Development of Architecture and Caching System for Improving the Performance of Fuel Management System

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Abstract. Fuel Management System (FMS) is about managing and accounting for fuel. While implementing FMS in Sudan, some problems are noted, like system delay, inaccuracy and unavailability of the system. These problems and others make fueling companies and customers unsatisfied with the FMS.
This paper aims to solve the noted problems by introducing enhanced system architecture and integrating a Caching System in the FMS architecture to enhance the performance, reduce system delay and increase the availability of the system.
After architecture was developed, simulation programs were implemented to simulate the interactions required to re-fuel and to provide statistics results that help in evaluating the proposed FMS. The results of simulation programs were presented as the average service time, number of customers in system, number of customers in queue, idle probability and other results. The average service time was reduced and all results obtained emphasize the effectiveness of the proposed solution.

1 Introduction

FMS consists of equipments and software designed to automate the process of purchase and sale of any fuel product inside fueling site. Fuel is delivered by the supplier to the tank at fuel distribution site and then to the customers; when distributing fuel, some features are required such as accuracy, integrity, and caution of every person that uses the facility to ensure that the losses is only due to natural causes such as evaporation. Losses are becoming a great concern for Management and Accounting departments especially in the public sector [1].

By using FMS many benefits can be gained such as it becomes easy to account for every liter of fuel purchased and to know where the fuel goes, hence the organization will avoid fuel theft and misuse [1], also re-fueling becomes easier and faster and ensuring the proper fuel was delivered for specific vehicle becomes available with the ability of restricting access to re-fueling until the maintenance is performed [1].

FMS principle is the connection and control of all dispensers to an interface unit which is connected to the controller computer to control these dispensers by the software installed on the computer, to enable all fueling operations to be reported,

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controlled, recorded and customers can easily monitor their vehicle's fueling operation [2].

FMS must have the ability to identify users (by using identification method like: Attend key, Smart cards, Automated Teller Machine (ATM) cards etc...) in order to enable the system give authorization to the dispenser for fueling. Fueling information are recorded at the end of the fueling [2]; then it's transferred automatically to the central server through an appropriate network connection [3].

As FMS consists of many components (hardware and software) and the system might be integrated with other systems such as Banking System and/or other sites through complicated network, the system will be affected with most of networks problems, so there is a need for techniques to reduce the effect of network problems to the system. Also the architecture of the automation system and the equipments used for connecting the dispensers to the system are important to be considered because any loss or delay of re-fueling data is not acceptable [2]. Therefore, it is vital to stick to international standards during the design and implementation of these systems [2], so it is powerful to construct simulation programs to test new systems before implementing them.

2 FMS Infrastructure

2.1 Fuel Management Sub-Systems

FMS is a complex system, so a good way to deal with the system is to divide it - according to functionalities - into small subsystems.

The main sub-system in FMS is *Pump Controlling System*; it connects all fuel dispensers to the station controller computer resulting in the controlling of these dispensers by the software installed on the computer [2]. The system operates the fuel dispenser only to valid customers and vehicles [4].

An optional system *is a Head-Office System*. It delivers the capability of programming identification devices. Head-office system sends all the fleet information to the automation solutions in all stations. The system stores data in the central database, since all the transactions in the stations are transferred to the head-office. Information stored in the head-office is later used to generate reports and submitted to the users [2].

2.2 Fuel Management Identification Equipment

FMS consists of a fuel island controller, software, some types of identification devices (as shown in Table 1) and the Central Controller that normally communicates with other sites to exchange the data [1].

Table 1. Identification equipment.

Identification equipment	Description
Smart Chip Key	Contains a microchip that can be programmed and reprogrammed.
Smart cards	Standard size card with an embedded read/write memory chip and it works exactly like smart Chip Key.
Credit cards	It allows 24 hour, unattended, self-serve operations for credit card holders [5].
Vehicle Identification System	It is a coil ring integrated with electronic chip that installed at the opening of the fuel tank to enable collecting data from the vehicle [6].

