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Using Theory of Constraints in Production Management and Scheduling (A Case Study)

Ahmad Hooshmand[1*], Ali Reza Mehrazeen[2], Ali Reza Davoody[3] and Mohamad Reza Shorvarzi[2]

[1] Department of Accounting, Torbat Heidareh Branch, Islamic Azad University, Torbat Heidarehr, Iran
[2] Department of Accounting, Neyshabur Branch, Islamic Azad University, Neyshabur, Iran
[3] Department of Mathematics, Neyshabur Branch, Islamic Azad University, Neyshabur, Iran

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Abstract

In manufacturing institutes the only access way to maximum profit is identifying the production mix of the products based on the limitations such as policies and politics, demand and production processes. This study identifies the constraints of a tile-manufacturing company including constraints in its production and demand line using LINGO software version 15, and identifying production bottleneck, i.e. fur-nace, production scheduling was provided and sensitivity analysis was conducted on the variables and right hand items. Positive shadow price of furnace shows efficiency of every unit on throughput. Also, in demand constraint, negative shadow price of product 16 shows decreasing effect of increase of every unit on throughput. Allowable increase and decrease of right hand items show allowable increase in furnace section and limitlessness of allowable decrease of product 16. Changes in this range causes that the current basis remains optimal changes in which causes changes in the optimal value of the target function regarding shadow prices.

Keywords:
Theory of Constraints
production scheduling
Bottleneck
sensitivity analysis

* **Correspondence E_mail**: ah_hoshmand2005@yahoo.com

INTRODUCTION

Production or service units' managers are forced to survive in the global market with limited resources and shortcomings, choosing a mix of products that maximizes their profits. Therefore, managers must use mathematical models, linear and nonlinear programming, and other tech-niques to maximize profits with respect to the existing limits (Namazi, 2015).

The large variability of internal and external factors is a serious problem hampering production management. To meet the standards and at the same time ensure the viability of production it is necessary to quickly respond to problems that arise during production processes, and to ade-quately correct plans. Measures taken in the management of made to order production are frequently single and unique, and therefore resemble the features of project management. (Trojan-owska & Dostatni, 2017)

This approach is significantly different with traditional management in which all corporate op-erations should be as much efficient as possible and all machinery and staff should do their bests. The basis of this constraint-based method is that every local optimization everywhere but in the bottleneck leads to the production beyond operating capability of that resource, leading to the increased surplus inventory. Since 1980s, Theory of Constraints (TOC) has been regarded as an important theme in operating management research. It suggests that improving institutional performance may be obtained by emphasizing some penetration points in the system. Based on this theory, every organization should be identified as a system with one goal. Thus, every conducted activity by every part of a system is judged by its effect on the whole system′s goal. While using production processes, TOC describes the idea of identifying and managing bottle-necks in the production process (Panizolo, 2016).

The main idea of TOC rests on the bottle neck management. This theory claims to lead to the continuous improvement by identifying constraints and production bottlenecks in the organiza-tions. In this vein, the main focus of this theory is identifying constraints and their management for increasing system efficiency. TOC is on-time production based on the continuous improve-ment like Japanese management philosophy (Golabchi & Amirfaraji, 2013).

TOC

The TOC is defined as a management philosophy with a continuous improvement focus which brings about improved organizational performance. The TOC is a management philosophy that focuses on continuous improvement. It has been deployed in areas such as production, market-ing, project management; services define the TOC as a theory that clearly identifies a "gain ori-entation" with its three dimensions: mental models, measures and methodology. According to the TOC, we can make speculations from the following three components:

(1) A logistic and operations approach, which involves the following methods: five steps focused on process improvement, production scheduling via DBR (drum buffer-rope) and the analysis of production systems through the VAT logic

(2) A system of performance indicators encompassing the definition of gains, inventories and operating expenses; definition of the product mix to be produced to maximize the results; and the logic of gains per day and inventories per day.

(3) A thinking process oriented to solving problems, which involves the following techniques: current reality tree, the cloud evaporation method, future reality tree, pre-requisites tree, and transition tree. (Jesus Pacheco et al., 2018)

One responsibility of non-profit entities′ managers especially manufacturing units is the optimum use of available resources for maximizing that entity ′s profitability. But, for reaching this goal, managers face the problems or constraints such as production resource constraints and market constraints such as demand and supply, competition, and customers′ needs. A manager is called successful when he/she can use the resources maximally, increasing profitability despite these constraints. For this means, managers need accurate and on-time information on the existing constraints in the system and available methods for the optimal use of these constraints in a production or service system all processes are related with its predecessor and successor if available. Each process has a limited production capacity within its constraints.

