Forward chaining and fuzzy logic tsukamoto methods for decision

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Abstract. Sales recognition at PT. X is important. This will determine the monthly business growth rate. The main factor determining sales recognition is the delivery of goods on time in the current month. In this regard, a well process of allocating goods is needed. This study focuses on goods allocation recommendations to maximize sales recognition. The expert system was built using forward chaining and fuzzy logic Tsukamoto methods. The main principles of Supply Chain Management are also added to the algorithm in order to achieve maximum recommendation results. The end result is "High" and "Standard" recommendations for the allocation of goods based on available data. Recommendation "High" is worth ~ 3.9M or the equivalent of ~ 10.4% of the total potential available. However, the real actions taken are still based on decisions from related parties.

1. Introduction

PT. X measures the growth rate based on sales results at the end of the month. The deadline for the recognition of the sale then becomes the initial basis for calculating the time of delivery. The delivery time of the goods is called lead time. Precise lead time calculations will determine whether sales can be "recognized" this month or recognized as "shifted". So, in order to maximize sales, stock availability is required at each plant. Stock availability is indeed a major problem in Supply Chain Management [1]. The company only has 2 plants, namely Jakarta (JKT) and Surabaya (SBY). Each customer already has their own default plant so that the main lead time will be calculated based on the default plant.

One strategy to control uncertain demand and supply is to prepare a safety stock [2]. But in reality, safety stock cannot always accommodate this uncertain demand. Therefore, it is necessary to process the stock transfer appropriately and periodically so as not to hinder the process of allocating goods. Stock availability can be determined by calculating each related element. These elements are: 1) Stock: goods available in the warehouse, 2) Pipeline: goods that have been allocated but are still in the warehouse, 3) Order: goods ordered by consumers.

In order to utilize stock availability to maximize sales recognition, a special strategy is needed. The strategy will determine the action of allocating goods according to the plant where the stock is available. This action is considered as the best solution because it has considered lead time and has the potential to be recognized. Therefore, these solutions are compiled in an expert system. Expert systems are one of the most popular fields of science today, such as data mining [17] [18]. The method that will be used next is a combination of forward chaining and Tsukamoto's fuzzy logic.

The forward chaining method has 2 main components, namely knowledge-base and inference engine [3]. The forward chaining method will be applied to calculate stock availability precisely by comparing the lead time. This action will be implemented for each order line. Therefore, the determination of stock
availability for each iteration uses cumulative calculations. Actions resulting from the forward chaining method are not the final. However, action in this phase can be called a basic solution because it has gone through a fact-finding process and ends up in a solution [4]. At this stage, an expert can be said to have transferred his expertise to the computer [5].

Furthermore, to get the final recommendation for the allocation of goods, the Tsukamoto’s fuzzy logic method is used. The factors that influence the calculation in this method are the volume per area and the lead time gap. The author did not find similar research before, but found several studies that were close to it [6][7]. Both studies have the same variable, namely stock. Stock is used as one of the influencing factors and is then calculated in such a way as to find the final result. Fuzzy logic is used because it has a degree of membership in the range of 0 to 1, which means that it can be expressed in linguistic language [8]. Then to determine how to calculate the solution, the Tsukamoto’s inference engine was used. Generally, the Tsukamoto method has 3 lines, namely 1) fuzzification, 2) inference engine and 3) defuzzification [9].

2. Methodology
2.1 Data Collection
Collecting data in this study using a quantitative approach method. The data used comes from the company's ERP system, namely SAP R / 3 - PR4. The data will contain several important fields, namely material, description, plant and quantity. Meanwhile, other fields may vary according to related data. The data that will be used are: 1) Stock which can be downloaded through the transaction code MB52, 2) Pipeline which can be downloaded through the transaction code VL06F and 3) Order which can be downloaded through the ZORDERS transaction code. All of this data is real-time, so for proportional calculation, the author will take the mid-month data sample, that was October 15, 2020.

Apart from data from SAP, other data is also needed to support calculations. These data are 1) Lead Time Master data which contains data customer code, customer area, plant and lead time per plant. 2) Pick Pack Load (PPL), which is the time it takes for the warehouse to prepare goods for delivery. PPL is specifically defined as 1 day. 3) Material Master Data which contains material, description, volume in CBM and weight in KG.

