# A FUZZY LOGIC APPROACH TO THE SETTLEMENT OF THE PROBLEMS ARISING IN THE JUST-IN-TIME PRODUCTION SYSTEM: A CASE STUDY OF TOYOTA

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**Abstract -** What is desired in the just-in-time production system is the availability of as many demands as needed in the right place when they will be used. In this system, one avoids the cost of inventory keeping by setting the lot size and the order quantity at the optimum level. The assembly and plastic plant of Toyota Motor Manufacturing Turkey uses the parts it procures from a large number of suppliers both in the country and abroad. These parts are taken into the plant and the short-term PC Inventory area and transported to the line side by the dolly operator at the time of their use. The flow of the line should be provided for 24 hours. This study aimed to carry on the flowing assembly line with complete parts and the plant logistics at the possible minimum abnormality level. In this line, it was aimed to keep the abnormalities occurring in supply and plant logistics at the minimum level and to reduce their effects. For this purpose, a fuzzy model was set up with the MATLAB program in order to detect the variables affecting the abnormalities in advance and to determine how the system will react in the possible situations of these variables.

**Key Words -** Supply Chain Management, Fuzzy Logic, MATLAB

## I. INTRODUCTION

Three different vehicles, namely Corolla, C-HR, and Verso, were being manufactured at Toyota Motor Manufacturing Turkey (TMMT) in the period when this study was prepared. Since it is a firm which carries out production upon orders, hundreds of different combinations of production sequences for these three different vehicles may occur. While the painted bodies are entering the assembly plant, the other necessary parts also reach the assembly stations in agreement with the principle of just-in-time production. In this system, the subparts meet the body just in time. This operation takes place neither early nor late. With perfect synchronization, the vehicles proceed on the line where the subparts are assembled. So,synchronous and harmonious work is achieved. At TMMT, Supply Chain Management is realized via the e-kanban system and parts are procured from a large number of domestic/foreign suppliers. These parts reach TMMT several hours or days before the time when they will be used in production according to the duration of supply.

An inventory monitoring system is available for inventory control. When the kanban number concerning this system is entered, one can see how many pieces of the relevant part are available on the line side, in the PC inventory area, on the opened container pallets, and in the container. This study will address the problem of an urgent part request from the line side, which does not comply with the standard job definition. It will be intended to find what the factors affecting this problem are.

## II. LITERATURE

A correlation analysis is a statistical method which is used to test the relationship of a variable with two or more variables and, if available,to quantify the degree of this relationship. The aim of a correlation analysis is to see in what direction the dependent variable (Y) will change when the independent variable (X) changes. Whether there is a linear relationship is found and, if available, the degree of this relationship is calculated as a result of a correlation analysis. The correlation coefficient is shown with “r” and takes values between -1 and 1. A positive correlation is the tendency of the values of variable Y to increase (decrease) when the value of variable X increases (decreases), whereas a negative correlation is the tendency of the values of variable Y to decrease (increase) when the value of variable X increases (decreases). We can see that the relationship between the variables increases as the correlation coefficient approaches 1, while the relationship decreases when it approaches 0. When the correlation is 1, it means that the relationship is very strong, but when it is 0, it means that there is no relationship (Marangoz, 2006).

Duan et al. (2017) build in their study the connection between correlation functions in correlation analysis and the modularity function in community detection, propose a framework that can utilize research progresses in correlation analysis to advance community detection, and identify better modified modularity functions to detect communities with different resolutions for better results through the proposed framework. While the modularity function in community detection guides the search for

partitions whose actual number of edges inside each community is greater than their expected number of edges inferred under the null hypothesis of random partition, correlation functions in correlation analysis guide the search for item sets whose actual occurrence is larger than their expected occurrence inferred under the null hypothesis of independence among items. Since both the modularity function and correlation functions are used to identify patterns whose actual occurrence is greater than their expected occurrence inferred under the null hypothesis of independence, the connection between them is built in the paper by Duan et al. In addition, there is much more existing research on improving correlation functions in correlation analysis (Zang et al., 2017; Saatçi, 2017; Gao et al., 2017) than on improving the modularity function in community detection.

