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Weighted Round Robin (WRR) Based Replenishment Model in Vendor Managed Inventory (VMI) System

Purba Daru Kusuma[1*]

[1]Computer Engineering, Faculty of Electrical Engineering,
Telkom University Jl Telekomunikasi, Bandung, 40258, INDONESIA

*Corresponding Author

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Abstract: Vendor managed inventory (VMI) is a popular supply chain system where vendor or supplier take responsibility and decision in managing its customers' inventory. Two important goals of the VMI are improving service level and maintaining inventory still low and available. Many studies in VMI compare their performance with the traditional system. Unfortunately, studies in improving VMI performance are rare. This work aims to improve VMI by implementing Weighted Round Robin (WRR), a popular scheduling model in computer system, in the replenishment model in VMI. WRR is popular because of its load balancing nature. Environment in this work is two-echelon supply chain. The vendor is a multi-product manufacturer. The customers are retailers. This WRR based replenishment model is then compared with two common replenishment models: (s, S) model and (r, Q) model. In this work, we observe two performance parameters: sales and inventory condition. Based on the simulation result, it is shown that the WRR model performs better than the existing (s, S) model and (r, Q) model and it occurs in most of the observed variables. In the certain condition, performance of the WRR model compared with the (s, S) model and the (r, Q) model is as follows. The WRR model performs 31 percent better than the (s, S) model and 12 percent better than the (r, Q) model in success ratio. Manufacturer's stock in the WRR model is only 36 percent than in the (s, S) model and 40 percent than in the (r, Q) model. Total stock in the supply chain in the WRR model is only 63 percent than in the (s, S) model and 89 percent than in the (r, Q) model.

Keywords: Supply chain management, weighted round robin, vendor managed inventory, replenishment, make-to-stock, multi product

1. Introduction

Today, supply chain management (SCM) plays very important role in business competition [1]. A sophisticated SCM collaboration strategy can provide new opportunities, efficiency, and customer loyalty [2]. In general, SCM aims two strategic goals. The first one is improving service level or product availability [1]. The second one is minimizing cost [3].

One popular SCM system is vendor managed inventory (VMI) system. It is different from the traditional one. In the traditional system, suppliers and customers manage their own inventory system and decision so that it implements local optimization [4,5]. In the other hand, in the VMI system, vendor takes over customers' responsibility in managing their inventory control [6,7]. It means that vendor decides when and how many products will be delivered into customers' warehouse. This system is proven in improving the service level and in the other side, maintaining the quality of the inventory [8]. This quality means the inventory cost is low and potential in shortage and or overstock is avoided [9].

Because of its popularity, there are many studies about VMI. These studies use various case studies, such as wood factory [10], instant noodle factory [3], chemical factory where the products are easy to evaporate [11], electronic industry [12], and sawmill industry [13]. Several studies in VMI implement two-echelon scenario where the upper entity is a manufacturer or distributor while the lower entities are retailers [14,15]. Many studies in VMI focus on how VMI can

*Corresponding author: purbodaru@gmail.com

minimize cost, for example in the inventory cost [1] or transportation cost [3]. Other study in VMI also relates this system with carbon emission reduction [16].

One important aspect in VMI system is the replenishment model [11]. Replenishment is very important aspect in make-to-stock (MTS) production system [17] and since VMI is an MTS system, it is important in VMI too. In the replenishment model, time and quantity of the products that will be delivered into the inventory are determined [18].

Although there are many studies in VMI, there are several aspects that are rare to explore. Many studies compare the VMI system with the traditional one. Several studies proved that the VMI system performs better than the traditional one [19,20]. Meanwhile, studies about improving the VMI system itself are rare [15,21]. Several studies in VMI use single product scenario [16,22] while several studies do not declare whether they use single product or multi products in their work explicitly [6,14]. Several studies also assume that product supply and or inventory capacity are unlimited [14,21], which is this condition is not realistic in the real world.

Based on these conditions, this work aims to develop replenishment model that can improve performance of the VMI system. This model is developed based on two-echelon, multi-product environment, limited production capacity, and limited inventory capacity scenarios. The upper entity is a manufacturer while the lower entities are retailers.

In this work, the proposed replenishment model is developed based on Weighted Round Robin (WRR) model. WRR or Round Robin (RR) is very popular scheduling model in computer system, for example in web server cluster [23] and cloud system [24,25]. It is also popular in data transmission or telecommunication system, for example in WiMAX [26], ATM [27], and 5G [28] networks. It is popular because of its simplicity and its basic advantage in load balancing among entities that use resource. Meanwhile, this model is not popular in production or manufacturing system, especially in the VMI system.

Based on it, there are several novelties in this work. The primary novelty is implementing WRR model to develop replenishment model in the VMI system. The secondary novelty is improving performance of the VMI system by comparing the proposed replenishment model with the common replenishment models, such as the (s, S) model and the (r, Q) model.