2.2 Order Sorting
After the data is complete, order sorting is carried out. In general, order sorting is done by first-in first-out (FIFO) basis from the order date. However, this will not reflect the maximum results for sales recognition. So that FIFO is changed based on the last good issue (LGI) at the first level then after that the order date is at the second level. The LGI is the last date an item left the warehouse with high potential sales recognition in the current month. LGI can be calculated backwards with the following formula:

\[ \text{LGI}_{\text{PlantArea}} = \text{Last Recognition Date} - \text{Lead Time} - \text{PPL} \]

Last Recognition Date (LRD) was defined as 30-Oct-20. By using LGI, of course, there will be orders that are fulfilled first, even though the order date is longer. For example, the order date is on 3-Oct-20 but because the customer area is in the Jakarta area with a lead time of 1 day, the LGI will be 29-Oct-20. Meanwhile, there is another order with an order date of 7-Oct-20 in the Ambon area which has a lead time of 20 days, so LGI becomes 10-Oct-20. This is why orders for the Ambon area will be prioritized first.

2.3 Forward Chaining
After performing the order sorting appropriately, then do the calculations using the forward chaining method. This calculation requires stock availability data which can be obtained with the following formula:

\[ \text{Stock}_{\text{PlantMaterial}} = \text{Data Stock} - \text{Data Pipeline} \]
Furthermore, such as a research conducted by Khurot Ul Aeni [3] entitled "Application of Forward Chaining Methods to Expert Systems for Diagnosis of Pests and Rice Diseases", IF-THEN rules were made with the following details:

Table 1. Forward Chaining Rule

| Rule | IF-THEN Rule |
|------|--------------|
| R1   | IF D-Stock = 0 AND X-Stock = 0 THEN Result = "NoStock" |
| R2   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI < Today THEN Result = "ShiftedDef" |
| R3   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI >= Today AND D-Stock > Order Qty THEN Result = "FullDef" |
| R4   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI >= Today AND X-Stock > D-Stock AND X-LGI >= Today AND X-Stock >= Order Qty THEN Result = "FullAgains" |
| R5   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI >= Today AND D-Stock < Order Qty AND X-Stock > D-Stock AND X-LGI < Today THEN Result = "ShiftedAgains" |
| R6   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI >= Today AND D-Stock < Order Qty AND X-Stock <= D-Stock AND X-LGI < Today THEN Result = "PartialDef" |
| R7   | IF D-Stock > 0 OR X-Stock > 0 AND D-LGI >= Today AND D-Stock < Order Qty AND X-Stock <= D-Stock Result = "PartialAgains" |

The calculation reference uses several variables, namely 1) D-Stock: stock availability at the default plant, 2) X-Stock: stock availability at the against plant, 3) D-LGI: the last good issue date at the default plant, 4) X-LGI: date of last good issue at the against plant, 5) Order Qty: number of goods per order line and 6) Today: today’s date assuming 15-Oct-20. Whereas the results are 1) Result: recommendation according to available facts, 2) Confirm Qty: number of goods according to stock availability, 3) Latest Plant: plant according to stock availability and 4) GI Result: last good issue date according to recommendation. Each order line is calculated; with each iteration it will reduce the available stock.

2.4 Tsukamoto’s Fuzzy Logic

After implementing calculations using the forward chaining method, the next step is to apply the Tsukamoto’s fuzzy logic method to produce the final recommendation. Fuzzy logic is used because it is easier to understand and if there is an error the data can be tolerated to a certain degree [14]. In addition, fuzzy logic is also used in various topics in the scope of Supply Chain Management [15] [16].

Fuzzification is a process of defining the degree of truth in linguistic language. In this process, there are only 2 input variables, namely volume per area and lead time gap. While the output variable is only 1, namely potential.

Table 2. Tsukamoto’s Fuzzy Logic Variable

| Input                      | Few         | 0.0 – 3.0 |
|----------------------------|-------------|-----------|
| Volume Per Area (CBM)      | Lot         | 3.1 – 12.0|
| Lead Time Gap (DAY)        | Near        | 0.0 – 3.0 |
|                            | Far         | 4.0 – 30.0|
| Output                     | Standard    | 1.0 – 7.5 |
|                            | High        | 7.6 – 10.0|

