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**Research Article**

# Food Supply Chain Strategy in Beer Game with Perishability and Fulfilment Level

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**ABSTRACT**

Food waste is a global problem and has a significant impact on economic level. In food supply chain, certain strategy can be applied to tackle this problem. In order to formulate the strategy, we use variant of Beer Game, by adding perishability and fulfilment level. Perishability is implemented by adding product's shelf life and waste while fulfilment level describe how good does supply chain do in term of fulfilling consumer's need. In this research we use two rules for perishability namely normal rule and one-third rule. Result shows that the lowest total cost for the whole experiment is 889.26 with normal rule, T/O of 5/10, and fulfilment level of 48%. While the maximum fulfilment level recorded is 63% with normal rule applied.

**Keywords:** Food Supply Chain Strategy, Beer Game Simulation, Perishability and Fulfilment Level.

## INTRODUCTION

According to Food and Agriculture Organization (FAO), approximately 32 percent of global food production ended up as waste in 2009. Food waste has both environmental and economic impacts. From the viewpoint of economic, this situation leads to reduced income for farmers and increased expenses for consumers. On the environmental side, food waste can pollute the environment, drive greenhouse gas emissions, and contribute to environmental degradation (Lipinski et al., 2013).

Indonesia has become the third biggest food waste producer in the world with 121 kilograms of waste that consist of retail, out-of-home consumption and household waste (United Nations Environment Programme, 2024). In order to appropriately tackle this problem, we need to manage waste from the food supply chain through effective supply chain management. By managing waste at every stage of the food supply chain, businesses do not only reduce environmental impacts but also improve sustainability (Nikolicic et al., 2021). From the perspective of Sustainable Development Goals, minimizing food loss and waste is included in Goal 12 which is responsible production and consumption (The World Bank, 2017).

Supply chain management needs certain strategies such as: collaboration across the supply chain, regulation and policy setting, measurement and reporting feedback. Collaboration across the supply chain can be depicted as using strategic alignment in every unit under any circumstances (Duong & Chong, 2020). Regulation and policy alignment that we consider in this research consists of 2 main parts: the normal rule and the one-third rule. In normal rule, we consider that food will turn into waste only when the shelf life reaches the expiration date. While in one-third rule, the expiration date is one-third of the shelf life (Parry et al., 2015). One problem that arise in simulation is stated by Sato et al. (2020), the deadline-reset which occurs when stock goes to the next process. This research will try to tackle this deadline-reset problem with proper algorithm.

In the measurement and reporting feedback part, we propose an additional measure of performance in Beer Game. Initially we use total cost as the only measurement, but in this research, we add fulfilment level. Fulfilment level will show if certain strategy produces good result not only in total cost but also in fulfilling consumer's need.

The remaining sections of this article are organized as follows. Section 2 describes variant of Beer Game and some related research. This section also includes information about the research method. Section 3 presents main result and discussion, as well as conclusion of our work.

## METHOD

Beer Distribution Game or better known as Beer Game is a simulation of supply chain that originally developed by Jay Forrester to introduce two main concepts: system dynamics and computer simulation (Sterman, 2000). Historically, Beer Game has gone through developmental phase in 1956 up to wide-dissemination phase in 1992 that include computerized version (Martinez-Moyano, 2024).

Based on previous research, Beer Game is mainly used for three objectives: learning tool, introducing new concepts, testing strategies in supply chain management. Beer Game as a tool for learning systemic thinking is shown in Goodwin & Franklin (1994) and (Neuwirth, 2020). This learning objectives also shown in (Đula & Größler, 2020) and (Saqib et al., 2019), who state that in complex systems with limited information sharing, Beer Game can be used to study human behaviour in decision-making. Dizikes (2012) outlines several things that can be learned from Beer Game, such as: how system works, how actions by individual units affect the system, and tendency of managers and employees to overlook situations, which can lead to errors. Meanwhile, Beer Game as part of serious games, has been shown through evaluations by William et al. (2019) to increase motivation and provide positive experiences for learners in understanding supply chain concepts.

