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تنظيم سلوك استهلاك الطاقة المنزلية المعتمد على تقنيات التعدين، النهج التعاوني لاستخدام الأجهزة المنزلية

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الملخص

يشير البحث إلى أن استهلاك الطاقة أصبح واحداً من الأهداف الاستراتيجية في جميع أنحاء العالم، والتي لا تُعَد التزاماً على الشركات فحسب بل لزاماً أيضاً على جميع المواطنين. يركز البحث على استهلاك الأفراد للطاقة ويتضح ذلك من خلال إبراز المنهج الأساسي لتوفير الطاقة عبر استراتيجية جماعية تهدف للمشاركة في الاستخدام الأفضل للأجهزة المنزلية. يوضح هذا البحث أن المنهج المُقترح يوصى بوضع خطة جماعية للمنازل المتجاورة التي تتبنى وجهات نظر متباينة، بحيث تتشارك في الأجهزة وتقلل من معدل الاستهلاك. يعتمد البحث على تقنيات التعدين بغرض فحص واستهداف الجمعيات المطلوبة لوضع خريطة طريق لاستهلاك الأجهزة. تمت دراسة النهج المُقترح من خلال تمثيل رسمي للجهات المساهمة وعلاقاتهم، كما تم تمثيل تلك العلاقات والجمعيات المطلوبة المطلوبة في شبكة دلالية وناقش البحث كل مرحلة بشكل تفصيلي. قام البحث بتطبيق التجربة على إثنين من مجموعات البيانات المعيارية بالإشارة إلى المراجع المذكورة، وفي هذا البحث تم تطبيق كافة المراحل ودراسة كل الجمعيات بمعدل ثقة يزيد على 90% وأكدت نتائج البحث قابلية تطبيق النهج المُقترح.

Reforming home energy consumption behavior based on mining techniques: a collaborative home appliances approach

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Abstract

More efficient energy consumption has become one of the strategic objectives all over the world. Not only is it the obligation of enterprises but should also be the obligation of all citizens. Focusing on individuals' energy consumption, a vital approach for saving energy is a collaboration strategy which aims at sharing home appliances for best usage. In this research, an approach is proposed for recommending a collaboration plan for adjacent houses in different perspectives, to share appliances, thus minimizing the consumption rate. The research adopts mining techniques in order to explore the required associations targeting to build a road map for appliance consumption. This is performed through a formal representation to the contributed stakeholders and their relations, representing the relations and the required associations in a semantic network representation, with each stage being discussed in detail. The research applied the experiment to two of the benchmark datasets the references of which are mentioned. All stages are applied and associations are explored with confidence above 90%, and the results confirmed the applicability of the proposed approach.

Keywords: Apriori algorithm; associations rules mining; collaborative approach; energy consumption; home appliances.

1. Introduction

Energy saving has been one of the critical subjects in many areas of research, such as considering fuel consumption (Ghahremani-Gol *et al.* ; Xuejun *et al.,* 2015). Although both studies considered the same issue of fuel waste, they proposed different directions for solutions, which included fuel recycling in (Xuejun *et al.* (2015) as well as minimizing vehicle routing in (Ghahremani-Gol *et al.*, 2016).

Energy consumption is not only the enterprises' obligation but it should also be all citizens' obligation. Individual citizens can effectively contribute to achieving the state strategic plan in many directions (Elmasry *et al.*, 2019). Manipulating home resource usage contributes to saving energy, which requires a new perspective on lifestyle while maintaining the satisfaction and enjoyment level. Sharing concepts as well as adopting the customer behavior has been successfully examined in different sectors (Idrees *et al.*, 2019) while these concepts and behavior have also been introduced in the resources utilization perspective (Khedr & Idrees, 2017a). A major example is the cloud computing paradigm, as well as the parallel processing approach (Ahmad *et al.,* 2016). The novelty lies in the proposed approach of sharing resources between individuals to ensure their willingness to apply.

From the scientific perspective, the most suitable resource utilization could be achieved through an effective customer operational orientation approach (Sultan *et al.,* 2017). While different studies have proposed solutions for preserving utilization in many business environments (Helmy *et al.*, 2019), to the authors' knowledge, little research has considered sharing individuals' resources. In this research, an approach is proposed for adopting customer resource consumption behavior. This approach aims at providing an efficient sharing plan for individuals by applying appropriate mining techniques to support the whole power utilization scheme in the determined environment. In addition, it presents a suitable utilization by recommending a road map for the utilization process.