The organization of this paper is as follows. In the first section, we describe the background, research purpose, methodology, and paper structure. In the second section, we review literatures related to this work and they are grouped into three areas: VMI, replenishment policy, and WRR. In the third section, we describe our proposed replenishment model that is developed based on WRR. In the fourth section, we explain the simulation result and discuss the findings. In the fifth section, we conclude our work and propose future research potentials.

2. Related Works

2.1 Vendor Managed Inventory (VMI)

VMI system is a popular system in supply chain management. It is different from the traditional way in the supply chain management in how supplier interacts with its customers. In the traditional way, supplier receives purchase order from their customers, prepares the ordered products, and then delivers the ordered products whenever they are ready [6]. In the other hand, in the VMI system, supplier can access its customers' inventory and then delivers products to them without receiving explicit purchase order [4]. It means that VMI system deploys pre-emptive strategy in managing customers' inventory [8]. Illustration about information flow and product flow in the traditional way and in the VMI system is shown in Fig. 1 where Fig. 1 illustrates the traditional product and information flows and Fig. 1b represents the VMI system. In Fig. 1, the dashed line arrows represent the information flow while the solid line arrows represent the physical flow.

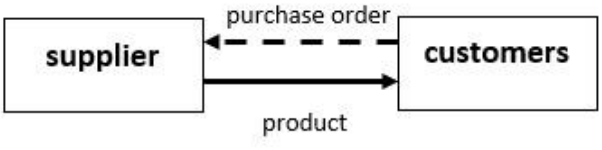

Fig. 1a – Traditional supply chain management model

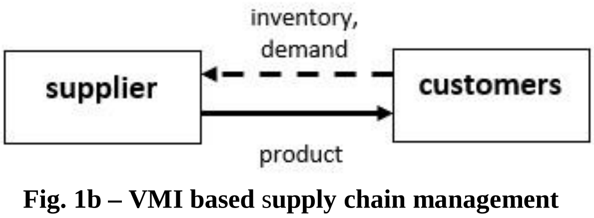

Fig. 1b – VMI based supply chain management model

Based on this illustration, it is shown that in the VMI system, supplier has right to access customers' inventory condition [8] and sometimes demand information [6]. It means that in case the customers are retailers, several studies state that supplier can access retailers point of sales (POS) data [16]. Based on this condition, strong information system plays important role in building an effective VMI system [1]. Besides, trust between supplier and customers must be secured [8].

Real time information access about customers' inventory in the VMI system gives important advantage in boosting performance of SC members that implement VMI rather than others that still use the traditional way [6]. In the traditional way, because supplier receives information only from customers' purchase order [8], information about the real condition (inventory and market) can be bias. By accessing directly to and managing the customers' inventory, supplier can get clear view about the real condition so that can make better decision, especially in the replenishment strategy and managing its own resource to fulfil its responsibility. Two main focuses in the studies in VMI are improving service level [15] and maintaining healthy inventory condition [21].

Information sharing from customers to supplier in VMI may improve global optimization [5]. Global optimization means optimization occurs in the entire supply chain members [5]. It is different from the traditional way that every member in the SC system is responsible only to their condition (sales and inventory) so that every member will decide its own strategy to optimize its own condition [29]. This situation is known as local optimization [29]. If in the VMI system, benefit is only received by one member, which is usually the supplier, then the customers may retract their membership from the VMI system. That is why in the several models in the VMI system, supplier gives more benefits for its customers. Supplier can give discount or extra commission when it fails in managing its customers' inventory, such as in shortage or overstock condition [22].

Based on the number of participants in the VMI system, studies in VMI can be divided into two groups. In the first group, which is more popular, VMI implements two-echelon supply chain. The upper entity is supplier which is distributor or manufacturer. The lower entities are retailers. In the second group, VMI implements three-echelon supply chain [20]. In this scenario, the members are raw material supplier, manufacturer, and retailer. Based on the number of participants in each level, many studies in VMI can be divided into three groups. The first group contains single supplier and multiple customers. We can name it as one-to-many relationship. The second group contains single supplier and single customer [4]. We can also name it as one-to-one relationship. The third group contains multiple suppliers and multiple customers. It is named as many-to-many relationship. In the real world, one-to-many relationship is more realistic.

Based on the warehouse or inventory location, there are three types of inventory model [1]. In the first model, inventory is distributed into customers' warehouse [1]. In the second model, both supplier and customers hold inventory although the inventory management is centralized in suppliers' authority [1]. In the third model, there is a central warehouse outside the supplier and customer which its location is the most efficient [1].

Although information system is important in VMI, studies about the usage of the information technology implemented in the VMI system are few. Genetic algorithm (GA) was used as the part of decision support system in determining when and how many products should be delivered to customers in the VMI system [19]. GA was also used to determine best solution in allocating truck in instant noodle industry so that transportation cost can be reduced [3]. Blockchain technology has been used in the information transmission between customers and vendor in VMI so that secure information link can be built to improve trust among VMI members [8].

Based on this review, there is huge opportunity in implementing or adopting information and computation technology into VMI. The role of this technology is not just assuring the real time and accurate information flow but more than this is improving mutual performance among VMI members and entire VMI system.