Reamer (2019) focuses more on Beer Game as a simulation that illustrates coordination problems in traditional supply chain systems. These coordination problems are evident in the lack of collaboration and information sharing, including the impact of supply chain structure, leading to the phenomenon known as the bullwhip effect (Roser et al., 2020). Turner et al. (2020) studied complex agricultural and natural resource management systems with the help of Beer Game. Factors such as biology, geology, socio-economics, and climate characteristics add complexity to this management system.

In other field, Beer Game has also been used to test strategies within systems. Research by Alfieri & Zotteri (2016) used an inventory strategy in Beer Game. Understanding inventory theory through the (Q, R) model helped participants place orders more effectively and reduce the gap between demand and supply. Additionally, example of applying the Economic Order Quantity strategy in Beer Game to minimize the bullwhip effect can be seen in (Alabdulkarim, 2020).

Application of new concepts in Beer Game is evident, such as analysing social factors of bullwhip effect, including psychological and behavioural factors (Yang et al., 2021; Perera et al., 2020). Variant of Beer Game was used to facilitate learning about bullwhip effect, information sharing, inventory control, forecasting, partnerships in the supply chain, and cross-docking. Research using Beer Game in the service sector in Pakistan measured the level of creative decision-making (CDM) in organizational leadership. This qualitative study showed that factors like human interaction, organizational processes, and technology play an important role in shaping creative decisions (Saqib et al., 2019). Beer Game has also been applied to new concepts and their influence on decision-making, such as Perceptual Control Theory (White et al., 2023). Other studies used game concepts, behavioural models, and agent-based simulations, known as Gamettes, alongside Beer Game to assess decision-making levels (Mohaddesi et al., 2020).

We use simulation which is the variant of Beer Game with certain strategy and conditions in supply chain (Roser et al., 2020). One important point which has not appeared in original version of Beer Game is the concept of perishability. Perishability concept with order dynamics and involving human player can be seen in (Rozhkov et al., 2022). Details of this variant with the research's parameter, according to comparison made by Rozhkov, is shown in Table 1.

Table 1. Research's parameter

| Parameter | This Research |
|---|---|
| Players | 4 |
| Initial Stock | 25 |
| Unit storage capacity | infinite |
| Lead time (order and inventory) | Minimum: ½ day<br>Maximum: 1 ½ day |

| | Mode: 1 day |
|---|---|
| Stock's shelf life | 15 days |
| Internet/LAN | Not needed |
| Batch inventory processing | no |
| Plant raw material | infinite |

This simulation applied most of methods and T/O notation which is used in (Gautama & Arifin, 2024). Steps in simulation development are as follows:

1. Creating four units which are the main player in Beer Game (Retailer, Wholesaler, Distributor and Factory) with Process Modelling Library in AnyLogic. Also, we create customer with *source* block, and using days as time model.
2. Every main player in Beer Game will have a stock variability, a fluctuating quantity in stock and different stock's age which in AnyLogic will be represented as an *ArrayList*.
3. Stock will be involved in two important methods every day:

a. Reducing Stock's Age and Age Verification: After the simulation runs, the stock's age is reduced by one. In both rule, after age verification, stock is automatically removed when its age falls below the shelf life.

b. Adding Stock Based on Orders: Stock is added according to the orders. The number of added stock depends on the stock's availability at the requested unit, and the added stock's age adjusts to its initial condition. This step is essential for providing solution to deadline-reset problem. Special case applies to Factory which essentially producing instead of getting stocks from elsewhere.

4. Strategy which we use in each unit can be written as T/O notation, T stands for Threshold and O stands for order. On certain level of stocks, that we called threshold, every unit make an order to the right with the same amount as defined by Order. By using the same T/O strategy instead of various one that usually used by human player, we can simplify the analysis process. These strategies are divided into four main parts according to threshold:

a. Ordering when stock reaches minimum level. Examples of T/O in this case are: 1/5, 1/10, 1/15, 1/20.
b. Ordering when stock approaches minimum level. T/O in this case are: 5/5, 5/10, 5/15, 5/20.
c. Ordering when stock reaches approximately half of level. T/O in this case are: 10/5, 10/10, 10/15, 10/20.
d. Ordering when there is a little depletion in stocks. T/O in this case are: 15/5, 15/10, 15/15 and 15/20.