**A Principal Component Analysis (PCA**)is a multivariate statistical method which is used in the areas of identification, classification, and image compressionand which provides dimensional reduction and interpretation by describing the variance-covariance structure of a set of variables by means of the linear combinations of these variables. In this method, (p) variables which display an interdependence structure and whose number of measures is (n) are converted into (k) new variables carrying the features of being linear, perpendicular(orthogonal), and independent of each other. PCA is a quite effective method ofrevealing the necessary information in the data. By finding the overall featuresin highly dimensional data, it allows reducing the number of dimensions and compressing the data. It is certain that some features will be lost through dimensional reduction; however, what is consideredis the fact that these lost featurescontain very little information about the dataset. The purpose of the PCA method is to find a new set of dimensions which will better catch the diversity of the data. The first dimension is selected to show as much diversity as possible, whereas the second dimension is selected to be perpendicular to the first dimension and again to show as much diversity as possible (Yıldız, 2010).

PCA is a widely used multivariate statistical method which can transform the original variables into a set of new orthogonal variables so that most information is contained in the first few components with the largest variance (Xiao et al., 2017). Ueki and Iwamori (2017) emphasized that PCA facilitated dimensional reduction and examination of the overall structure of the data by transforming the original set of variables into a new set of variables, called the principal components (The following sources may be examined for different examples about PCA: Han et al., 2017; Dai et al., 2017; Zeinalzadeh and Rezaei, 2017).

**Fuzzy systems are** useful in two general contexts: (1) in situations involving highly complex systems whose behaviours are not well understood and (2) in situations where an approximate, but fast, solution is warranted (Ross, 2016). One of the principal contributions of fuzzy logic is the providing of a basis for a progression from binarization to graduation, from binarism to pluralism, and from black and white to shades of gray. Graduation involves association of a class which has unsharp (fuzzy) boundaries with degrees/grades of membership. Classes with unsharp boundaries are pervasive in human cognition. Most words in natural language are labels of such classes (Zadeh, 2015).

Fuzzy logic is much more than a logical system. It has many facets. The principal facets are: logical, fuzzy-set-theoretic, epistemic, and relational. Most of the practical applications of fuzzy logic are associated with its relational facet (Zadeh, 2008). The principal distinguishing features of fuzzy logic are (a) graduation and (b) granulation. More specifically, in fuzzy logic everything is, or is allowed to be, graduated, that is, be a matter of degree or, more or less equivalently, fuzzy. Furthermore, in fuzzy logic all variables are allowed to be granulated, with a granule being a clump of values drawn together by indistinguishability, similarity, proximity or functionality. Graduation and granulation underline the concept of a linguistic variable (Zadeh, 2006). The Fuzzy System Theory can have utility in assessing some of our more conventional, less complex systems. For example, for some problems exact solutions are not always necessary. An approximate, but fast, solution can be useful in making preliminary design decisions, or as an initial estimate in a more accurate numerical technique to save computational costs; or in the myriad situations in which the inputs to a problem are vague, ambiguous, or not known at all (Ross, 2016).

**The MATLAB Fuzzy Logic System** is a fourth-generation programming language developed by the firm 'MATLAB MathWorks'. To perform fuzzy logic operations with MATLAB, the Fuzzy Logic Toolbox should be downloaded into MATLAB. Thanks to the Fuzzy Logic Toolbox,MATLAB functions, graphic tools and the Simulink blocks, which allow making analyses, designs, and simulations, for fuzzy logic-based systems are added to the MATLAB program. To obtain a result with fuzzy logic, it has applications which guide at every stage while designing. The MATLAB Fuzzy Logic Toolbox allows building a fuzzy inference system to model complicated system behaviors with simple logic rules and then to implement these rules (Taçyıldız, 2013).