2.3 Fuel Management System Sensors

A sensor can be defined as "a device that detects (senses) changes in the ambient conditions or in the state of another device or a system, and conveys or records this information in a certain manner" [7]. FMS and its subsystems contain many sensors to monitor system status (i.e. volume, motion, temperature and other sensors) where all sensors are connected with FMS network through defined protocols. FMS Sensors are located in station forecourt (to detect vehicle motion), in fuel dispenser (to measure delivered fuel volume), in station fuel tanks (to measure temperature, viscosity and other physical parameters) and in the vehicle .All sensors are responsible for the accuracy and performance of the system.

2.4 Off-line Automation and On-line Automation

Vehicle identification and station automation operate in two different modes [2]:

Off-line automation: All the vehicle information, Black/White List is stored in the automation systems located at the station. The vehicle approaching the station is controlled by this automation system and then re-fueled. Daily sales are transferred to the oil company head-office on a batch transfer. During the batch transfers, the fleet list definitions are updated [2].

On-line automation: All the vehicle information, Black/White List is stored in the servers of company head-office or in the servers of the Internet Service Provider (ISP) that is responsible for central communication and data storage. The vehicle that approaches the station is detected by the station controller and queried on the head-office system. Fueling, regional and time limitations of the vehicle are checked from the head-office [2].

2.5 Payment Methods

Payment methods are an important issue that can be considered when designing FMS. In general, there are two types of payments, post-paid and pre-paid [2].

In the post-paid method the customers will take fuel and can also be provided with some services and/or products and will pay the money later, so the off-line automation is suitable for this case.

In the pre-paid method the customers will take fuel and can also be provided with some services and/or products only if they have sufficient amount defined in the system, so the on-line automation is suitable for this case.

3 Related Works

This section discusses some FMSs according to the author experience, and then an ATM network model is highlighted to help in designing the enhanced FMS.

PumpOmat is a forecourt automation system developed by Turpak – Turkish company- for dispenser automation .When installing and running *PumpOmat* in Sudan, the author found that there were some problems in the system. The first problem is that when the customer presents his identification, the system takes long time (approximately 40 Sec.) to start the dispenser and the dispenser can not stop at the target volume or amount exactly. Also the system supports only post-paid customers.

Another FMS is *EasyFuel Plus* which is developed by OTI. Also this system has many problems; the first problem is that when the customer presents his identification, the system takes long time (approximately 36 Sec.) to start the dispenser. Another problem is, although the system supports pre-paid customers but the tag that holds the data must be returned to the fuel company for balance reloading, so from the author point of view it is not practical.

The author observes that the FMS is similar to the ATM Network in which the ATMs are owned by different banks, and the customer may use any ATM even it doesn't belong to his bank. All *ATMs* are connected using a *main switch* which connects them to the *core systems* [8]; this scenario has been applied to proposed FMS for network considerations.

4 Methodology

4.1 Caching System

Caching is a technique aimed at bringing parts of an overall data set closer to its processing site [9], and can be used in FMS to retrieve customer data from 'outside' servers to the station computer to enhance the performance.

Caching can improve network performance in two ways. First, when serving clients locally (customer data), caches hide wide-area network latencies. Second, temporary unavailability of the network can be hidden from customers, thus making the network appear to be more reliable [10].

Caching systems eliminate the need to contact the originating server. Thus, additional network communication can be avoided, so caching systems can save bandwidth, enhance server load balancing, perceived network latency reduction, and increase content availability [10].

The main drawback of caching system is data inconsistency, and this drawback does not affect the FMS because the data is retrieved when the customer is in the station and the update occurs after the customer leaves the station.

4.2 Simulation and Modeling

Simulation is used as a tool to better understand and optimize the performance and reliability of systems [11]. Modeling and simulation is a valuable tool in the analysis of large-scale networks and computer systems [12].

Simulation and modeling technique will be used after the development of architecture and Caching System for FMS to ensure the correctness of the design.

4.3 Queuing Analytical Models

Queuing theory is usually used to define a set of analytical techniques in the form of mathematical formulas to describe properties of the processes with a random demand and supply (waiting lines or queues). Queuing formulas are usually applied to a limited number of pre-determined simplified models of the real processes for which analytical formulas can be developed [13].

There are three main concepts in queuing theory which are customers, queues, and servers (service mechanisms). In queuing systems, customers are generated by an input source according to a statistical distribution that describes their interarrival times (the times between arrivals of customers). The customers join a queue and waiting for some event to occur (i.e. take a fuel). At various times, customers are selected for service by the server (service mechanism). The basis on which the customers are selected is called the queue discipline which can First-come-first-served (FCFS) or Last-come-first-served (LCFS) or Random selection or Priority selection [14] .In some models customers can decide not to join a queue if the queue length is too long. This phenomenon is called *Balking* [14].