In almost all cases, there is only one process that limits or restricts the performance of entire system. Theory of constraints is based on the premise that the rate of goal achievement by a goal oriented system is limited by at least one constraint and adopts the common idiom as “a chain is no stronger than its weakest link”. That is to say systems or part of systems are vulnerable because the weakest element or part can always damage or break them or at least adversely affect the output. In other words, if there is no obstacle that prevents a system from achieving higher throughput, its throughput would be infinite which is not possible in a real-life system. Overall throughput can be increased only by increasing the flow through the constraint. (Gundogar et al., 2016)

One evolving managerial approach and philosophy in recent years with considerable outcomes is TOC. This managerial philosophy suggested by Dr. Eliyahu Goldratt (1980s) postulates that every system has at least one constraint which inhibits it from reaching its goals.

Principals of TOC

The main philosophy of this theory is optimal use of constraints and production bottlenecks. It views the production system as a chain of related processes like loops of a chain the most im-portant of which is the weakest. Since a weak loop slows down value creation process. In the units in which producing service or products is done in several steps, starting each step needs completing the process in the previous stage. In other words, no process can work unless its prior process has been completed. From one hand, different manufacturing and service pro-cesses don’t have full balance normally. Some of these processes may have extra capacity and some other may face the shortage of capacity. The factor which creates constraint in reaching corporate goals is called bottleneck. It refers to that part of operation which limits production and service offering processes, creating fluctuations in the operations. Evidently, a bottleneck increases finished costs of the products and services, presentation time, decreasing quality. The main message of TOC is that constraints determine the performance of each system and every system has at least one constraint which inhibits it from reaching the goal for which it has been developed. In other words, reaching a high level of performance and profitability is a function of knowing organizational constraints and their management (Golabchi & Amirfaraji, 2013).

TOC is measured by three criteria of throughput, operating costs, and inventory.

Throughput is the amount of money a unified system gains by sale or the whole money entering the system (Detmer, 2015). Goldratt defines throughput as the income after subtracting direct material sand equals it with the profit margin in variation costing.

This technique supposes other costs which are considered as the variable costs in variable costing as the fixed costs and thus it is called throughput costing (Namazi, 2015).

Operating costing: It refers to the spent cash in the system for making sure that the operations in the system will be continued. Despite common definitions, operating costs include general, administrative, sale, direct payment, and manufacturing overhead costs. All of these costs are concerned as the period cost (Namazi, 2015).TOC deals with operating costs as a fixed cost in short term. This is done for preventing from wrong and misleading information disclosure through allocating indirect costs. If fixed costs are dealt like variable costs, wrong decisions may be induced in selecting optimal conditions for producing products.

Inventory: Inventory is all cash a system invests on the items it wants to sell. Since managers believe that all system parts should be always working, there is always some unused inventory which decreases system performance because in this state organizational cash is blocked as in-ventory. This is while that cash can be invested on the profitable plans. Moreover, inventory expansion conceals the underlying issues of the company. Therefore, to improve the system, inventory should be gradually reduced (Golabchi & Amirfaraji, 2013). Therefore, the inventory is all the money that is contained within the system. Obviously, in addition to the raw materials, the goods in the manufacturing process, the purchased parts, and equipment are also included. Goldratt claims that all of these dimensions are interdependent. A change in one of them causes spontaneous changes in one or two other ones. Suppose that if we increase the output by increasing sales, the inventory and operating costs will also increase. Because we probably need more inventories to support sales, we will also need to spend more to produce more. But if we can make the same sale revenue with less inventory and lower operating costs, we have been able to maintain more of the money entering the company. Then, increasing throughput and simultaneously reducing inventory and operating costs will improve the system (Detmer, 2015).