## III. DEFINITION OF THE PROBLEM

The parts of the vehicles to be manufactured at TMMT are ordered according to the e-kanban system. When the parts procured to be used in production arrive at the plant, they are taken to the PC Inventory area for a short period of time. At the time of their use in production, they are carried to the production line side by means of a Dolly operator.

When the Assembly layout of TMMT is considered, it is seen that letters are assigned to the roads between the lines. Dolly Operators that provide the flow of parts are available for each road. A Dolly Operator is responsible for the flow of parts to the line side according to the list of orders (the order of parts for 40 vehicles to be included in production) he has received from hissuperior. This flow is repeated once in every 40 vehicles. The workflow of a Dolly Operator consists of five steps: (1) Leave the empty boxes on the Dolly to the empty box process; (2) Get the list of orders from your superior; (3) Collect the parts from the PC Inventory to the Dolly; (4) Carry the parts to the line side and feedthem into the line addresses; and (5) Leave the parts in full boxes to the addresses on the line side, collect the empty boxes on the line side, and place them onto the dolly. The operation proceeds in this cycle for all dolly operators inplant logistics.

Regarding the parts procured (which also constitute the subject of this study), the part abnormalities can be listed as follows:

- Making a “HOTCALL” when the operator working in the process on the line is unable to reach the necessary part.
- “WAITING” until the necessary part reaches the operator.
- “ROBBING” from the parts of the coming period in order to save the current productionif the necessary part is not at the plant but if it is available in the unopened containers containing the parts to be used in the coming production.
- Occurrence of “OVERFLOW” when this part is available at the plant and in a large quantity (if the PC Inventory shelf capacity is inadequate). These parts are placed in the Overflow area.

In addition, a dolly and its operator are in charge of carrying only the hotcalled parts in every shift. An operator who has received the hotcallsearches for the requested part at the PC Inventory address. If the part is available in the PC Inventory, the operatorgets the part and feeds it into the line side, but if the part is unavailable in the PC Inventory, the operator informs his superior and the inventory state of that part in the system and in which area the part is available are checked from the database system. The container containing the part is opened and the pallet containing the part is opened too. This operation has been defined as non-standard. It is seen that the most common part problem in the one-month analysis was the hotcall.

By definition, a hotcallmeans that when a part has beenhotcalled, the part is at the assembly plant of TMMT but has not reached the place where it is defined on the line, if no tapping from the container has been performed. In the event that some parts have not passed the quality approval, these quality-disapproved parts enter the process of return in order to be returned, while the parts pertaining to the following period are obtained from the Container Area of TMMT and used, which is called planned tapping. If an unreturned part has been set aside in quality or is unavailable in production for any reason, the part is procured by air. If the part to be brought by air is going to fail to reach the production manifest of the vehicle, that vehicle is taken out of the line and when its part arrives, it is again accepted to the line. The state of overflow is contrary to the principles of JIT production. It refers to the bringing of the parts to the plant before they are accepted for production. Since there is no area to keep long-terminventory at the plant, anextra part is left on the floor. If no intervention is made from the e-kanbansystem, that part will always overflow.

## IV. APPLICATION

In this study, the data about the part requests occurring on the assembly line of TMMT were collected; the features intended to be studied were gathered in a single document; first of all, the relationshipsof the parameters affecting the problem with the correlation coefficient were quantified; and it was intended to understand the most important parametersaffecting the part request problem as the input variable in the fuzzy logic model.