5 FMS Architecture

This section proposes FMS architecture with discussion of two system scenarios and suggests a solution for them.

One solution to reduce the waiting time, increase the availability and enhance the integrity at the fuel station is the 'Caching System' that is to start retrieving the fueling data while the vehicle/customer in the waiting queues.

When the customer needs re-fueling at fuel station, two situations may occur. The first situation is that the customer does not find any vehicle in re-fueling process, so there is no queue and he/she can stop at the fuel dispenser directly. The second situation is that the customer finds there is a vehicle in re-fueling and/or other vehicles are waiting in the queue for re-fuel, in this case the customer will join a queue.

In the first situation the customer can use his/her identifier to re-fueling, and the customer will wait for a few times while the system is retrieving the data.

In the second situation, there is a possibility that the fueling information for the customer is stored in some server outside the station, a good technique is to retrieve the fueling information while the customer is waiting in the queue.

When a customer comes to station and joins a queue, he/she will be waiting in the queue until he/she becomes the first customer in the queue, and then a capturing device will capture the vehicle plate number and transfer it through the controller to the station computer. The station computer will establish a communication with other severs to get the fueling information for this vehicle and store them temporally in the station computer. When the customer leaves the waiting queue and stops at the dispenser and uses his/her identifier, the request will be forwarded by the Central Controller to the station computer and the data will be found in the station computer because it is prepared while the customer was waiting, so by implementing this solution the waiting time will be reduced.

5.1 Components

FMS must contain *Station Computer (SC)* at each station to provide and process data for station devices.

Since the one fuel company can have more than one fuel station, there is a need for a centralized server (*Fuel Company Server (FCS)*) to collect and analyze data from different stations.

Since there is more than one Fuel Company and the customers need the ability to take their quantities from any station, there is a need for a common centralized server (*Main Server (MS)*) to enable data exchange between different FCSs and SCs. Since all traffic must pass through the MS it can act as a point of solving conflicts and coordinating between fueling companies.

In some cases if the customer uses his/her banking card, there is a need for *Banking System* (BS).

Also customers can use their computers (*Customers Computer (CC)*) to manage and monitor their fleet remotely.

5.2 System Architecture

This section proposes an enhanced system architecture that helps in reducing the waiting time, increasing the availability and enhancing the integrity of the system.

The architecture as shown in Fig. 1 consists of the *Main Server*, *Banking System*, *Fuel Company Server*, *Station Computer* and *customer Computer*.

In this architecture The *MS*, *FCSs* and *SC*s connect through one network, but each transaction must pass through the *MS*. Also, the *MS* is connected with the *BS* to provide services to the customers who have banking account.

In general, when the customer needs to re-fuel or needs a service from fuel station, there are two ways for paying, using FMS identifiers or using banking cards.

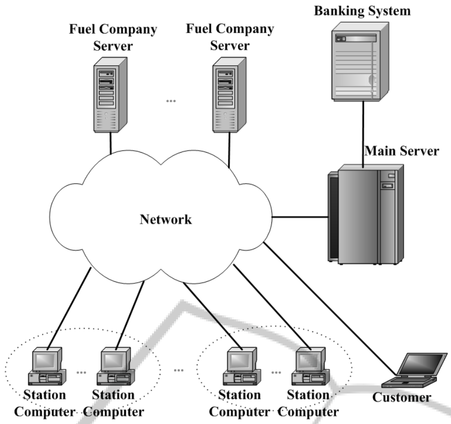

Fig. 1. The proposed architecture.

The first case, If the customer uses one of FMS identifiers, the *SC* will request the *MS* to retrieve the fueling information from the place where it is stored; the *MS* searches in its database to determinate the appropriate *FCS* and then requesting it to get the fueling information, the *FCS* will response to the *MS* and the response will be forwarded from the *MS* to the *FCS* and then to the *SC*.

The second case, if the customer uses his/her banking card, the *SC* will request the *MS* to dept the amount of money needed from the *BS*; the *MS* requests the *BS* to dept the customer account, the *BS* will search for customer account and the result is sent to the *MS*; the *MS* will forward the result to the *SC*.

