,040	79,040	79,040	Tonnes / year
$XsmNH3_{1,1}$	0	0	0	0	0	
$XsmNH3_{1,2}$	0	0	0	0	0	
$XsmNH3_{2,1}$	0	0	0	0	0.98	
$XsmNH3_{2,2}$	112,000	112,000	112,000	112,000	111999.01	
$XsmNH3_{3,1}$	0	0	0	0	0.0348	
$XsmNH3_{3,2}$	135,000	135,000	135,000	135,000	134,999.97	
$XsmProp_{1,1}$	0	0	0	0	0	
$XsmProp_{1,}$	0	0	0	0	0	

2						
$XsmProp_{2,1}$	0	0	0	0	0	
$XsmProp_{2,2}$	0	0	0	0	0	
$XsmProp_{3,1}$	0	0	0	0	0	
$XsmProp_{3,2}$	100,051	100,051	100,051	100,051	100,051	
$Xmanc_{1,1}$	0	0	0	0	0	
$Xmanc_{1,2}$	0	0	0	0	0	
$Xmanc_{2,1}$	0	0	0	0	0.0967	
$Xmanc_{2,2}$	79,040	79,040	79,040	79,040	79,037.95	
$Xmanc_{3,1}$	0	0	0	0	0.0106	
$Xmanc_{3,2}$	0	0	0	0	1.9333	
$Xmanc_{4,1}$	0	0	0	0	0	
$Xmanc_{4,2}$	0	0	0	0	0	
Ya	247,000	247,000	247,000	247,000	246,999.99	
Yp	100,051	100,051	100,051	100,051	100,051	
$Xpropylene_1$	0	0	0	0	0	
$Xpropylene_2$	0	0	0	0	0	
$Xpropylene_3$	100,051	100,051	100,051	100,051	100,051	
$Xammonia_1$	0	0	0	0	0	
$Xammonia_2$	112,000	112,000	112,000	112,000	111,999.99	
$Xammonia_3$	135.000	135,000	135,000	135,000	135,000	

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Table 8. Results obtained in each program for Case 2.

	CASE 2					
	GAMS			*EXCEL*	*MATLAB*	
	CPLEX	*LINDO-GLOBAL*	*BARON*	*Simplex*	*fmincon*	
Profit	4,574,801	4,574,801	4,574,801	4,574,801	4,574,801	\$/year
Xproduced	79,040	79,040	79,040	79,040	79,040	Tonnes / year
$XsmNH3_{1,1}$	0	0	0	0	0	
$XsmNH3_{1,2}$	0	0	0	0	0	
$XsmNH3_{2,1}$	25,000	25,000	25,000	25,000	25,000	
$XsmNH3_{2,2}$	87,000	87,000	87,000	87,000	87,000	
$XsmNH3_{3,1}$	0	0	0	0	0	
$XsmNH3_{3,2}$	135,000	135,000	135,000	135,000	135,000	
$XsmProp_{1,1}$	0	0	0	0	0	
$XsmProp_{1,2}$	0	0	0	0	0	
$XsmProp_{2,1}$	0	0	0	0	0	
$XsmProp_{2,2}$	0	0	0	0	0	
$XsmProp_{3,1}$	20,000	20,000	20,000	20,000	20,000	
$XsmProp_{3,}$	80,051	80,051	80,051	80,051	80,051	

2						
$Xmanc_{1,1}$	0	0	0	0	0	
$Xmanc_{1,2}$	0	0	9,040	0	4,522	
$Xmanc_{2,1}$	0	0	0	0	0	
$Xmanc_{2,2}$	50,000	50,000	50,000	50,000	50,000	
$Xmanc_{3,1}$	5,000	5,000	5,000	5,000	5,000	
$Xmanc_{3,2}$	5,000	5,000	5,000	5,000	5,000	
$Xmanc_{4,1}$	10,000	10,000	10,000	10,000	10,000	
$Xmanc_{4,2}$	9,040	9,040	0	9,040	4,518	
Ya	247,000	247,000	247,000	247,000	247,000	
Yp	100,051	100,051	100,051	100,051	100,051	
$Xpropylene_1$	0	0	0	0	0	
$Xpropylene_2$	0	0	0	0	0	
$Xpropylene_3$	100,051	100,051	100,051	100,051	100,051	
$Xammonia_1$	0	0	0	0	0	
$Xammonia_2$	112,000	112,000	112,000	112,000	112,000	
$Xammonia_3$	135,000	135,000	135,000	135,000	135,000	

Table 9. Results obtained in each program for Case 3.