2.2 Replenishment Model

Replenishment is an important part in the supply chain (SC) system that adopts MTS model. In it, production is not determined by the incoming order but based on the inventory level [17]. Incoming orders are fulfilled from the inventory so that one important parameter in the MTS system is the inventory level [30]. Both shortage and overstock should be avoided [18]. Shortage makes longer lead time for the incoming orders and it can decrease customer satisfaction [17]. Meanwhile, overstock may increase inventory cost and reduce liquidity because too much cash that is transformed into products [17]. Related to this, replenishment is a policy or strategy to determine time and quantity of products should be produced or purchased to restore the inventory level [31]. Because VMI system is an MTS system, replenishment model is also important for this system.

In this paper, we will review two common replenishment models. The first model is (s, S) model and the second one is (r, Q) model. In the mathematical model below, we assume that the entity is a manufacturer. In the (s, S) model, *s* represents the minimum stock while S represents the maximum stock [32]. If q is the current stock level, q_{prod} is quantity of product that should be produced, and A is the action that should be taken, then the mathematical model of the (s, S) model is formalized by using Eq. (1) and Eq. (2) [33].

$$A = \begin{cases} produce, q < s \\ do\ nothing, q \geq s \end{cases} \tag{1}$$

$$q_{prod} = S - q \tag{2}$$

(r, Q) model is also known as reorder point-lot size model [34]. In the (r, Q) model, *r* represents the inventory point while *Q* represents the quantity of the production or lot size [35]. Similar from the (s, S) model, the mathematical model of the (r, Q) model is formalized by using Eq. (3) and Eq. (4).

$$A = \begin{cases} produce, q < r \\ do\ nothing, else \end{cases} \quad (3)$$

$$q_{prod} = Q \quad (4)$$

2.3 Weighted Round Robin (WRR)

Scheduling and or jobs distribution does not occur in manufacture only but also occurs in computer system. Similar from manufacture process, computer system also faces jobs scheduling. There are several jobs that should be executed by using limited resource so that these jobs must be scheduled. The difference is that in the computer system, a single job can be split into several chunks or smaller packets so that single resource is not dedicated to single job. The goal is to reduce waiting time.

One popular scheduling model in computer system is Round Robin (RR) model. RR model is popular because of its simplicity and load balancing concept, especially in timesharing system [36]. It is widely implemented in the cloud system [25], client-server system [23], and data transmission [36].

The concept of RR model is based on the job rotation [26]. The explanation is as follows. Suppose that we have n_p packets that must be transmitted through a single transmission channel. Then, every packet will be split into several same size chunks. A token k is used to determine which packet has turn to send its chunk at timeslot t. In a timeslot, each packet may send same number of chunks, for example, only one chunk permitted to be sent in one timeslot. After a packet sends its chunk then the next packet gets turn to send chunk or hold resource in the next timeslot. RR model is formalized by using Eq. (5). The illustration of RR model is shown in Fig. 2.

$$k_{t+1} = \begin{cases} p_t + 1, p_t < n_p \\ 1, p_t = n_p \end{cases} \quad (5)$$

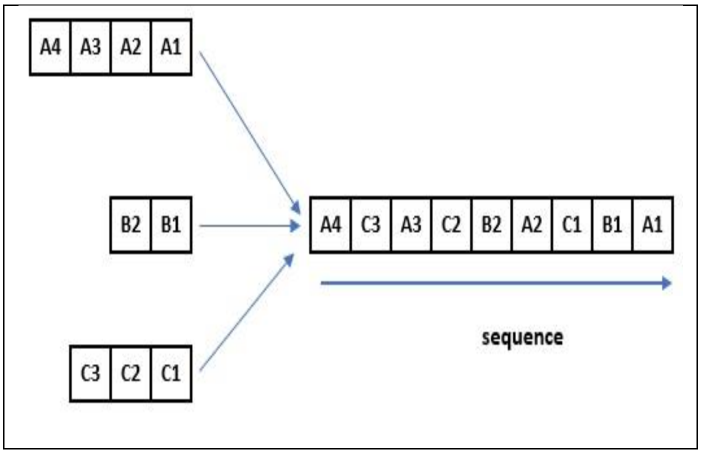

Fig. 2 - Round Robin sequence illustration

The explanation of Fig. 2 is as follows. There are three packets {A, B, C} that must be transmitted through single channel. These packets have different size so that when each packet is split into chunks, the number of chunks in the packets set is {4, 2, 3}. It is time to send these packets. In every turn, each packet may send a chunk only. In the first and second rounds, all packets have their turn to occupy the channel. In the end of the second round, the second packet has finished to send all its chunks. So, in the third round, when the first packet has sent its third chunk, token will be passed to the third packet.

In general, this model is fair. Meanwhile, in some cases, there is condition that some packets are more important than the other packets. In other case, the size gap among packets is wide. In this condition, prioritization can be given. The solution is Weighted Round Robin (WRR) model. WRR model is a derivative of RR model. In general, the rotation concept and the usage of the token are same. Packets are also split into chunks and process in Eq. (5) is also used. The difference is that more prioritized packets may send more chunks in the single round than the less prioritized packets [27]. In the other word, WRR model is the extension of RR model with static weighting [36]. The illustration is shown in Fig. 3. Meanwhile, the WRR model also has derivatives. One of these derivatives is Dynamic Weighted Round Robin (DWRR) model [27]. In this model, the weight of every packet is not static but dynamic due to its load compared to other packets' load.