Stages of TOC

One basic concept is identifying the importance of the role of the system or bottleneck con-straint. The first stage is identifying the system goal for which the system has been developed. Before concerning continuous development, the goal of the system and evaluation criteria for the effect of each subset and every trivial decision on the total systemic goal should be defined. The process of continuous improvement and TOC results from the thinking that all attempts should focus on the system goal. This process has five stages as follow:

1-Identifying system goals

2-Decision making about how to benefit from the system constraint as much as possible

3-Subordinating all sections to the constraint for more utilization from it

4-Increasing the performance of system constraint or elevating the bottleneck

5-If the constraint is removed in prior stages, return to the first stage (Rahnemay Roodposhti, 2008)

LITERATURE

After representing TOC in 1980s by Goldratt, different studies were conducted for optimizing constraint-based production such as Peterson (1992) who calculated optimum production mix based on the hypothetical data. But, by changing data of Peterson problem and adding to the constraints, in his study titled" Optimizing theory of constraints when multiple constrained re-sources exist", Gerhard Plenter (1993) and Fredendall and Lea (1997) showed that in the condi-tions with one constraint, results from linear scheduling and TOC will be the same. But, by add-ing to the constraints, optimum production mix is determined regarding other bottlenecks. Then, researchers calculated optimum production mix in the conditions with several constraints using extractive algorithms. For example, Godfrey et al. (2001) used generic algorithm and compared it with other methods such as TOC, concluding that this approach can be used in the manufac-turing companies. Godfrey (2001) used taboo search-based algorithm for the TOC product mix decision. Nishikant et al.(2005) compared hybrid taboo search- based and simulated annealing based approach and found that hybrid taboo-simulated annealing based approach is better than exploratory TOC, modified exploratory TOC, taboo search, simulated annealing based, and linear scheduling algorithms. In their study titled" A simulated annealing approach for product mix decisions", Chaharsooghi and Jafari (2007) showed that simulated annealing approach yields better results than other algorithms such as taboo search and generic algorithms. Amitava et al. (2008) suggested a completed model of a hybrid of Laplas and TOC in a context with several constraints. They compared the model output with standard costing and TOC, showing that this model offers more realistic state of resource allocation and measuring financial performance. Rafiei and Torabi (2012) suggested a new algorithm for the processes of innovative and meta-innovative solutions using the concepts of group decision-makings. Rashidikomijan et al. (2009) suggested a new and different approach towards traditional, modified, and improved TOC and linear scheduling which facilitated reaching an optimum response in short-term whose results were more desirable than prior algorithms. Suggesting a policy for TOC, Badri and Aryanezhad (2011) offered a model based on it and introduced an exploratory algorithm for solving that. Badri et al. (2014) suggested an integrated model for the problem of production mix and sched-uling regarding operational overlap. The suggested model is based on the difference between process group and the size of transformation group which may have overlapping operations. In comparison, obtained results showed higher performance than traditional mix model. Golmo-hammadi and Mansouri (2015) suggested a new exploratory approach based on TOC by which they examined main effective factors on throughput. Hadidi and Moawad (2017) designed a model in a case study titled" The product-mix problem for multiple production lines in se-quenced stages" which maximized throughput by meeting production constraints.

METHODOLOGY

This study aimed to find optimum product mix in a tile-manufacturing firm. Since product manufacturing has constraints such as demand and manufacturing facilities, infinite goods pro-duction is not possible and a mix of products is required to yield maximum return. Such a mix is obtained regarding the studied firm and the constraints and conditions using the software of optimum production mix. This company has 29 wall tiles in various colors, patterns, and sizes each with a different price. Gathered data included sale price and directly consumed materials of each product. Production time per each squared meter of the products was calculated by tim-ing and market demand for each product.

The model is based on linear programming that takes into account the effect of the constraints of lines, sources, and demands for calculating throughput each product deducted direct material from sale price.

The model was also executed in Lingo software whose throughput is as follows:

$$\begin{aligned}
&\max Z \\
&\sum_{i=1}^{29} a\ x_i \leq b_1 \\
&. \\
&. \\
&\sum_{i=1}^{29} a\ x_i \leq b_6 \\
&x_1 \geq s_1 \\
&. \\
&. \\
&x_{29} \geq s_{29}
\end{aligned} \tag{1}$$

In the above model, a is parameter, x_i are products, b_i are capacities of production lines, and s_i are product demands. In the data file in appendix shows throughput 29 products, 6 lines that are producing products and demand of products.

RESULTS

This information shows the optimum value of the objective function and the value of the variable in the optimum answer. In the following, the effect of variation parameters of the model in the optimum answer is examined by doing sensitivity analysis.