The one-month requested kanban information was extracted from the database by means of the Access program and the reasons for requesting 25,754 kanbans were investigated. The most important reason for the requesting of the part (which had a rate of 28% among all requests) is the overflowing of the part. To divide this problem into small parts and to find the basic reason for the problem of overflow, the data about the numbers of requests for 430 parts requested andfor 430 parts not requested within the same period, their lot sizes, from which dock they arrived (for the restriction of milkrun), their frequencies (how many times per day the part was fed into the line side), in how many models the part was

used in total, the daily average number of their uses, the piece weight of the part (g), and their types of packing were obtainedand the correlation coefficient was calculated.

In the correlation analysis, the dependent variable to be used against the independent variables is the number of requests.

| | NUMBER OF REQUESTS | LOT SIZE | DOCK | FREQUENCY | MODEL | AVERAGE USE | PART WEIGHT | TYPE OF PACKING |
|---|---|---|---|---|---|---|---|---|
| NUMBER OF REQUESTS | | 0.244928662 | -0.094373734 | 0.007903025 | 0.200950345 | 0.473963992 | -0.001039168 | -0.014799458 |
| LOT SIZE | 0.244928662 | | -0.091981155 | 0.070761795 | 0.378824246 | 0.510910141 | -0.254049977 | -0.128675351 |
| DOCK | -0.094373734 | -0.091981155 | | 0.046505 7 | -0.130169 | -0.104621 | 0.027477 4 | -0.01729 |
| FREQUENCY | 0.00790325 | 0.070761795 | 0.046505 7 | | 0.069146 62 | 0.048309 89 | 0.046560 73 | -0.040181 4 |
| MODEL | 0.200950345 | 0.378824246 | -0.130168 | 0.069146 62 | | 0.418854 7 | -0.128428 5 | -0.008568 9 |
| AVERAGE USE | 0.473963992 | 0.510910141 | -0.104621 | 0.048309 89 | 0.418854 7 | | -0.131152 3485 | -0.071168 912 |
| PART WEIGHT | -0.001039168 | -0.254049977 | 0.027477 4 | 0.046560 73 | -0.128428 5 | -0.131152 3485 | | 0.252186 |
| TYPE OF PACKING | -0.014799458 | -0.128675351 | -0.01729 | -0.040181 4 | -0.008568 9 | -0.071168 912 | 0.252186 | |

**Table 1. The correlation analysis**

According to the calculation of the correlation coefficient shown in Table 1, the three most important elements influencing the requesting of the part are: (1) the daily average number of uses of the part (USAGE) (r1=0.473963992), (2) in how many models the part is used in total (MODEL) (r2=0.300950345), and (3) the lot size of the part (LOT) (r3=0.284928662). As the correlation coefficients of the other components werevery low and their power of affecting the part request state was weak, there occurred a need for making another analysis with the principal component analysis.

Following the correlation study performed, a principal component analysis was made so as to quantify the interrelationship of all variables and to find a new set of dimensions to better catch the diversity of the data. The principal component analysis is demonstrated in Table 2.

Principal Components

Coefficients

| | Component 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| İSTEK SAYISI | -0,427 | 0,258 | -0,378 | 0,361 | -0,350 | 0,080 | 0,055 | -0,588 |
| LOT | -0,482 | -0,073 | 0,029 | -0,252 | 0,327 | -0,676 | -0,322 | -0,172 |
| DOCK | 0,217 | -0,029 | -0,618 | 0,261 | 0,695 | -0,001 | 0,137 | -0,014 |
| MODEL | -0,386 | 0,191 | 0,393 | -0,189 | 0,500 | 0,528 | 0,227 | -0,209 |
| Frekans | -0,035 | 0,126 | -0,525 | -0,804 | -0,157 | 0,178 | 0,048 | 0,047 |
| daily average usage | -0,573 | 0,114 | -0,171 | 0,226 | -0,045 | 0,076 | 0,033 | 0,755 |
| Part PCS Weight | 0,196 | 0,658 | 0,019 | 0,054 | 0,103 | 0,138 | -0,701 | 0,060 |
| pack type | 0,147 | 0,655 | 0,122 | -0,043 | -0,006 | -0,447 | 0,573 | 0,072 |