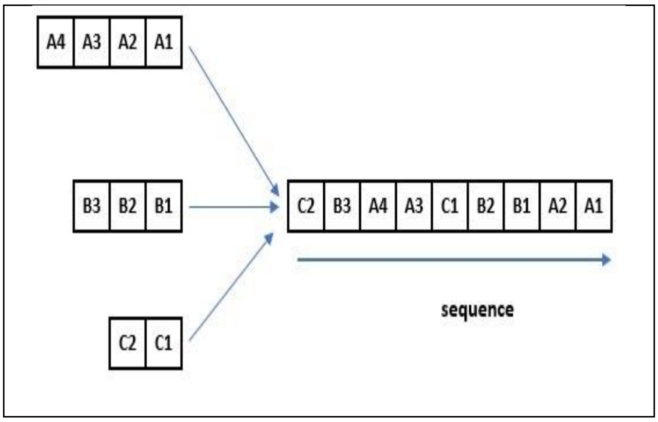

Fig. 3 - Weighted Round Robin sequence illustration

The explanation of Fig. 3 is as follows. There are three packets {A, B, C} with different size that will be transmitted through single channel. The set of number of chunks is {4, 3, 2}. Packet A and packet B are more prioritized so that they can send two chunks in every turn. Meanwhile, because packet C is less prioritized, it can send only one chunk in every turn. Based on this scenario, the transmission sequence is also shown in Fig. 3.

We can see that WRR model can also be implemented as replenishment model in VMI system. Vendor has similar function as transmission channel, server, or any other processing unit. In the other side, customer has similar function as packet or job. Based on this explanation, in this work, we develop replenishment model based on the WRR model to improve service level and maintain inventory.

3. Materials and Method

3.1 System Overview

In this work, we develop replenishment model in the VMI system based on several scenarios. The system consists of two echelons. The upper entity is a manufacturer. The lower entities are retailers. It implements one-to-many relationship. Both entities have inventory or storage with the manufacturer's inventory capacity is larger than retailer's inventory capacity. The architecture of the VMI system is shown in Fig. 4.

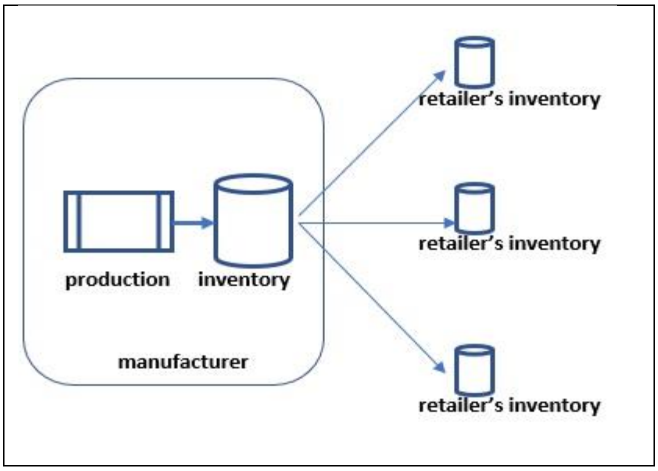

Fig. 4 - Two-echelon VMI architecture

Manufacturer produces multiple products. Manufacturer also has several machines. In this work, we assume that every product can be produced by any machines in the factory in equal production rate. Besides, every machine has same production capacity. Based on this assumption, there are not any machines in the factory dedicated to certain products. It means that relationship between machines and products is many-to-many relationship. This relationship is illustrated in Fig. 5.

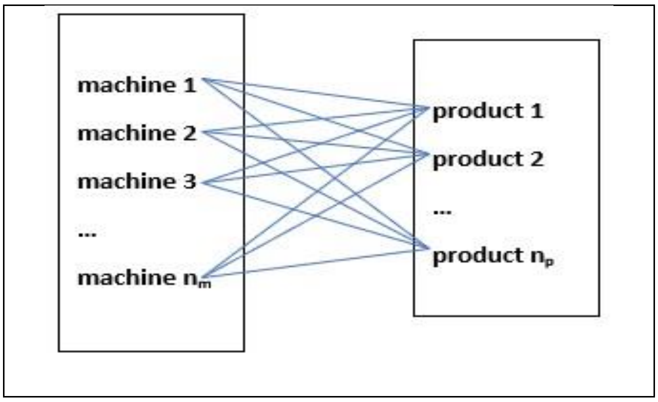

Fig. 5 - Machine-to-product relationship

The assumptions in transportation aspect are as follows. Manufacturer and retailers are in the same city. It means that the manufacturer can monitor and replenish retailers' inventory daily. Manufacturer has unlimited number of trucks so that the manufacturer can deliver products to the customers immediately.