In all cases, after re-fueling the dispensed fuel amount and cost will be processed and transferred to the *FCS* and/or other Server(s) and it depends on if the customer belongs to the fuel company or others.

While availability is an important issue when designing FMS, Table 2 shows the effect of component and/or link failure to the system.

Table 2. The effect of component or link failure to the system.

Component / Link	Effect of component or Link failure to the system
SC / Link between SC and network	The station is out of service, so customers of this fuel company and customers of other fuel companies can not use this station.
FCS / Link between FCS and network	Customers of the fuel company can not fuel at fuel company or each other station (also if it's owned by different companies). But company customers can use their banking card.
MS / Link between MS and network	Customers of any fuel company can use company fuel stations only (required to modify the *SC* logic and became that: if it detects the failure of the *MS*, it can connect directly to its *FCS*). Since the *BS* is connected to the *MS*, the customers are unable to use their banking cards.
BS / Link between BS and MS	Customers of any fuel company can not use their banking cards.

As shown above this architecture retrieves the data from the FCS in 6 steps only, so it reduces the time to retrieve the data and enhances the availability of data as shown in the case of component or link failure, thus it is a powerful architecture to implement.

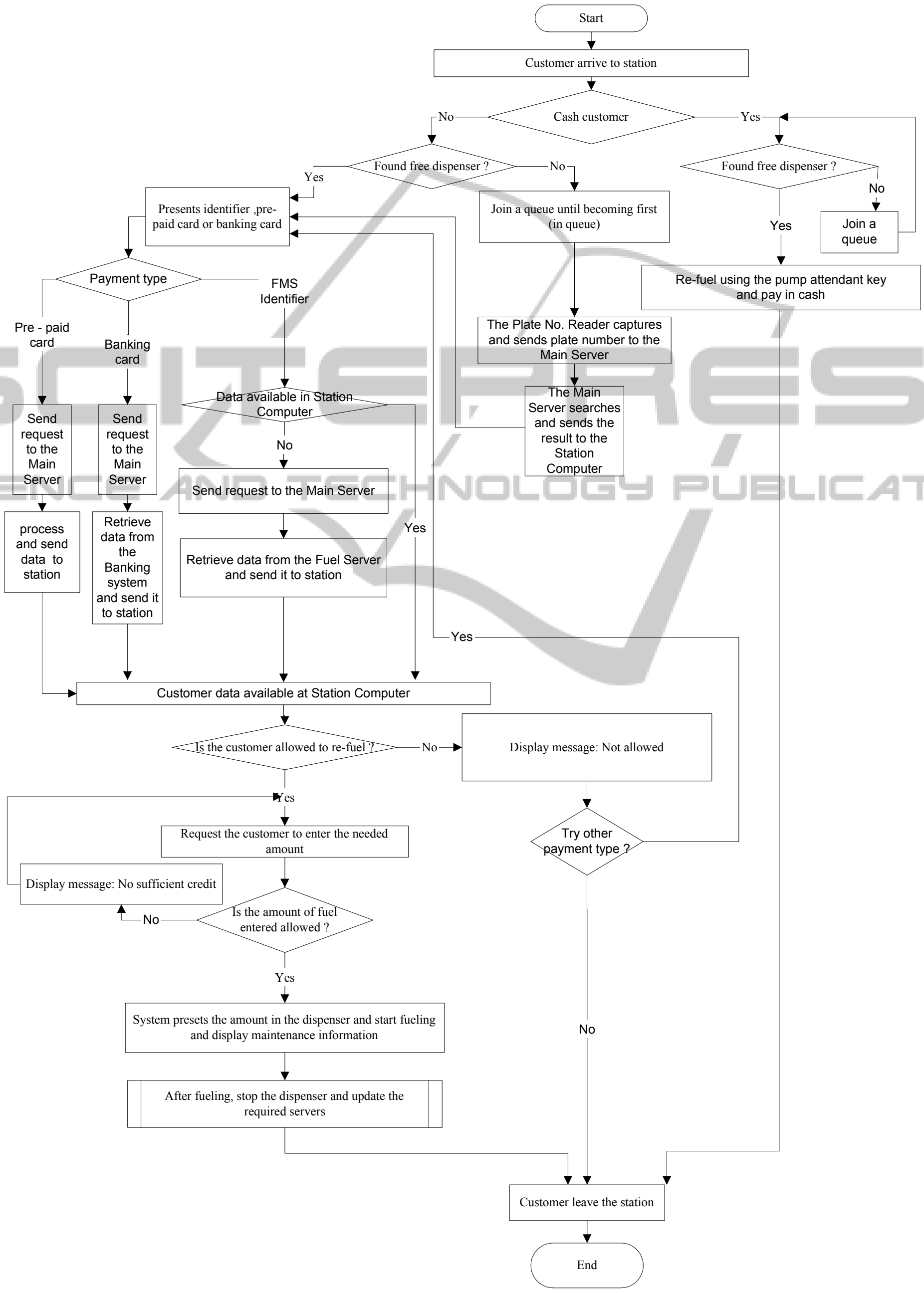

Fig. 2. FMS Framework.

5.3 System Framework

By integrating the station system with other servers, it produces a Comprehensive FMS that provides several services to customers with 'acceptable' performance. Fig. 2 shows an FMS framework that summarizes the steps required to re-fuel.