All steps can be summarized as a flowchart and Figure 1 shows an example of Retailer's flowchart. The simulation scenario is set as follows:

a. Customer's orders follow random numbers ranging from 0 to 20, while the stock's age at the start of the simulation is set to 15 days.

b. In the normal rule the shelf life is set to one. Thus, when the stock's age reaches below one, which is zero, the stock is removed from the supply chain. In one-third rule, shelf life will be 5 days.

c. Customer's orders are scheduled based on the interarrival time value in AnyLogic, which is set to 1 day. The same interarrival time is also used to reduce the stock's age in each unit. This concept is implemented with the help of *Event* block in AnyLogic.

d. The fulfilment level is stated as percentage and calculated using the ratio of stock given by retailer to customer demand. This value is then accumulated and averaged into a variable called *PersenPesanan*. If customer's order is zero in certain point of time, we assume that fulfilment level at that time is 100%.

e. Inventory cost is set to 0.5 per stock, backlog cost is 1 per stock while waste cost is 0.7. Total cost will be the sum of all of these costs. Simulation will use the discrete-event method added by Monte-Carlo simulation with 5000 cycles (Fatimah, 2021). Based on Tajima et al. (2023), we are not applying information sharing concept within the simulation.

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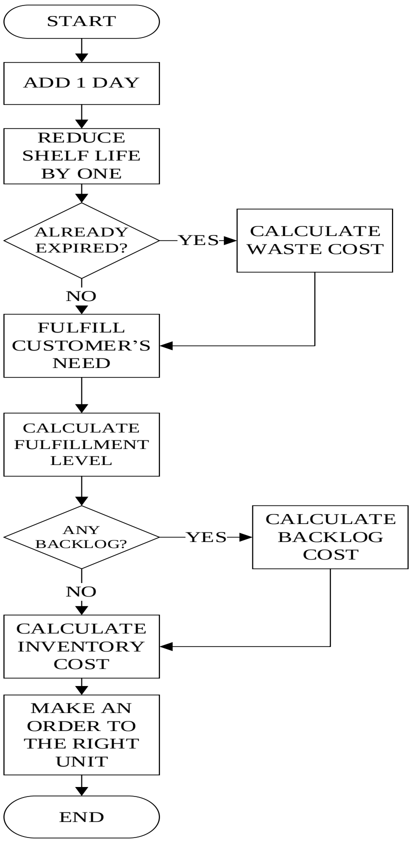


Figure 1. Retailer's Flowchart

After finishing the scenario setting, we implement it in AnyLogic as shown in Figure 2. This scenario would only be run for one cycle. To implement 5000 cycles as stated in Monte-Carlo method, we have to use other feature in Anylogic, namely Parameter Variation.

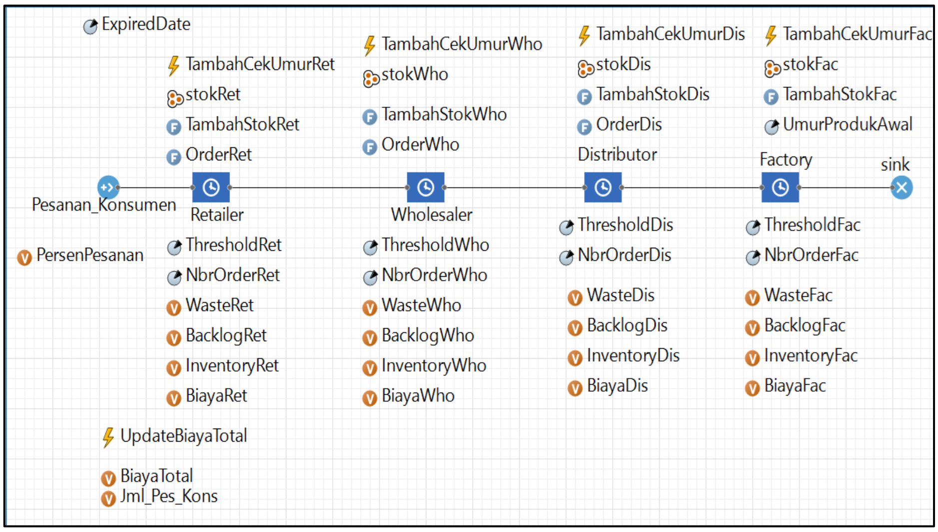


Figure 2. Scenario setting in AnyLogic

## RESULTS

By implementing Parameter Variation, we can use Anylogic's capability to do multiple iteration with the same value of T/O. Figure 3 shows screenshot of our experiment with T/O value of 15/15 on every unit.