3.2 Mathematical Model

Before we explain the mathematical model, first we will describe variables that are used in this modelling.

i retailer index
j product index
k machine index
l slot index
d day index
n_r number of retailers
n_p number of products
n_m number of machines
n_d number of operational days
n_{avbpd} average number of buyers that visits a retailer in one day
n_{avppb} average number of products bought by a buyer
q_{avpp} average quantity bought by a buyer in every product
$n_{buyer,i,d}$ number of buyers that visit retailer i in day d
$n_{prod,b,i,d}$ number of products requested by buyer b that visits retailer i in day d
c machine production capacity
r_{sel} selected retailer
p_{sel} selected product
$w_{r,i,j}$ retailer's weight
$w_{m,j}$ weight of product j in manufacturer
$g_{r,i}$ retailer i's product j gap
$g_{m,j}$ product j gap in the manufacturer
$g_{rmin,j}$ retailers minimum gap of product j
$g_{rmax,j}$ retailers maximum gap of product j
g_{mmin} manufacturer minimum gap
$s_{i,j}$ stock of product j in retailer i
$s_{min,i,j}$ minimum stock of product j in retailer i
$s_{max,i,j}$ maximum stock of product j in retailer i
$s_{m,j}$ stock of product j in the manufacturer
$s_{mmin,j}$ minimum stock of product j in the manufacturer
$s_{mmax,j}$ minimum stock of product j in the manufacturer
s_{tman} total stock held by manufacturer
$s_{tret,i}$ total stock held by retailer i
s_{totret} total stock in all retailers
s_{tsc} total stock in the supply chain
s_{gapret} stock gap among retailers
f_r retailer multiplication factor
f_m manufacturer multiplication factor
$q_{max,i,j}$ maximum quantity of product j delivered to retailer i in single round

$q_{i,j}$ quantity of product *j* delivered to retailer *i* in single round
$q_{mtot,j}$ maximum quantity of product *j* that must be produced
$q_{m,j,l}$ quantity of product *j* in slot *l*
$q_{mrem,j}$ remaining of quantity of product j that must be produced
$q_{req,b,i,j,d}$ requested quantity of product *j* by buyer b that visits retailer *i* in day *d*
$q_{tra,b,i,j,d}$ requested quantity of product *j* by buyer b that visits retailer *i* in day *d*
$\Delta_{s,i,j}$ gap between maximum stock and current stock of product *j* of retailer *i*
r_{suc} success ratio

In this work, we develop two replenishment model. The first model is retailer's inventory replenishment model. The second model is manufacturer's inventory replenishment model. Both models implement WRR. First, we will explain the retailer's replenishment model. Replenishment occurs for all products that are produced by the manufacturer. It occurs sequentially from the first product until the last product. This retailer's replenishment model in every arrangement is formalized by using Eq. (6) to Eq. (11).

$$g_{r,i,j} = s_{i,j} - s_{min,i,j} \tag{6}$$

$$g_{rmin,j} = min(g_{i,j}) \tag{7}$$

$$w_{r,i,j} = \begin{cases} 0, g_{r,i,j} \geq 0 \\ int(\frac{g_{r,i,j}}{g_{rmin,j}} \times f_r) \end{cases} \tag{8}$$

$$q_{max,i,j} = w_{r,i,j}.q_{c,r} \tag{9}$$

$$\Delta_{s,i,j} = s_{max,i,j} - s_{i,j} \tag{10}$$

$$q_{i,j} = \begin{cases} q_{al,i,j}, q_{al,i,j} \leq s_{m,j} \wedge q_{al,i,j} \leq \Delta_{s,i,j} \\ s_{m,j}, q_{al,i,j} > s_{m,j} \wedge q_{al,i,j} \leq \Delta_{s,i,j} \\ \Delta_{i,j}, q_{al,i,j} \leq s_{m,j} \wedge q_{al,i,j} > \Delta_{s,i,j} \end{cases} \tag{11}$$

Rotation model during retailer's replenishment model is as follows. There are two tokens. The first token is daily token. The second token is round token. In day one, the first retailer holds the daily token. In the next day, the daily token will be passed to the next retailer. If the current retailer is the last retailer, then the daily token will be passed to the first retailer. In the beginning of the day, the round token will be held by retailer who holds the daily token first. In the next round, the round token will be passed to the next retailer. In case the current retailer is the last retailer, the round token will be passed to the first retailer. This first replenishment model can also be called DWRR based model because in every arrangement, the retailers' weight is recalculated.

Replenishment process for certain product ends if one of these two events occur. First, stock of this product in the manufacturer's inventory is empty. Second, all retailers have reached maximum stock of this product. This scenario adopts (s, S) model. The second replenishment model is manufacturer inventory replenishment. System will check whether certain machine will produce goods or not in daily basis. If this machine will produce goods, this system also determines the product item and quantity. This process is applied for all machines.