A part of this examination is shadow prices which show the maximum value that should be paid for an extra unit of a resource. By investigating the throughput of the model, shadow price of the constraints of the resources except for the fifth resource, furnace (with the shadow price of 592844.5) was obtained to be 0. This shows that first the bottleneck of the company is its fur-nace and second, the shadow price reflects the growing effect of every unit of it in the through-put. Besides, in the surplus or shortage column, its value is 0, reflecting the consumption of all related resources in the production process. On the contrary, in other resources in which there is a surplus with the shadow price of 0, the lack of consumption of all resources is seen whose enhancement has no increasing effect on the throughput. Shadow price of the demand constraints except for the product 16 is negative, showing the decreasing effect of their increase on the throughput.

Table 1: Global optimal solution found$_a$

Objective value: 0.1659006E+11	Nonlinear variables: 0
Infeasibilities: 0.000000	Integer variables: 0
Total solver iterations: 5	Total constraints: 36
Elapsed runtime seconds: 1.84	Nonlinear constraints: 0
Model Class: LP	Total nonzeros: 232
Total variables: 29	Nonlinear nonzeros: 0

Table 2: Global optimal solution found$_b$

Variable	Value	Reduced Cost	Variable	Value	Reduced Cost
X1	5921.000	0.000000	X16	11134.06	0.000000
X2	1856.000	0.000000	X17	14786.00	0.000000
X3	5396.000	0.000000	X18	300.0000	0.000000
X4	8579.000	0.000000	X19	15782.00	0.000000
X5	13752.00	0.000000	X20	5760.000	0.000000
X6	23119.00	0.000000	X21	8212.000	0.000000
X7	2304.000	0.000000	X22	24915.00	0.000000
X8	2590.000	0.000000	X23	2216.000	0.000000
X9	7611.000	0.000000	X24	5702.000	0.000000
X10	13812.00	0.000000	X25	8616.000	0.000000
X11	2114.000	0.000000	X26	1622.000	0.000000
X12	4086.000	0.000000	X27	17773.00	0.000000
X13	10849.00	0.000000	X28	7738.000	0.000000
X14	24711.00	0.000000	X29	5280.000	0.000000
X15	11293.00	0.000000			

Table 3: Global optimal solution found$_c$

Row	Slack or Surplus	Dual Price	Row	Slack or Surplus	Dual Price
1	0.1659006E+11	1.000000	19	0.000000	-77303.67
2	1050.852	0.000000	20	0.000000	-33581.64
3	14481.83	0.000000	21	0.000000	-32925.64
4	13319.71	0.000000	22	0.000000	-9478.644
5	0.000000	592844.5	23	3038.056	0.000000
6	1405.302	0.000000	24	0.000000	-30762.64
7	0.000000	385.0336	25	0.000000	-7536.644
8	0.000000	-30034.64	26	0.000000	-30996.64
9	0.000000	-79208.67	27	0.000000	-80081.67
10	0.000000	-81462.67	28	0.000000	-74917.67
11	0.000000	-26903.64	29	0.000000	-80442.67
12	0.000000	-82582.67	30	0.000000	-52646.64
13	0.000000	-27803.64	31	0.000000	-34031.64
14	0.000000	-81429.67	32	0.000000	-32569.64
15	0.000000	-84863.67	33	0.000000	-29762.64
16	0.000000	-41330.64	34	0.000000	-37988.64
17	0.000000	-82721.67	35	0.000000	-31993.64
18	0.000000	-76396.67	36	0.000000	-29384.64

For the constraints with non-zero shortage or surplus, the value of shortage or surplus is related to AI and AD columns (for further explanation, a larger or equal constraint has a negative shadow price then every smaller or equal constraint will have a non-negative shadow price).

In the coefficients′ variation domain of the objective function, the increase or decrease in the coefficient of the objective function, which leads to the current base remaining optimal, can be shown. Part AI shows the increased value of an objective function coefficient while the current base remains optimal while in AD the value an objective function coefficient can be reduced and the current base remains the best is identified. Results showed that for all coefficients ex-cept for the product column 16, allowed increase is limited and in this case allowed decrease is 5017.964 units. In the variation domain on the right hand, variation domain on the right hand is reflected in a way that the current basis remains optimal. AI column shows the allowable increase and AD column indicates the allowable decrease. Allowable increase of the resources except for the resource number 5 which is furnace in the case study is unlimited and only this resource of allowable increase is limited to 318.1838.As seen in Fig.1, change in the capacity of furnace increases at the allowable increase level of throughput.