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Figure 3. Experiment with T/O of 15/15

Table 2 and 3 show the experimental results when we apply one-third rule and normal rule respectively. The "Best" row shows the outcomes when the best T/O strategy in each unit is applied simultaneously. In the case of the one-third rule, Retailer unit applies 10/15, the Wholesaler unit uses 15/10, Distributor unit applies a T/O of 5/5, and Factory unit uses a T/O of 15/5. Despite being the best strategy for each unit, the total cost is 981.01, which is still bigger than the lowest total cost of 905.58. In normal rule, "Best" strategy gives total cost of 947, still higher than the lowest one which is 889.26.

Some key points that derived from this experiment:

1. High costs are dominantly borne by the Factory. This situation suggests that the bullwhip effect is happened, and its impact will be higher in Factory or upstream stages (Coppini et al., 2010).

2. By applying strategy that increase the number of orders, we have higher costs across all units, particularly in the Factory unit.

3. By using the combination of best strategy in each unit, we are not lowering the total cost.

To verify the first point, we repeat the experiment to analyse the fulfilment level which is represented by variable *Persen Pesanan*. The results are shown in Table 3.

## CONCLUSION

By increasing the order level we tend to have a rising in fulfilment level, but not always accompanied by rising in total cost. Maximum fulfilment level of 63% with normal rule shows that supply chain with normal rule can only satisfied 63% of consumer's need at maximum. Quite interesting to see what kind of impact that this level gives when simulation includes a competition between two or more supply chains.

The one-third rule causes stock in the supply chain to be disposed of more quickly, reducing the stock that reaches the Retailer unit. One-third rule has certain advantage in this situation over normal rule, because of less waste cost. After some periods of time, this situation can also leads to higher backlog cost. Understandably backlog cost is the biggest cost of all three, so normal rule will have its advantage over one-third rule. From this experiment we conclude that the lowest total cost of 889.26 in T/O strategy of 5/10 in normal rule, but this comes at the expense of the fulfilment level which is as low as 48%.

In the original version of the BDG, we are focusing on minimizing total costs. However, in this variant, it becomes evident that total cost can't be the sole consideration. When dealing with perishable goods, trade-off between total costs and fulfilment level must be taken into account.

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**Suggestions**

Future suggestions: we are not including revenue in this food supply chain simulation. Future research can calculate profit based on every stock that is being sold to the customer. Other development of BDG in the future could add the material capacity that can be used by Factory to produce stock. While using T/O strategy that run on intervals of 5, we missed some result from in between, for example in the T/O value of 2/6, 7/17, 1/13. It would be more precise if we get result from this range of T/O and be more comprehensive by adding profit calculation.

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Table 2. Result in one-third Rule