6 Results and Discussion

This section is divided into three sub-sections that show and discuss three implemented FMS simulation programs. The first program is for simulating the behavior and steps required to re-fuel. The second program is for calculating the average service time while the third program is about calculating average waiting time, calculating the number of customers in the system and the number of customers in the waiting queues and other results.

6.1 FMS Behavior Simulation

A simulation program that illustrates all cases and steps for re-fueling using the proposed architecture is implemented. Fig. 3 shows a screen shot from the simulation program.

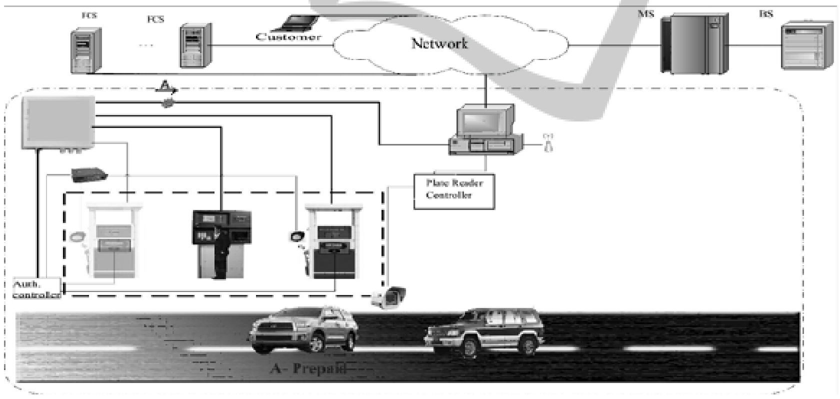

Fig. 3. Screen shot of FMS behavior simulation.

6.2 FMS Average Service Time Calculator

Average service time is a basic parameter that is required in any simulation program. Since FMS has different customers type (customers with different authentication methods), and the way to retrieve the data is different from method to other, it is required to calculate the retrieving time.

Customers come to station to re-fuel in different quantities, and that will affect the dispensing time (time required to re-fuel the desired quantity).

Since the retrieving time and dispensing time mostly compose the service time, then the average service time for FMS customers is the summation of data retrieving time and fueling (dispensing) time divided by the number of customers.

As shown in Fig. 4, a simulation program that calculates the average service time was implemented (values used for transmitting and processing times are approximate times and can be changed and it determined by author experiments and experience).