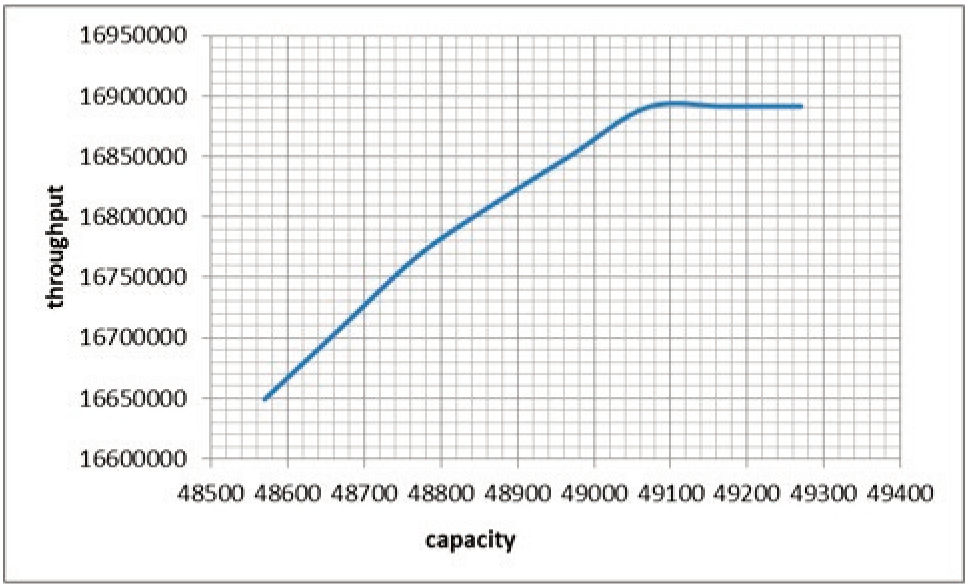

Fig. 1.allowable increase level of throughput

In case of demand constraints, only the product row 16 has unlimited allowable decrease and for other products allowable increase and decrease is constrained. Thus, if the changes on the domain are allowed, variations in that constraint cause change in the optimal value of the objective function regarding shadow prices. But if changes over the domain are allowed, optimal val-ue of the objective function can be estimated based on the related changes. Ranges in which the basis is unchanged.

In the variation domain on the right hand section, variation domain on the right hand is reflected in a way that the current basis remains optimal. AI column shows that the allowable increase and AD column indicates the allowable decrease. Allowable increase of the resources, except for the resource number 5 which is furnace in the case study, is unlimited and only this resource of allowable increase is limited to 318.1838. And allowable increase for all products are limited but allowable decrease expect product number 23 are limited.

Table4: Objective Coefficient Ranges

Variable Current	**Coefficient**	**Allowable Increase**	**INFINITY**
X1	63716.00	30034.64	INFINITY
X2	61417.00	79208.67	INFINITY
X3	59163.00	81462.67	INFINITY
X4	66847.00	26903.64	INFINITY
X5	58043.00	82582.67	INFINITY
X6	65947.00	27803.64	INFINITY
X7	59196.00	81429.67	INFINITY
X8	55762.00	84863.67	INFINITY
X9	52420.00	41330.64	INFINITY
X10	57904.00	82721.67	INFINITY
X11	64229.00	76396.67	INFINITY
X12	63322.00	77303.67	INFINITY
X13	60169.00	33581.64	INFINITY
X14	60825.00	32925.64	INFINITY
X15	84272.00	9478.644	INFINITY
X16	62420.00	INFINITY	5017.964
X17	62988.00	30762.64	INFINITY
X18	86214.00	7536.644	INFINITY
X19	62754.00	30996.64	INFINITY
X20	60544.00	80081.67	INFINITY
X21	65708.00	74917.67	INFINITY
X22	60183.00	80442.67	INFINITY
X23	41104.00	52646.64	INFINITY
X24	59719.00	34031.64	INFINITY
X25	61181.00	32569.64	INFINITY
X26	63988.00	29762.64	INFINITY
X27	55762.00	37988.64	INFINITY
X28	61757.00	31993.64	INFINITY
X29	64366.00	29384.64	INFINITY