The volume value per area based on car volume is 3 CBM for the Carry / L300 type and 12 CBM for the CDD type. Meanwhile, if it is found that the volume is more than 12 CBM, then the volume is considered to be 12 CBM. The value of the lead time gap (LTG) is based on the total difference in days between result_gi and today. The potential value is based on the assumed potential level to achieve sales recognition. In general, determining the value of each variable in the fuzzification process uses the following formula [12]:

\[
\mu_{\text{Variable}}(x) = \begin{cases} 
\frac{x_{\text{max}} - x}{x_{\text{max}} - x_{\text{min}}} & \text{if } x_{\text{min}} \leq x \leq x_{\text{max}} \\
0 & \text{if } x < x_{\text{min}} \\
1 & \text{if } x > x_{\text{max}} 
\end{cases} (3)
\]

and

\[
\mu_{\text{Variable}}(x) = \begin{cases} 
0 & \text{if } x_{\text{min}} \leq x \leq x_{\text{min}} \\
\frac{x - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}} & \text{if } x_{\text{min}} \leq x \leq x_{\text{max}} \\
1 & \text{if } x > x_{\text{max}} 
\end{cases} (4)
\]

The Tsukamoto’s method is used as the Fuzzy Inference System (FIS). This method uses the MIN function to obtain the \(\alpha\)-predicate value for each rule \((\alpha_1, \alpha_2, \ldots, \alpha_n)\). Then each \(\alpha\)-predicate value is used to calculate the inferential (crisp) result of each rule \((z_1, z_2, \ldots, z_n)\) [10]. The calculation reference is different from forward chaining, that is, this process is based on the customer area because the delivery of goods will be consolidated.
The final result is carried out in the defuzzification process. In the Tsukamoto method, the calculation uses the centered average method with the following formula [13]:

$$Z = \frac{\sum a \cdot z}{a}$$

(5)

After the calculation, then the results are converted back into linguistic language in the output variable, namely "High" or "Standard". These results will later be displayed so that users can see recommendations in order to prioritize allocations properly.

3. Result and Discussion

3.1 Research data

This study uses data samples per 15-Oct-20 with details: 1) Stock as much as 2,269 lines, 2) Pipeline as many as 948 lines and 3) Order as many as 7,020 lines. Given the large amount of data, this study will only present some data. Forward chaining calculations based on material will display the data "59466 MESON 150 17W xxx" (Meson). Meson has 32 order lines with various order quantity and 17 different customer areas. Meanwhile, Tsukamoto fuzzy logic calculation based on customer area orders will display data "Batam". Batam has a lead time of 9 days if shipped from Jakarta and 12 days if shipped from Surabaya. However, Batam orders should have been sent from Jakarta according to the default plant. There are 210 order lines with varying order quantities.

3.2 Forward Chaining

Each order line is calculated based on the rules that have been made using the forward chaining method. Each iteration will reduce stock availability. Meson has a stock of 2,991 PCEs in JKT and a pipeline of 1,463 PCEs in JKT. So that the actual stock is 1,528 PCEs by using formula (2). Apart from stock availability, LGI is also needed before calculating forward chaining. LGI is calculated for each order line based on its customer area. As a sample, calculations are made for the Batam area with the result 20-Oct-20 for JKT and 17-Oct-20 for SBY by using formula (1). The data below shows the results after the calculation according to the rules is executed. Lines 1-5 produce "Shifted Against" according to R6's rule of forward chaining. Line 6-18 is a confirmed order as there is a total available stock of 1,528 PCEs according to the R3, R4 and R7 rules. The rest of lines 19-32 could not be confirmed because the stock was out of stock.

| line | order_area | plant | result | confirm_qty | result_gi | confirm_qty | result_gi |
|------|------------|-------|--------|-------------|-----------|-------------|-----------|
| 1    | BERAU      | JKT   | ShiftedAgainst | 0           | 17        | TANJIMALAYA | JKT       |
| 2    | TARAKAN    | JKT   | ShiftedAgainst | 0           | 18        | BOGOR       | JKT       |
| 3    | TARAKAN    | JKT   | ShiftedAgainst | 0           | 19        | JAKARTA     | JKT NoStock |
| 4    | KENDARI    | JKT   | ShiftedAgainst | 0           | 20        | BANDUNG     | JKT NoStock |
| 5    | KENDARI    | JKT   | ShiftedAgainst | 0           | 21        | BOGOR       | JKT NoStock |
| 6    | BATAM      | JKT   | FullDef    | 240         | 22        | JAKARTA     | JKT NoStock |
| 7    | BATAM      | JKT   | FullDef    | 240         | 23        | JAKARTA     | JKT NoStock |
| 8    | BATAM      | JKT   | FullDef    | 240         | 24        | JAKARTA     | JKT NoStock |
| 9    | BANJARMASIN| JKT   | FullAgaints | 36          | 25        | JAKARTA     | JKT NoStock |
| 10   | BANJARACEH | JKT   | FullDef    | 24          | 26        | JAKARTA     | JKT NoStock |
| 11   | MEDAN      | JKT   | FullDef    | 24          | 27        | SURABAYA    | SBY NoStock |
| 12   | MEDAN      | JKT   | FullDef    | 38          | 28        | MALANG      | SBY NoStock |
| 13   | MEDAN      | JKT   | FullDef    | 8           | 29        | TANGERANG   | JKT NoStock |
| 14   | PEKANBARU  | JKT   | FullDef    | 240         | 30        | SIDOARJO    | SBY NoStock |
| 15   | DENPASAR   | JKT   | FullAgaints | 120         | 31        | JAKARTA     | JKT NoStock |
| 16   | DENPASAR   | JKT   | FullAgaints | 10          | 32        | JAKARTA     | JKT NoStock |