| T/O | Total Cost | | | Retailer's Cost | | | Wholesaler's Cost | | | Distributor's Cost | | | Factory's Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| 1/5 | 895.00 | 1120.76 | 1381.10 | 194.90 | 333.10 | 495.50 | 262.50 | 325.97 | 398.00 | 80.00 | 130.06 | 205.00 | 267.00 | 331.05 | 387.50 |
| 1/10 | 681.50 | 943.78 | 1278.10 | 185.50 | 280.76 | 403.70 | 102.50 | 207.24 | 283.00 | 52.50 | 145.63 | 255.50 | 197.50 | 310.15 | 427.50 |
| 1/15 | 763.00 | 1038.21 | 1454.10 | 150.50 | 244.28 | 393.30 | 147.50 | 212.05 | 304.00 | 72.50 | 182.66 | 317.00 | 262.50 | 399.22 | 567.50 |
| 1/20 | 963.90 | 1311.50 | 1680.10 | 156.00 | 249.61 | 374.00 | 155.00 | 223.12 | 337.00 | 132.50 | 234.52 | 364.00 | 416.00 | 604.24 | 792.50 |
| 5/5 | 686.50 | 919.27 | 1144.50 | 170.00 | 300.31 | 436.50 | 185.00 | 264.67 | 327.00 | 70.00 | 122.51 | 199.00 | 152.50 | 231.78 | 309.00 |
| 5/10 | 605.50 | 910.06 | 1277.00 | 160.20 | 277.87 | 391.80 | 107.50 | 201.58 | 305.50 | 52.50 | 145.24 | 252.50 | 160.00 | 285.38 | 418.00 |
| 5/15 | 736.00 | 1035.81 | 1464.00 | 145.40 | 243.71 | 359.40 | 147.50 | 212.11 | 310.00 | 70.00 | 181.26 | 329.50 | 272.50 | 398.74 | 567.50 |
| 5/20 | 949.00 | 1364.02 | 1692.60 | 152.30 | 249.63 | 380.40 | 150.00 | 223.13 | 342.00 | 127.50 | 275.72 | 420.00 | 430.00 | 615.53 | 780.00 |
| 10/5 | 703.50 | 915.32 | 1185.50 | 177.50 | 298.84 | 446.00 | 170.00 | 262.97 | 335.50 | 81.00 | 141.47 | 246.50 | 125.00 | 212.04 | 290.00 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/10 | 704.00 | 958.60 | 1377.70 | 171.10 | 269.81 | 434.20 | 102.50 | 184.77 | 293.00 | 70.00 | 191.96 | 335.50 | 180.00 | 312.06 | 460.50 |
| 10/15 | 740.50 | 1003.65 | 1459.60 | 146.50 | 240.64 | 360.80 | 150.00 | 209.52 | 293.00 | 83.50 | 194.10 | 362.50 | 230.00 | 359.39 | 549.50 |
| 10/20 | 1012.50 | 1391.87 | 1742.90 | 130.00 | 250.40 | 384.50 | 150.00 | 223.11 | 343.50 | 162.00 | 308.94 | 500.00 | 407.50 | 609.43 | 792.50 |
| 15/5 | 675.00 | 905.58 | 1224.60 | 172.20 | 298.21 | 446.00 | 172.50 | 261.35 | 353.00 | 102.00 | 154.64 | 331.50 | 100.00 | 191.38 | 288.00 |
| 15/10 | 725.50 | 951.52 | 1334.50 | 150.50 | 267.83 | 401.60 | 95.00 | 179.60 | 283.00 | 85.00 | 222.01 | 397.00 | 157.50 | 282.08 | 438.00 |
| 15/15 | 847.90 | 1191.83 | 1584.90 | 147.90 | 243.75 | 387.70 | 145.00 | 206.99 | 300.00 | 105.00 | 362.91 | 511.50 | 237.50 | 378.17 | 590.00 |
| 15/20 | 1002.50 | 1404.49 | 1917.10 | 149.50 | 252.58 | 413.50 | 145.00 | 221.67 | 331.00 | 136.00 | 322.38 | 609.50 | 405.00 | 607.87 | 795.00 |
| Best | 700 | 981.01 | 1290.9 | 160.5 | 298.26 | 432 | 180 | 256.50 | 345.5 | 105 | 223.07 | 325.5 | 97.5 | 203.17 | 295 |