The remainder of this study discusses the research aim in section 2, and then different previous research is discussed in section 3, while the proposed approach and the experimental study are discussed in section 4 and 5, respectively. Finally, the conclusion is given in section 6.

2. Literature Review

Customer behavior has been considered in many research perspectives, such as in Victor *et al.* (2018), which considered the impact of parameters on customer behavior for online purchases. Another study posited predicting the consumption rate (Wahid & Kim, 2017). On the other hand, energy consumption has also been examined (Konstantinos & Georgios, 2019) and a proposal made to attempt to reduce energy loss through detecting the illegal consumers by using data mining techniques in residential areas to compare the readings over a period of time in the determined area. Yet another study (Kapitonov, 2019) focused on the legal perspective for power resource integration.

Mining has been successfully employed in customer behavior analysis (Dogan, *et al.*, 2019) which focused on the main research parameters, such as the individuals' activities in a set of houses, by detecting the process deviation. The research applied clustering techniques for determining the similarity of individuals' behavior according to their normal usage flow, amount, and consumption time. Mining has also been used to detect customer behavior in other research (Abdi & Abolmakarem, 2018), including detecting the expected future behavior. The approach was based on the customers' demographic data and was applied to the telecom field. The approach targeted the traditional view of clustering the customers to determine their needs.

The field of energy has been examined in a variety of research projects. Research by Jeswiet *et al.* (2015) considered the energy consumption of the mining machines and presented a comparative study for a different measure of attempts to reduce the consumption rate in different countries. Another study was conducted by Ali *et al.* (2016), who focused on the analysis of the consumption data through applying mining techniques and building a user profile by determining the peaks of the user according to his consumption history. Moreover, Chung *et al.*(2017) focused on the user's daily behavior to detect an effective energy management methodology. Another study (Singh & Yassine, 2017) analyses energy consumption, detecting the responsibility for power consumption through supervised mining techniques. The research recommends the proposed methodology for power management. Finally, in Shaker *et al.* (2019), an approach was recommended for power consumption for houses that was based on the total house consumption without considering either the individual appliances' consumption or the collaboration approach.

3. Research Gap

Finding a solution to most of these strategic problems is not only the government's responsibility. The individual members of society should also play a role. As individuals are one of the stakeholders' beneficiaries from different sources of energy, it is essential that they should also contribute to finding a solution for minimizing the consumption rate. This research highlights the vital necessity of engaging individuals to effectively contribute to the energy consumption issue by proposing an approach for the individual's behavior adaptation in energy consumption that depends on a collaborative perspective.

4. The Proposed Collaborative Home Appliances Approach Based on Mining Techniques

This research focuses on tracking the users' utilization and detecting the user's behavior trends (Shaker *et al.*, 2019). The proposed approach is based on smart meters measurements (Gabaldón, *et al.,* 2018) which are considered as the main data source. The proposed approach which is illustrated in fig. 1 includes four main phases which are discussed in the following sections.