	CASE 3					
	GAMS			***EXCEL***	***MATLAB***	
	CPLEX	*LINDO-GLOBAL*	*BARON*	*Simplex*	*fmincon*	
Profit	3,970,389	3,970,389	3,970,389	3,970,389	3,970,384.74	$/year

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Xproduced	90,000	90,000	90,000	90,000	90,000	
$XsmNH3_{1,1}$	0	0	0	0	1.5712	
$XsmNH3_{1,2}$	34,250	34,250	34,250	34,250	34,248.4	
$XsmNH3_{2,1}$	0	0	0	0	1.407	
$XsmNH3_{2,2}$	112,000	112,000	112,000	112,000	111,998.59	
$XsmNH3_{3,1}$	0	0	0	0	0.44	
$XsmNH3_{3,2}$	135,000	135,000	135,000	135,000	134,999.5	
$XsmProp_{1,1}$	0	0	0	0	0	Tonnes / year
$XsmProp_{1,2}$	0	0	0	0	0	
$XsmProp_{2,1}$	0	0	0	0	0	
$XsmProp_{2,2}$	0	0	0	0	0	
$XsmProp_{3,1}$	0	0	0	0	0.417	
$XsmProp_{3,2}$	113,924	113,924	113,924	113,924	113,923.6	
$Xmanc_{1,1}$	0	0	0	0	0	
$Xmanc_{1,2}$	0	0	0	0	0	
$Xmanc_{2,1}$	0	0	0	0	0.066	
$Xmanc_{2,2}$	90,000	90,000	90,000	90,000	89,999.86	
$Xmanc_{3,1}$	0	0	0	0	0.008	

$Xmanc_{3,2}$	0	0	0	0	0	
$Xmanc_{4,1}$	0	0	0	0	0.0619	
$Xmanc_{4,2}$	0	0	0	0	0	
Ya	281,250	281,250	281,250	281,250	281,250	
Yp	113,924	113,924	113,924	113,924	113,924	
$Xpropylene_1$	0	0	0	0	0	
$Xpropylene_2$	0	0	0	0	0	
$Xpropylene_3$	113,924	113,924	113,924	113,924	113,924	
$Xammonia_1$	34,250	34,250	34,250	34,250	34,250	
$Xammonia_2$	112,000	112,000	112,000	112,000	112,000	
$Xammonia_3$	135,000	135,000	135,000	135,000	135,000	

Table 10. Results obtained in each program for Case 4.

	CASE 4					
	GAMS			***EXCEL***	***MATLAB***	
	CPLEX	*LINDO-GLOBAL*	*BARON*	*Simplex*	*fmincon*	
Profit	3,869,389	3,869,389	3,869,389	3,869,389	3,869,389	$/year
Xproduced	90,000	90,000	90,000	90,000	90,000	
$XsmNH3_{1,1}$	0	0	0	0	0	Tonnes / year
$XsmNH3_{1,2}$	34,250	34,250	34,250	34,250	34,250	
$XsmNH3_{2,}$	25,000	25,000	25,000	25,000	25,000	

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1					
$XsmNH3_{2,2}$	87,000	87,000	87,000	87,000	87,000
$XsmNH3_{3,1}$	0	0	0	0	0.3352
$XsmNH3_{3,2}$	135,000	135,000	135,000	135,000	134,999.66
$XsmProp_{1,1}$	0	0	0	0	0
$XsmProp_{1,2}$	0	0	0	0	0
$XsmProp_{2,1}$	0	0	0	0	0
$XsmProp_{2,2}$	0	0	0	0	0
$XsmProp_{3,1}$	20,000	20,000	20,000	20,000	20,000
$XsmProp_{3,2}$	93,924	93,924	93,924	93,924	93,924
$Xmanc_{1,1}$	0	0	0	0	0
$Xmanc_{1,2}$	0	0	20,000	0	6,358
$Xmanc_{2,1}$	0	0	0	0	0
$Xmanc_{2,2}$	50,000	50,000	50,000	50,000	50,000
$Xmanc_{3,1}$	5,000	5,000	5,000	5,000	5,000
$Xmanc_{3,2}$	5,000	5,000	5,000	5,000	5,000
$Xmanc_{4,1}$	10,000	10,000	10,000	10,000	10,000
$Xmanc_{4,2}$	20,000	20,000	0	20,000	13,642
Ya	281,250	281,250	281,250	281,250	281,250
Yp	113,924	113,924	113,924	113,924	113,924

Xpropylene1	0	0	0	0	0
Xpropylene2	0	0	0	0	0
Xpropylene3	113,924	113,924	113,924	113,924	113,924
Xammonia1	34,250	34,250	34,250	34,250	34,250
Xammonia2	112,000	112,000	112,000	112,000	112,000
Xammonia3	135,000	135,000	135,000	135,000	135,000

In all cases, the maximum profit was achieved in Case 1. In this case, the amount of acrylonitrile produced in the plant is 79,040 tonnes/year. The output of GAMS and Excel are the same in this case but MATLAB has a few differences. Total profit is obtained as 4,664,835.75 $/year in MATLAB and 4,664,841 $/year in other solvers. The difference in the variables obtained causes the difference in profit values (Table 7) (Armay, 2017). As it is presented in Table 7, the slight differences in the:

- amount of ammonia bought from supplier 2 and transported to the plant by transportation mode of 1 ($XsmNH3_{2,1}$),
- amount of ammonia bought from supplier 3 and transported to the plant by transportation mode of 1 ($XsmNH3_{3,1}$),
- amount of ammonia bought from supplier 3 and transported to the plant by transportation mode of 2 ($XsmNH3_{3,2}$),
- amount of product transported to customer 2 by transportation mode of 1 ($Xmanc_{2,1}$),
- amount of product transported to customer 2 by transportation mode of 2 ($Xmanc_{2,2}$),
- amount of product transported to customer 3 by transportation mode of 1 ($Xmanc_{3,1}$),
- amount of product transported to customer 3 by transportation mode of 2 ($Xmanc_{3,2}$),

obtained in MATLAB & other programs cause the slight difference in profit values.