Table5: Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
2	51423.00	INFINITY	1050.852
3	52044.00	INFINITY	14481.83
4	61314.00	INFINITY	13319.71
5	48470.00	318.1838	319.8738
6	47881.00	INFINITY	1405.302
7	48365.00	INFINITY	385.0336
8	5921.000	2022.764	5921.000
9	1856.000	1348.512	1856.000
10	5396.000	1348.512	4373.728
11	8579.000	2022.764	8579.000
12	13752.00	1348.512	4373.728
13	23119.00	2022.764	13602.52
14	2304.000	1348.512	2304.000
15	2590.000	1348.512	2590.000
16	7611.000	2022.764	7611.000
17	13812.00	1348.512	4373.728
18	2114.000	1348.512	2114.000
19	4086.000	1348.512	4086.000
20	10849.00	2022.764	10849.00
21	24711.00	2022.764	6539.598
22	11293.00	2022.764	6539.598
23	8096.000	3038.056	INFINITY
24	14786.00	2022.764	13412.16
25	300.0000	2022.764	300.0000
26	15782.00	2022.764	6539.598
27	5760.000	1348.512	4373.728
28	8212.000	1348.512	4373.728
29	24915.00	1348.512	4373.728
30	2216.000	2022.764	2216.000
31	5702.000	2022.764	5702.000
32	8616.000	2022.764	8616.000
33	1622.000	2022.764	1622.000
34	17773.00	2022.764	13412.16
35	7738.000	2022.764	7738.000
36	5280.000	2022.764	5280.000

CONCLUSION

In this research, the goal of production planning is due to resource constraints and the amount of demand in the company under studying. After collecting the necessary data, using linear pro-gramming and lingo software, the optimal combination has been achieved in this study, real data was used and besides showing the bottleneck, sensitivity analysis was conducted and the effect of variations in the variables and values on the right hand side of constraints on the optimum answer were examined. As stated, furnace, which is one of the sources of the company studied, is designated as a bottleneck, and is the only resource whose allowable increase is limited and the effect of its increase on the throughput is shown in the graph. Therefore, the company decides to increase the throughput considering its incremental effect and the funds needed to invest in this stage. In demand limits, the product of row 16 with a negative shadow price indi-cates a decreasing effect on sales of Trumpet, and, as shown in the calculations, its permissible limit to maintain the current base is limited. Applying the above model will increase throughput at 8/4 %. This study can be regarded as a basis for using TOC for production scheduling and management in indefinite conditions in which the coefficient of the variables and right-hand values of the numbers won't be definite, following fuzzy approach.

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APPENDIX

Data file

variable	Through-put	Production Time(1)	Production Time(2)	Production Time(3)	Production Time(4)	Production Time(5)	Production Time(6)	Demand
X1	63716	96	1094	1400	778	1854	678	5921
X2	61417	129	1048	1278	1167	1917	706	1854
X3	59163	129	1048	1278	1167	1917	706	5396
X4	66847	96	1096	1400	778	1854	678	8579
X5	58043	129	1048	1278	1167	1917	706	13752
X6	65947	96	1094	1400	778	1854	678	23119
X7	59196	129	1048	1278	1167	1917	706	2304
X8	55762	129	1048	1278	1167	1917	706	2590
X9	52420	96	1094	1400	778	1854	678	7611
X10	57904	129	1048	1278	1167	1917	706	13812
X11	64229	129	1048	1278	1167	1917	706	2114
X12	63322	129	1048	1278	1167	1917	706	4086
X13	60169	96	1094	1400	778	1854	678	10849
X14	60825	129	699	851	778	1278	470	24711
X15	84272	129	699	851	778	1278	470	11293
X16	62420	96	7029	933	518	1236	452	8096
X17	62988	96	1094	1400	778	1854	678	14786
X18	86214	96	1094	1400	778	1854	678	300
X19	62754	129	699	851	778	1278	470	15782
X20	60544	129	1048	1278	1167	1917	706	5760
X21	65708	129	1048	1278	1167	1917	706	8212
X22	60183	129	1048	1278	1167	1917	706	4915
X23	41104	129	699	851	778	1278	470	2216
X24	59719	96	1094	1400	778	1854	678	5702
X25	61181	96	1094	1400	778	1854	678	8616
X26	63988	96	1094	1400	778	1854	678	1622
X27	55762	96	1094	1400	778	1854	678	17773
X28	61757	96	1094	1400	778	1854	678	7738
X29	64366	96	1094	1400	778	1854	678	5280