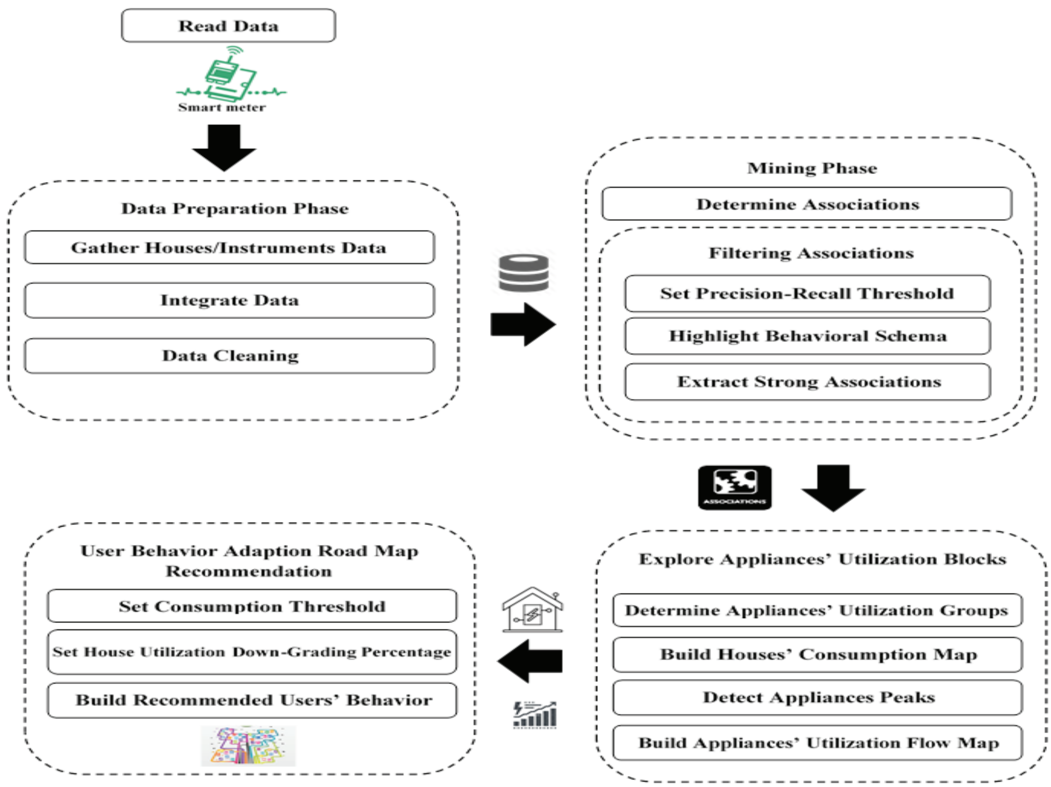

Fig. 1. The Proposed Collaborative Home Appliances Approach

4.1 Phase 1: data preparation phase

– Gather Houses/Instruments Data: A series of house readings for each appliance is registered. The research will follow the formal description of the data and information flow in each step (Khedr & Idrees, 2017b). Therefore, we will start by formally describing the data as follows:

- The set of all houses

Houses (H)=$\{h_1,h_2,h_3\ldots h_n\}$

Where: $h_1, \ldots h_n$ are the houses under study, $n\in\mathbb{N}$, $n>0$

- The set of all appliances

Appliances (AP)=$\{Ap_1,Ap_2,Ap_3\ldots Ap_m\}$

Where: $Ap_1, \ldots Ap_m$ are the appliances, $m\in\mathbb{N}$, $m>0$

- The set of appliance Ap_m readings in the house h_n

$\forall h_n \forall Ap_m, h_n\in Houses, Ap_m\in Appliances, (RA_{nm}=\{ApRa_{nmdt}\}, ApRa_{nmdt}=\langle d_d, t_t, ra_{xynm}\rangle)$

Where: $ApRa_{nmdt}$ is a reading vector of appliance *m* in the house *n* at date *d* and time *t*

RA_{nm} represents the set of the devices' readings for the *m* device in the house *n*

– Integrate Data: The data is integrated into a single source (Mostafa, Khedr, & Abdo, 2017) with respect to the recorded time. The set of all houses' appliances readings

AllApp(Houses)= $\{AllApp(h_1),AllApp(h_2),..AllApp(h_n)\}$

The readings to all appliances for each house

$$AllAp(h_n) = \|_{i=1}^{m} ApRa_{nidt}$$

$$ApRa_{nidt} = ApRa_{nidt} \| ApRa_{nidt} \| \ldots\ldots \| ApRa_{nidt}$$

– Data Cleaning: Mining techniques efficiently contribute to detecting the missing data and outliers. In the proposed framework, the nature of the received data is applied in selecting one of these techniques. The description is continued as follows:

$$AllAp(h_n) = \|_{i=1}^{m} ApRa_{nidt}$$

$$ApRa_{nidt} = ApRa_{nidt} \| ApRa_{nidt} \| \ldots\ldots \| ApRa_{nidt}$$

Where $\forall h_n, \forall Ap_m, (\exists ApRa_{nidt}$ and $ApRa_{nidt} \geq 0)$

4.2 Phase 2: mining phase

Applying the mining techniques is performed by exploring the required relations.

– Explore Associations: An association rules mining algorithm is applied for exploring the relations among attributes. The association rules are as follows:

$X_1, X_2, \ldots, X_i \rightarrow Y_1, Y_2, \ldots, Y_j$

Where i, j∈ℕ, i, j>0, X_i , Y_j∈Houses(H)| Appliances(AP)| RA_{nm}|Date(D)|Date(D)

– Set Precision-Recall Threshold: the accepted minimum threshold is 0.9, which is considered high due to providing the most suitable recommendations.