3.3 Tsukamoto’s Fuzzy Logic

The calculated data from forward chaining then becomes the basis for Tsukamoto's fuzzy logic calculations. But there needs to be a conversion first with the following details:

1. Volume Per Area; calculated by multiplying confirm_qty with material_volume, then adding it based on the customer area. Meson has a volume of 0.00154300 CBM, so for the order 240 PCEs
on line 6 in table 3 the result is 0.37031999 CBM. Furthermore, the sum of all orders in the Batam area is done with the result of 12.84550381 CBM. This result was then fulfilled to 12 according to the maximum volume rule in table 2.

2. Lead Time Gap (LTG); calculated from the difference between the \( result_{gi} \), namely 20-Oct-20 for Batam area and today, which is 15-Oct-20 so the result is 5 days.

Then to calculate the value of the set membership (fuzzification), then use the formula (3) and (4). The results are below:

| Table 4. Fuzzification Result |
|-----------------------------|
| **Input** | **Volume Per Area (CBM)** | **Few** | **Lot** | \(\mu_{_result}\) |
| Lead Time Gap (DAY) | Near | (4) | 12 | 0.00 |
| | Far | (3) | 5 | 0.83 |
| **Output** | **Potential** | | | |
| | Standard | (4) | \(Z\) | \((10-Z)/9\) |
| | High | (3) | \(Z\) | \((10-Z)/9\) |

Furthermore, the rules of the Fuzzy Inference System (FIS) are formed to obtain the \(\alpha\) and \(Z\) values of each rule with the following details:

| Table 5. Fuzzy Inference System Result |
|-----------------------------|
| **Formula** | \(\alpha\) | \(Z\) |
| **R1** IF vol_lot AND gap_near THEN pot_high | 0.00 | \((10-Z)/9 = \alpha\) | 0.00 |
| **R2** IF vol_lot AND gap_far THEN pot_standard | 0.00 | \((2-1)/9 = \alpha\) | 0.00 |
| **R3** IF vol_few AND gap_near THEN pot_high | 0.17 | \((10-Z)/9 = \alpha\) | 8.50 |
| **R4** IF vol_few AND gap_far THEN pot_standard | 0.83 | \((2-1)/9 = \alpha\) | 8.50 |

After the FIS calculation process is complete, then defuzzification to determine the crisp output, in this case, is potential. This method calculates the centered average using formula (5) with result 8.5. In accordance with the potential variable, 8.5 is vulnerable to "High" because it is between 7.6 - 10.0.

3.4 Final Recommendation

The final recommendations of this study are "High" and "Standard". Both can be used as a reference when allocating goods, but the main priority is those with a “High” recommendation. Even so, the actions taken can dynamically adjust to the latest situation and conditions considering that orders are real time and volatile. If converted into net value, the “High” recommendation is worth IDR ~ 3.9 billion from the total potential of IDR ~ 37.5M or ~ 10.4% of the total potential.

4. Conclusion

From this research it can be concluded that the results of the recommendation of the allocation of goods using the forward chaining method and Tsukamoto’s fuzzy logic can be a reference that is considered proportionally. The main priority is that the results are "High" and "Standard" is the second priority. However, from the business side, these two results still need to be served as well as possible so that the service level does not fall. The results of these recommendations are also not standardized, but dynamic so that business goals can be maximally achieved. And it starts with a good allocation process.

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