In Case 2, profit was obtained in each program as 4,574,801 $/year. This is the second highest value in all cases designed for multi transportation. In this case output of Cplex & Lindoglobal (in GAMS) and Simplex LP (in Excel) solvers are the same. On the other hand, Baron (in GAMS) and fmincon (in MATLAB) provide some alternative solutions for the problem such as (Armay, 2017):

- Amount of product transported from manufacturer to customer 1 and 4 by transportation mode 2 is 0 and 9,040 tonnes per year, respectively in Cplex, Lindoglobal and Excel. But in Baron, these values are vice versa (Table 8). Since the unit transportation cost of product between manufacturer and customer 1 & 4 is the same as 6 $ per tonne, product can be sold to customer 4 instead of customer 1 without causing any change in total profit. Likewise product may be sold to both customers by transportation mode 2 in different amounts (in fmincon).

In Case 3 (the only difference between Case 1 and Case 3 is the constraint that determine the amount of acrylonitrile produced in the plant), results obtained in GAMS and Excel are the same, but in MATLAB there are a few differences.

In the last case, 3,869,389 $/year of profit is obtained when the plant operates at full capacity (which means the quantity of product produced in the plant is equal to the capacity of manufacturer) and by taking into consideration of constraints.

The comparison of profits obtained in each case is presented in Figure 2 (Armay, 2017).

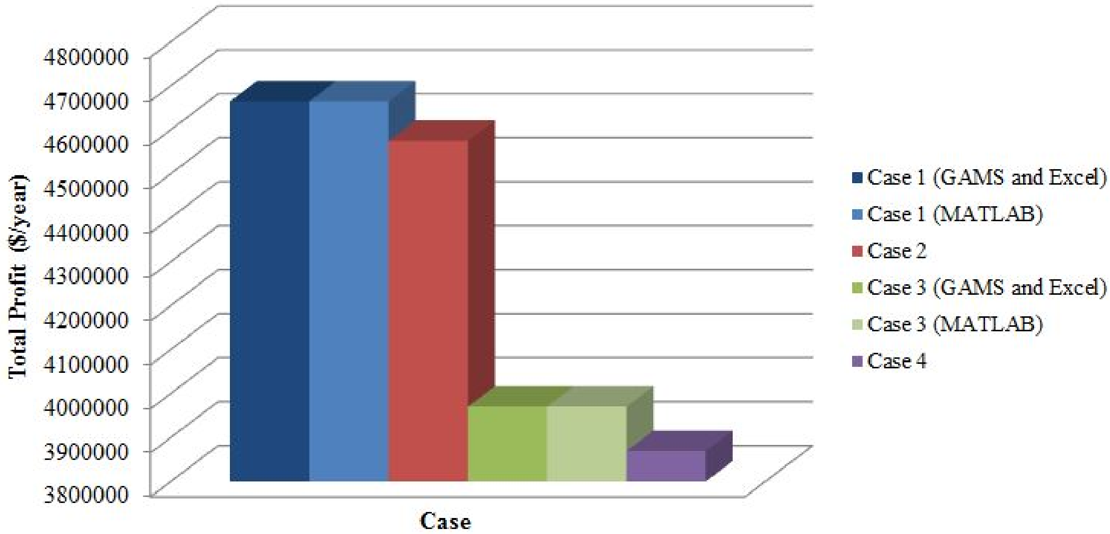

Figure 2. Maximum profit obtained in each case.

Conclusion

Within the framework of this study, a single objective optimization problem is performed for a supply chain network consists of three suppliers, one production plant and four customers. It was aimed to achieve maximum profit for the network by taking into consideration of constraints.

This study provides an opportunity to investigate the effects of constraints for: the amount of raw materials & product transported by two different modes of transportation, product sold to customers, raw materials purchased from suppliers and production capacity of the plant on profit. Thus, it can be evaluated that whether the plant operates at full capacity or with constraint has the highest profit.

According to the results presented in Tables 7 to 10, the highest profit is achieved in Case 1 as 4,664,841 $/year (in GAMS and Excel) and as 4,664,835.75 $/year (in MATLAB). On the other hand the lowest profit is obtained in Case 4 as 3,869,389 $/year.

As it is seen from the results that if the plant operates at full capacity it has a less profit (comparison between Case 1 and Case 3). The reason of this situation can be explained as follows: to produce 90,000 tonnes of acrylonitrile in yearly basis, minimum 281,250 tonnes of ammonia and 113,924 tonnes of propyplene are required. Since the ammonia capacity of supplier 2 and 3 which have lower cost than

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supplier 1 (sum of purchase and unit transportation cost) is not enough to produce desired amount of product, additional required amount of ammonia is purchased from supplier 1. This causes a decrease in the profit.

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