– Highlight Behavioral Schema

Assuming that CR refers to the consumption rate and CT refers to the consumption time, then this stage highlights the following relations:

- The relation between different houses' consumption rates:

$\exists h_o \exists h_j \in$Houses, CR-ASS(<$h_o$,$CR_o$>, (<$h_j$,$CR_j$>)

- The relation between a house's consumption rate and consumption time:

$\exists h_o \in$Houses, CRT-ASS(<h_o,CR_o>,(<h_o,CT_o>)

- The relation between the appliances' consumption rate in the house:

$\exists h_x \in$Houses, $\exists$ Ap_o $\exists$ $Ap_j \in$ Appliances, CRA-ASS(<h_x, Ap_o, CR_o, CT_o>, (<h_x, Ap_j, CR_j, CT_j>)

- The relation between the similar appliances' consumption rate and time in houses:

$\exists$ h_o $\exists$ h_j, $\in$ Houses, $\exists$ $Ap_x \in$ Appliances, CRH-ASS(<h_o, Ap_x, CR_o, CT_o>, (<h_j, Ap_x, CR_j, CT_j>)

– Extract Strong Associations: Finally, the strong association rules that follow the highlighted schemas are extracted which have a minimum threshold of 0.9. This is the final required output from the mining phase, which is then submitted to the following phase for the exploration task.

4.3 Phase 3: explore appliances' utilization blocks

Detecting appliance groups from the utilization perspective highlighted the houses' appliance relations that are required to build the consumption peer-to-peer network.

- Determine Appliances' Utilization Groups: This research argues that associations- based categorization can be considered as an additional representation on the utilization map.
- Build Houses Consumption Map: As the system is considered as a correlated system view, a semantic network of the stakeholders is illustrated in fig. 2(a,b), which highlights the interrelated beneficiary for the system's stakeholders.
- According to the utilization configuration, a map is built for each house as well as for each appliance over the houses to explore the consumption traffic.

The consumption map is represented as a mesh semantic network, a schematic representation of the map stakeholders' relations, as in Figure 3.