Quality of representation

| Component | İSTEK SAYISI | LOT | DOCK | MODEL | Frekans | daily average usage | Part PCS Weight | pack type |
|---|---|---|---|---|---|---|---|---|
| 1 | 0,358 | 0,458 | 0,092 | 0,293 | 0,002 | 0,646 | 0,076 | 0,042 |
| 2 | 0,098 | 0,008 | 0,001 | 0,054 | 0,023 | 0,019 | 0,637 | 0,630 |

**Table 2. The principal component analysis**

As seen in Table 2, all components either weakly or strongly interact with each other. The factors affecting the number of requests in the representation of highest quality are the factors of LOT with the coefficient of 0.458, MODEL with the coefficient of 0.295, and USAGE with the coefficient of 0.646. Then, the independent variables will be the factors of USAGE, MODEL, and LOT; consequently, the dependent variable to be used will be the number of requests. Then, the input variables for MATLAB will be "Lot", "Model", and "Usage". The input variables created are rated one by one. For instance, 5 degrees for variable 'Lot' [between 1 and 5,900]were created as in Table 3. By entering the lot variables into the membership function editor, the limits and intensity range of variable 'lot'have been entered. The representation of the membership function in MATLAB for variable 'lot' is provided in Figure 1.

| Lower Value | Upper Value | DEGREE | Abbreviation |
|---|---|---|---|
| 1 | 1180.8 | Very Little | VL |
| 1180.8 | 2360.6 | Little | L |
| 2360.6 | 3540.4 | Moderate | M |
| 3540.4 | 4720.2 | Very | V |
| 4720.2 | 5900 | Maximum | M |

Table 3. Ratingof variable 'lot'

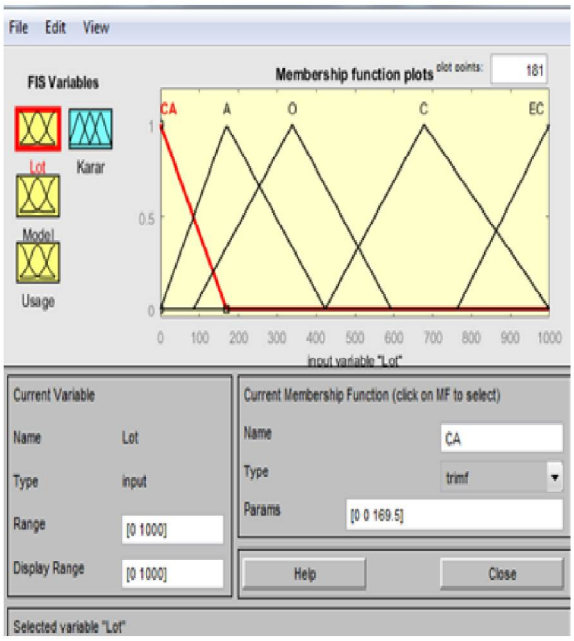



Figure 1. The membership function editor for variable 'lot'

Similar rating and membership function operations are also performed for variables 'MODEL' and 'USAGE'. The rules were drawn up on the window of MATLAB Fuzzy Logic rules. A total of 75 rules were written, with the first input variable having 5

degrees, the second input variable having 3 degrees, and the third input variable having 5 degrees. The rules drawn up are shown in Figure 2.