Table 3. Result in Normal Rule

| T/O | Total Cost | | | Retailer's Cost | | | Wholesaler's Cost | | | Distributor's Cost | | | Factory's Cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| 1/5 | 890.00 | 1138.99 | 1462.80 | 175.50 | 328.55 | 476.50 | 255.00 | 323.30 | 382.00 | 70.00 | 128.59 | 224.00 | 255.00 | 358.56 | 457.50 |
| 1/10 | 638.00 | 938.34 | 1306.60 | 166.00 | 269.77 | 388.60 | 117.50 | 199.34 | 292.50 | 50.00 | 140.69 | 262.50 | 197.50 | 328.55 | 480.50 |
| 1/15 | 723.50 | 1005.58 | 1441.50 | 136.50 | 229.34 | 344.50 | 145.00 | 202.21 | 292.00 | 75.00 | 174.24 | 297.50 | 255.00 | 399.79 | 585.00 |
| 1/20 | 937.00 | 1327.40 | 1714.60 | 140.50 | 229.77 | 337.20 | 152.50 | 214.93 | 371.50 | 132.50 | 232.67 | 364.00 | 427.50 | 650.03 | 862.50 |
| 5/5 | 669.50 | 904.73 | 1315.40 | 172.70 | 292.62 | 474.00 | 182.50 | 254.79 | 343.00 | 70.00 | 115.59 | 232.50 | 155.00 | 241.73 | 372.50 |
| 5/10 | 644.00 | 889.26 | 1273.00 | 157.40 | 261.79 | 401.50 | 115.00 | 189.59 | 287.50 | 47.50 | 140.98 | 265.50 | 180.00 | 296.91 | 472.50 |
| 5/15 | 720.00 | 1007.60 | 1443.50 | 124.50 | 229.69 | 353.00 | 147.50 | 202.09 | 302.00 | 55.00 | 174.45 | 319.50 | 257.50 | 401.36 | 604.50 |
| 5/20 | 938.50 | 1394.85 | 1811.90 | 146.00 | 226.22 | 333.33 | 147.50 | 220.53 | 341.50 | 140.00 | 295.16 | 425.00 | 412.50 | 652.94 | 857.50 |
| 10/5 | 708.00 | 924.33 | 1222.00 | 164.50 | 289.44 | 422.00 | 175.00 | 249.92 | 328.50 | 87.50 | 169.43 | 248.00 | 127.50 | 215.55 | 356.50 |
| 10/10 | 661.00 | 930.53 | 1392.50 | 166.00 | 254.35 | 380.40 | 102.50 | 174.67 | 282.00 | 62.50 | 188.21 | 320.50 | 177.50 | 313.29 | 542.50 |
| 10/15 | 710.00 | 993.19 | 1371.10 | 131.50 | 226.72 | 339.80 | 152.50 | 201.29 | 319.50 | 87.50 | 202.36 | 382.50 | 237.50 | 362.82 | 515.00 |
| 10/20 | 1019.00 | 1439.84 | 1815.10 | 142.50 | 225.46 | 340.10 | 152.50 | 221.43 | 328.00 | 160.00 | 349.35 | 505.00 | 422.50 | 643.60 | 837.50 |
| 15/5 | 715.70 | 975.34 | 1330.00 | 164.00 | 286.87 | 451.00 | 165.00 | 247.98 | 329.50 | 110.00 | 247.75 | 348.50 | 97.50 | 192.75 | 350.00 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15/10 | 664.50 | 936.57 | 1352.50 | 166.00 | 254.59 | 384.50 | 90.00 | 168.69 | 270.00 | 97.50 | 230.38 | 385.00 | 165.00 | 282.91 | 457.50 |
| 15/15 | 769.50 | 1155.62 | 1560.00 | 143.00 | 225.33 | 341.20 | 142.50 | 199.49 | 295.50 | 122.50 | 352.93 | 524.50 | 237.50 | 377.87 | 550.00 |
| 15/20 | 1042.00 | 1445.60 | 1888.80 | 141.00 | 226.68 | 335.10 | 145.00 | 221.83 | 332.50 | 170.00 | 350.43 | 599.50 | 435.00 | 646.65 | 837.50 |
| Best | 701 | 947 | 1321 | 168 | 285.52 | 428 | 137.5 | 243.87 | 329.5 | 110 | 211.4 | 324.5 | 100 | 206.2 | 370 |

Table 4. Comparison of Fulfilment Level (average value)

| T/O | Fulfilment Level (avg) | |
|---|---|---|
| | One-third Rule (%) | Normal Rule (%) |
| 1/5 | 27.00 | 26.00 |
| 1/10 | 48.00 | 49.00 |
| 1/15 | 62.00 | 61.00 |
| 1/20 | 61.00 | 62.00 |
| 5/5 | 38.00 | 38.00 |
| 5/10 | 49.00 | 48.00 |
| 5/15 | 60.00 | 61.00 |
| 5/20 | 62.00 | 62.00 |
| 10/5 | 39.00 | 39.00 |
| 10/10 | 51.00 | 52.00 |
| 10/15 | 60.00 | 61.00 |
| 10/20 | 60.00 | 62.00 |
| 15/5 | 39.00 | 39.00 |
| 15/10 | 53.00 | 52.00 |
| 15/15 | 60.00 | 63.00 |
| 15/20 | 59.00 | 63.00 |
| Best | 40.00 | 40.00 |