In the beginning, the system will check whether there is an active production sequence plan. Production sequence plan is a set that contains the sequence of product item and the quantity. Example of the product item sequence is $\{(p_1, q_1), (p_2, q_2), (p_3, q_3), (p_4, q_4), (p_5, q_5), (p_6, q_6)\}$. In this example, the production sequence plan contains six slots. Each slot then will be allocated to a machine. It means that quantity in a slot cannot surpass a machine production capacity. Another example of production sequence plan is {(1, 50), (1, 50), (2, 50), (2, 30), (3, 50)}. In this production sequence plan, the first slot is product 1 with quantity is 50 units. In the fourth slot, machine will produce product 2 with quantity is 30 units. If there are three machines in the factory, so the first machine will handle the first and the fourth slots, the second machine will handle the second and the fifth slots and the third machines will handle the third slot. The production sequence plan creation is formalized by using Eq. (12) to Eq. (14). If the production sequence plan is created, then this plan will be arranged. Before the arrangement, system will determine the products weight and the total quantity of every product that must be produced in one production sequence plan. The product weight is determined by using Eq. (15) and total quantity that must be produced is determined by using Eq. (16). In Eq. (16), it is shown that (r, Q) model is adopted. This second replenishment model can also be called DWRR based model because in every arrangement, the products' weight is recalculated.

$$g_{m,j} = s_{m,j} - s_{mmin,j} \tag{12}$$

$$g_{mmin} = min(g_m) \tag{13}$$

$$A = \begin{cases} create\ plan, g_{mmin} < 0 \\ do\ nothing, g_{mmin} \geq 0 \end{cases} \tag{14}$$

$$w_{m,j} = \begin{cases} 0, g_{m,j} \geq 0 \\ int(\frac{g_{m,j}}{g_{mmin}} \times f_m) \end{cases} \tag{15}$$

$$q_{mtot,j} = s_{mmin,j} . q_{c,m} \tag{16}$$

WRR model is used during the production sequence plan arrangement. Similar from the retailer's replenishment model, in the manufacturer replenishment model, we also use two tokens. The first token is the main token. The second token is the round token. In the first arrangement, the first product holds the main token. In the next plan arrangement, the main token will be passed to the next product. If the current product is the last product, then the main token will be passed to the first product.

In the beginning of an arrangement, the round token is held by product that holds main token. In every turn, number of slots or chunks that are allocated to the product is equal to the product weight. It means that higher value of product weight means more slots that are allocated. In the next turn, the round token will be passed to the next product. If the current product is the last product, then the round token will be passed to the first product. The quantity in each slot is determined based on the machine production capacity and the remaining quantity that must be produced. It is formalized by using Eq. (17).

$$q_{m,j,l} = \begin{cases} c, q_{mrem,j} \geq c \\ q_{mrem,j}, q_{mrem,j} < c \end{cases} \tag{17}$$

3.3 Simulation

In this work, we evaluate performance of this proposed model by implementing it into simulation process. In this simulation, we compare this proposed model with the existing (s, S) model [33] and (r, Q) model [37]. In this simulation, a manufacturer serves several retailers in the VMI system. Both manufacturer and retailers are in the same city so that manufacturer can visit retailers in daily basis. In this simulation, several variables are adjusted. They are shown in Table 1. This simulation runs in various number of retailers. The n_r ranges from 3 to 30 retailers. The step size is 3 retailers.

Table 1 - Adjusted variables

Variable	Value
n_m	40 units
c	50 units per day
n_p	20 items
n_d	10 days
n_{avbpd}	5 buyers per day
n_{avppb}	5 items per buyer
q_{avpp}	5 units per items
$s_{mmin,j}$	200 units
$s_{mmax,j}$	1000 units
$s_{min,i,j}$	20 units
$s_{max,i,j}$	100 units
$q_{c,r}$	2
$q_{c,m}$	3
f_r	5
f_m	5

In the beginning of the simulation, several variables are generated. The initial stock of the manufacturer and retailers are generated randomly. The average number of buyers that visit certain retailer in a day also generated randomly and it follows exponential distribution. These processes are formalized by using Eq. (18) to Eq. (20).

$$s_{m,j}(0) = uniform\_random(s_{mmin,j}, s_{mmax,j}) \tag{18}$$

$$s_{i,j}(0) = uniform\_random(s_{min,i,j}, s_{max,i,j}) \tag{19}$$

$$n_{avbpd,i} = exponential\_random(n_{avbpd}) \tag{20}$$

After initial value of all variables is set then the simulation runs. The simulation runs from the first day until the operational days. Every day, every retailer is visited by several buyers. Each buyer requests several products with certain quantity. These variables are determined by using Eq. (21) to Eq. (23).