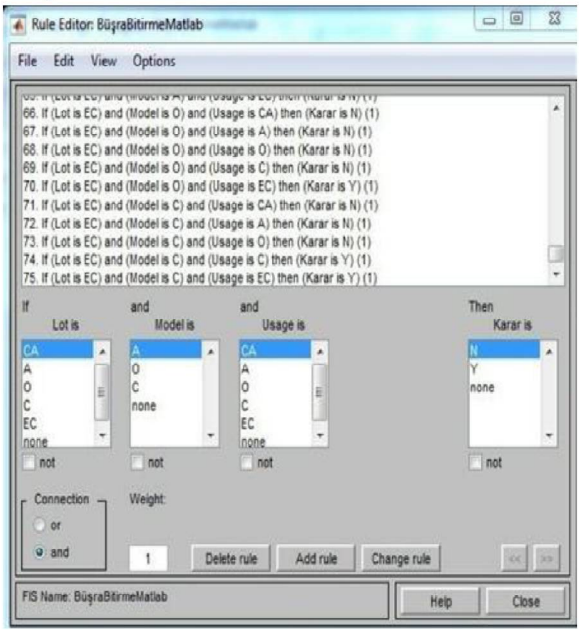



Figure 2. **MATLAB Rule Editor -the rules**

After the rules had been drawn up and saved, the program was run; values were assigned to the variables; and the program outputs were observed. The information on the never requested part with kanban no. 1729 was entered into the MATLAB program. The request situations likely to occur when the information on this part with kanban no. 1729is entered are shown in Figure 3. It is seen that the program provided the decision to request this part as0.369.

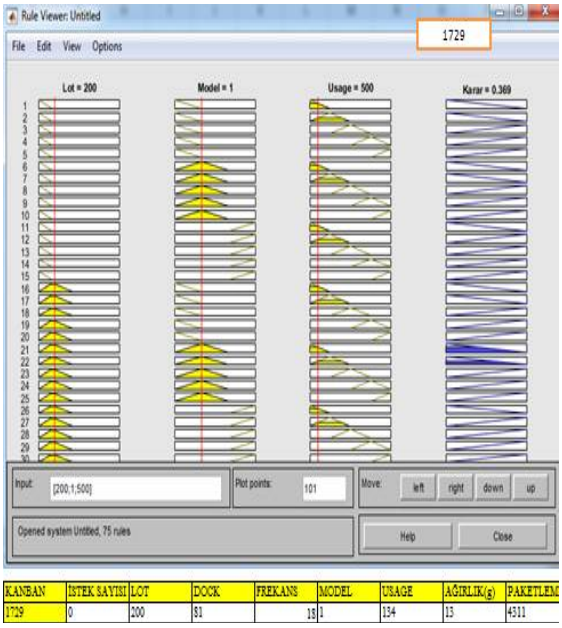



**Figure 3. The program output for the part with kanban no. 1729**

Figure 4 demonstrates the program output for the part with kanban no. 3391, which was requested for 26 times within the same period, was used in the three models to be produced, and had the same lot size as the part with kanban no. 1729.




Figure 4. **The program output for the part with kanban no. 3391**

In Figure 4, it is seen that when the information about the part with kanban no. 3391 was written in the input variables, the program provided the decision to request as 0.67.

## CONCLUSION AND RECOMMENDATIONS

The part abnormalities occurring at the plant of Toyota, performing production with the just-in-time production system, were described and "the Part Request" out of these abnormalities was addressed in this study. By calculating the correlation coefficients, it was investigated which features of the part affected the part request problem. In addition to the correlation analysisand also by making use of the result of the principal component analysis, three variables were considered. The output variable in the rule-based fuzzy logic model built in MATLAB was defined with two degrees (Y/N).

The lot sizes for the two parts described in the study are the same. What is particularly intended to be shown here is that the changes in the models and the number of uses in the parts with the same lot sizesdirectly increase the percentage of requesting the part. The fuzzy logic system built will help realize the part abnormality and then help with what kind of a decision will be taken. If a kanban request has been made and if it is at a critical level likely to halt the line, that part is urgently brought by air. If the decision occurring when the program is run after entering the previously and abundantly requested kanbans into MATLAB is greater than 0.8, a safety

stock may be kept for the part and the lot size of the part may be increased; however, if the part is at a critical level, it may be procured by air and if the decision ranges from0.6to0.8, a lower level of safety stock may be kept.

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