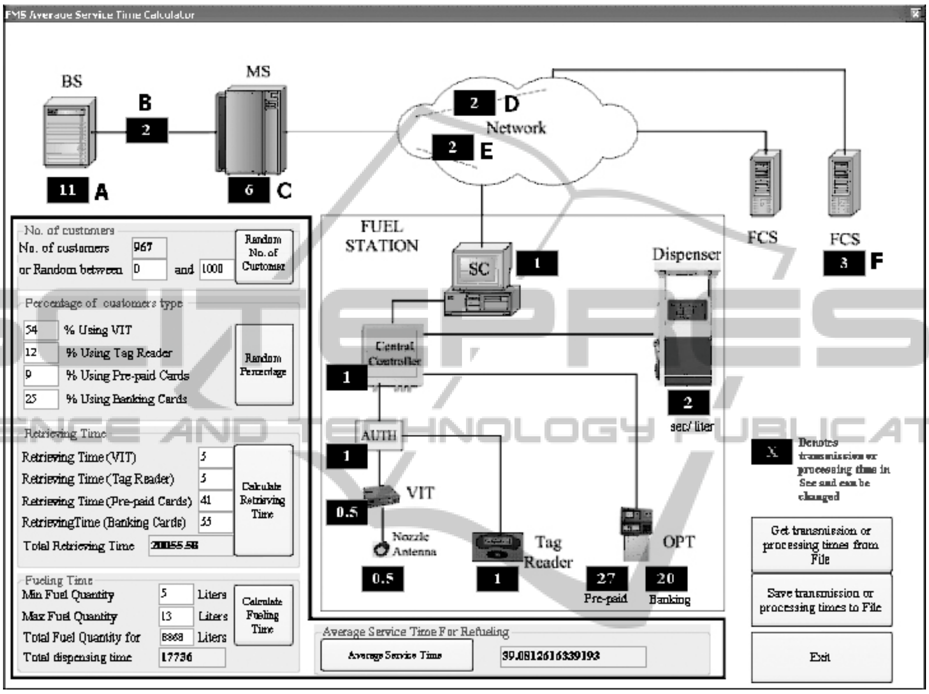

Fig. 4. Average Service Time Calculator.

As shown in Fig. 4 above, when using the proposed architecture the Average Service Time is 39.081.

When integrating Caching System with the proposed architecture (the time parameters A, B, C, D, E, F, set to zero because the data is available at the Station Computer) , the Average Service Time will be 30.431Sec.

6.3 FMS Statistics Calculator

A simulation program (*M/M/1 Solver & Simulator* that is available at : http://staff.um.edu.mt/jskl1/simweb/simmm1.html) which is developed by Jaroslav Sklenar was used to get the number of customers in system (Ls), number of customers in queue (Lq), Time in system (Ws), Time in queue (Wq), Idle probability (p0), Server utilization (r) and other results.

When using 'FMS Average Service Time Calculator' program, the calculated average service time is (approximately 0.5 Min.). And each customer arrives after

(1.0 Min.) from the previous one, the arrival rate will be (1 customer/minute) and the service rate will be (2 customers/minute). The author assumes that if there is 10 customers in waiting queue the customer will not join the system (buffer size is 10 customers). Fig. 5 and Fig. 6 below show the simulation results.

Result	Computed value	Simulated value
Customers in system (L_s)	1	0.846563734570
Customers in queue (L_q)	0.5	0.378510907293
Time in system (W_s)	1	0.914947275906
Time in queue (W_q)	0.5	0.408645353463
Idle probability (p_0)	0.5	0.551724137931
Server utilization (ρ)	0.5	0.468052827273

Fig. 5. Basic simulation results.

Result	Value
Number of arrivals	928
Minimum arrival interval	0.00001914620
Maximum arrival interval	8.31071467253
Number of services	927
Minimum service duration	0.000477153806
Maximum service duration	3.54353940953
Maximum waiting time	5.71670667345
Maximum time in system	6.67693533453
Maximum queue length	7

Fig. 6. Additional simulation results.

When simulating other systems, a simulation program shows that systems are unstable because the arrival rate is greater than the service rate. In the proposed system the architecture helps to improve the service rate by introducing common fuel servers. Also as shown in Fig. 5 and Fig. 6, the Caching System reduces the average service time that improves the system.

7 Conclusions

A powerful architecture that connects all fuel stations (for all fueling companies) in the same network to enable customers to re-fuel at each fuel station regardless of the station owner is designed to provide a set of services with 'acceptable' performance and to reduce system delay and increase the accuracy of fuel volumes taken by customers. Also the proposed architecture enables customers to re-fuel using various payments methods.

According to the importance of evaluating the performance of the proposed FMS, various simulation programs developed to illustrate the interaction scenarios between different components, and to measure some system statistics such as average service time, average waiting time and other statistics that considered important for fueling companies and customers. The results obtained from the simulation programs reflected the efficiency of the proposed FMS.

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