$$n_{buyer,i,d} = exponential\_random(n_{avbpd,i}) \tag{21}$$

$$n_{prod,b,i,d} = exponential\_random(n_{avppb}) \tag{22}$$

$$q_{req,b,i,j,d} = exponential\_random(q_{avpp}) \tag{23}$$

There are five variables evaluated in this simulation: success ratio (r_{suc}), total retailers' stock (s_{totret}), manufacturer's stock (s_{tman}), total stock in the supply chain (s_{totsc}), and stock gap among retailers (s_{gapret}). The definition of these variables has been explained in the beginning of sub section 3.2. Success ratio is calculated by dividing the total quantity bought by buyers during simulation and the total potential quantity asked by buyers during simulation. Total retailers' stock is the total stock held by all retailers in the end of simulation. Manufacturer's stock is total stock in the manufacturer in the end of simulation. Total stock in SC is the accumulation of total retailers' stock and manufacturer's stock. Stock gap is the difference between maximum stock and minimum stock among retailers in the end of simulation. The first variable represents the service level [1] or sales [8]. The second to the fifth variables represent the inventory quality [6]. The calculation of these observed variables is formalized by using Eq. (24) to Eq. (29).

$$r_{suc} = \frac{\sum_{d=1}^{n_d} \sum_{i=1}^{n_r} \sum_{b=1}^{n_b} \sum_{j=1}^{n_p} q_{tra,b,i,j,d}}{\sum_{d=1}^{n_d} \sum_{i=1}^{n_r} \sum_{b=1}^{n_b} \sum_{j=1}^{n_p} q_{req,b,i,j,d}} \tag{24}$$

$$s_{totret}(n_d) = \sum_{i=1}^{n_r} s_{tret,i}(n_d) \tag{25}$$

$$s_{tret,i} = \sum_{j=1}^{n_p} s_{i,j} \tag{26}$$

$$s_{tman}(n_d) = \sum_{j=1}^{n_p} s_{m,j}(n_d) \tag{27}$$

$$s_{totsc}(n_d) = s_{totret}(n_d) + s_{totm}(n_d) \tag{28}$$

$$s_{gapret}(n_d) = max(s_{totret}(n_d)) - min(s_{totret}(n_d)) \tag{29}$$

4. Result and Discussion

The simulation result is shown in Fig.6. Fig. 6a shows the success ratio. Fig. 6b shows the total retailers' stock. Fig. 6c shows the total manufacturer's stock. Fig. 6d shows the total stock in the supply chain (SC). Fig. 6e shows the stock gap among retailers.

Fig.6a shows that the success ratio declines due to the increasing of the number of retailers. It occurs in all replenishment models. It is also shown that the WRR model performs the best among models. Meanwhile, the (s, S) model performs the worst among models. The success ratio of the WRR model is 19 to 31 percent better than the (s, S) model. Meanwhile, success ratio of the WRR model is 7 to 12 percent better than the (r, Q) model.

Fig.6b shows that the total retailers' stock inclines due to the increasing of the number of retailers. It occurs in all replenishment models. It is also shown that the WRR model performs moderate between the (s, S) model and the (r, Q) model. The total retailers' stock of the WRR model ranges from 86 to 103 percent compared with the (s, S) model. The total retailers' stock of the WRR model ranges from 99 to 155 percent compared with the (r, Q) model.

Fig.6c shows that the manufacturer's stock declines due to the increasing of the number of retailers. It occurs in all replenishment models. It is also shown that the WRR model performs the best among models. Meanwhile other existing models perform equally when the number of retailers is high. Manufacturer's stock of the WRR model ranges from 36 to 87 percent compared with the (s, S) model. Meanwhile, manufacturer's stock of the WRR model ranges from 40 to 117 percent compared with the (r, Q) model.

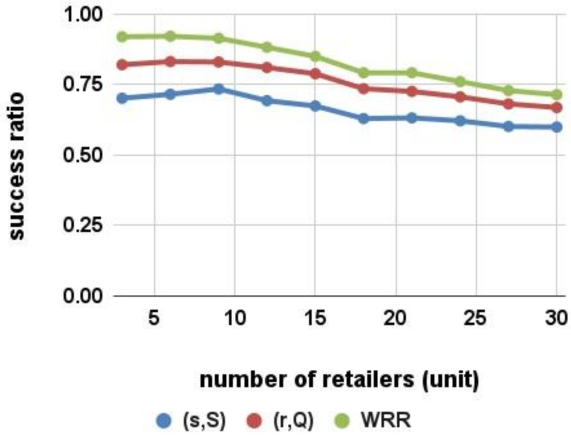

Fig. 6a - Simulation result – success ratio

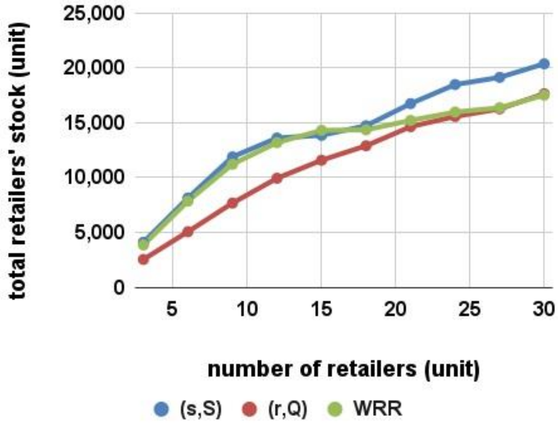

Fig. 6b - Simulation result – total retailers' stock

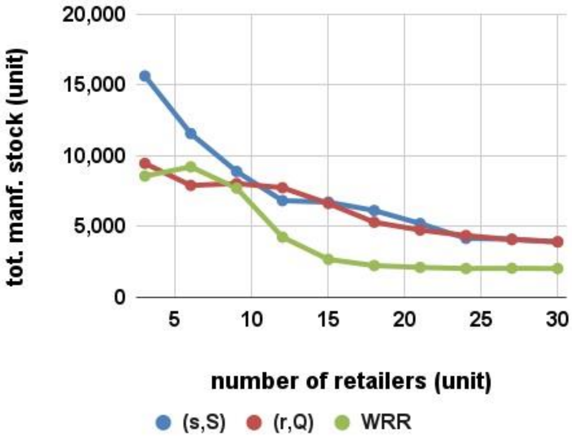

Fig. 6c - Simulation result – total manufacturer's stock

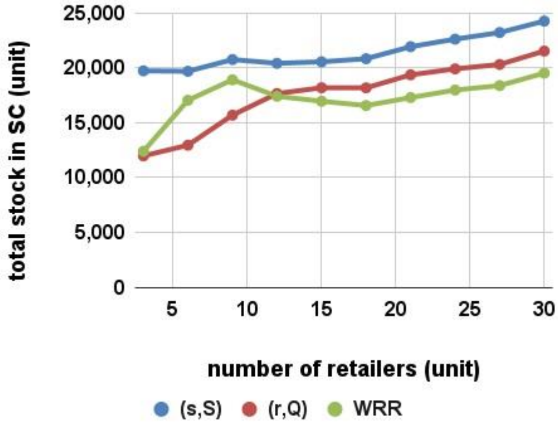

Fig. 6d - Simulation result – total stock in the supply chain

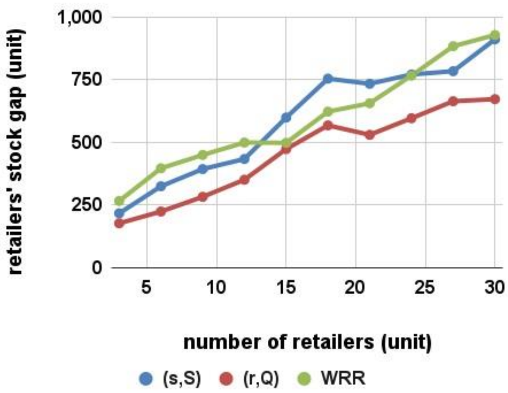

Fig. 6e - Simulation result – stock gap among retailers

Fig.6d shows that the total stock in SC inclines due to the increasing of the number of retailers. It occurs in all replenishment models. It is also shown that the WRR model performs the best among models, especially when the number of retailers is high. Meanwhile the (s, S) model performs the worst among models. The total stock in SC of the WRR model ranges from 63 to 91 percent compared with the (s, S) model. Meanwhile, the total stock in SC of the WRR model ranges from 89 to 132 percent compared with the (r, Q) model.

Fig.6e shows that the stock gap inclines due to the increasing of the number of retailers. It occurs in all replenishment models. The WRR model produces wider stock gap among retailers. The stock gap of the WRR model ranges from 83 to 123 percent compared with the (s, S) model. Meanwhile, the stock gap of the WRR model ranges from 89 to 132 percent compared with the (r, Q) model. Based on this result, the stock gap of the WRR model is competitive compared with the (s, S) model and worse than the (r, Q) model. The reason is in this work, during the operation, the rotation concept is also adopted in the retailer's replenishment system of the (s, S) model and the (r, Q) model although splitting is not adopted so that it cannot be said as RR based model. Although in a single day, some retailers are prioritized than others, in the whole operational time, all retailers are treated equally. Based on this explanation, rotation can balance the opportunity in the whole system.

5. Conclusion

In this work, it is shown that our proposed model, the Weighted Round Robin (WRR) model performs as the best replenishment model compared with the (s, S) model and the (r, Q) model in the VMI system. It occurs in most of the observed variables. The WRR model is proven in increasing sales and maintaining low inventory level, especially in the manufacturer (upper) side. In the certain condition, performance of the WRR model compared with the (s, S) model and the (r, Q) model is as follows. The WRR model performs 31 percent better than the (s, S) model and 12 percent better than the (r, Q) model in success ratio. The manufacturer's stock in the WRR model is only 36 percent than in the (s, S) model and 40 percent than in the (r, Q) model. The total stock in the supply chain in the WRR model is only 63 percent than in the (s, S) model and 89 percent than in the (r, Q) model. In the total retailers' stock, the WRR model performs moderate and in the middle between the (r, Q) model and the (s, S) model. In the stock gap among retailers, the WRR model is competitive with the (s, S) model and little bit higher than the (r, Q) model because in this work, both the (s, S) model and the (r, Q) model also adopt rotation mechanism during the operation.

There is a lot of future research potential due to this work. This replenishment model still can be improved by using other algorithms and evaluated in other environments. Improving VMI system by implementing algorithms that are popular in computer system is also potential. Implementing techniques in artificial intelligence and machine learning into VMI system is also challenging.

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