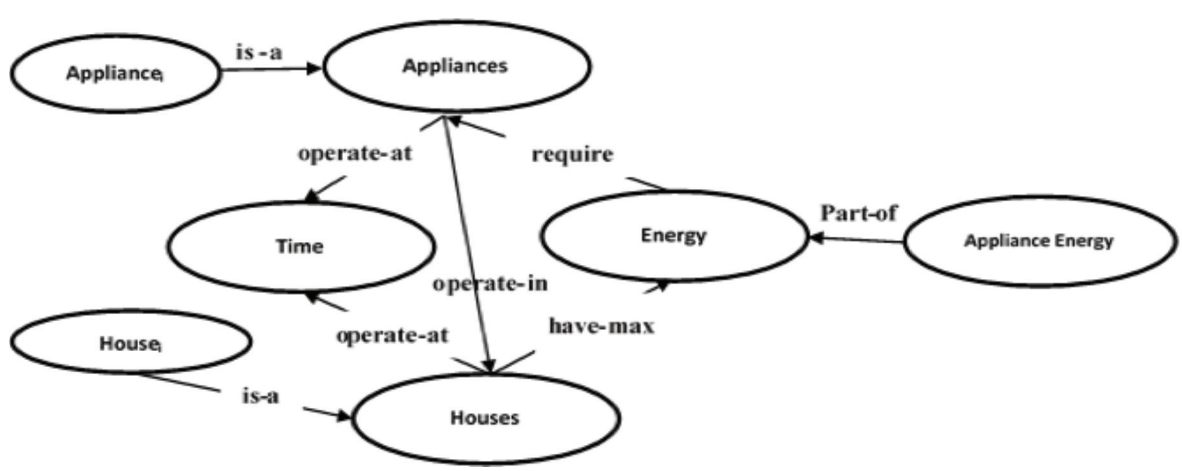

Fig. 2(a). Semantic Network for the System's Stakeholders

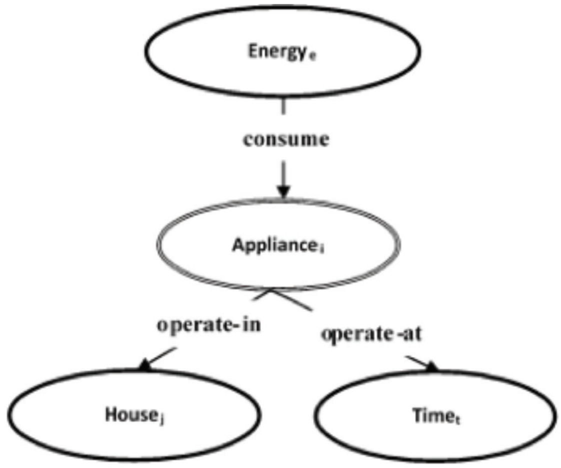

Fig. 2(b). Semantic Network for the System's Stakeholders

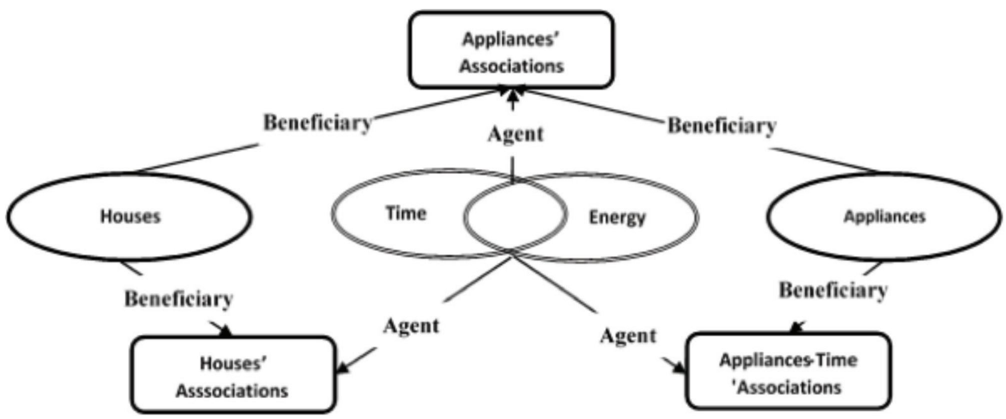

Fig. 3. A Schematic Representation of the Stakeholders' Associations

– Detect Appliance Peaks: Following the constructed utilization map, the appliance peaks are then determined, which highlights the first recommendations' target. The critical level of the detected peaks is also determined for the prioritization process. The representation of the appliance peak is as follows:

$\forall Ap_j \in$ Appliances, Peak(Ap_x, max(CR_x), CT_x)

– Build Appliances' Utilization Flow Map

This is the last required step for preparing all the required information for building the users' behavior road map. The appliances' utilization is structurally determined, according to the pre-determined relations and information, the whole view of the utilization is clarified in this step.

4.4 Phase 4: user behavior adaptation road map recommendation

Tracking the user behavior has been previously highlighted. This phase tracks a gradual solution until it finally presents the required recommendations.

– Set Consumption Threshold: The required consumption threshold is determined according to different criteria; examples of these criteria are the financial level and the acceptable maximum energy level.

– Set Required House Utilization Down-Grading Percentage:

The gap between the consumption thresholds with the current situation threshold is determined, then measurements are applied to downgrade the utilization.

– Build Recommended Users' Behavior Road Map: According to the extracted information as well as the explored relations, a recommendation for each appliance is provided with a sharing perspective which ensures the users' satisfaction and the economic situation by sharing devices. Moreover, a road map for the unlikely to be shared devices is also recommended according to the required threshold for each house individually while ensuring the total utilization consumption threshold. A simple formal recommendation for the houses' consumption road map is characterized as:

$\forall h_i \in$ Houses, $\forall Ap_j \in$ Appliances, Recommendation $_{ij}(CT_{ij}, CR_{ij})$

$\forall h_i$, $h_j \in$ Houses, $\forall Ap_k \in$ SH_Appliances, SH_Appliances $\subseteq$ Appliances, Recommendation$_{ij}$ (CT_{ik}, CR_{ik}), Recommendation$_{ij}(CT_{jk}, CR_{jk})$ where $CT_{ik} \neq CT_{jk}$

5. Experimental Study

The experiment is applied over two datasets (Kelly & Knottenbelt, 2015) (ewood, 2016). The first dataset is an updated version of the dataset included in (Kelly & Knottenbelt, 2015) which is collected in the UK in the period from 2012 to 2017 representing the consumption of 5 houses for a total of 25 appliances with 970 million records. The second dataset (ewood, 2016) included 5 appliances' consumption in a resident. The experiment applied on the two datasets followed the 5-folds' strategy for the evaluation process.

In the first experiment, only five appliances are considered; they are the microwave, washing machine, TV, and boiler. As these appliances are not continuously used, the records included in the experiment are only those which had these appliances' consumption. According to this condition, the dataset has been reduced to 30 million records using a simple SQL query. To further minimize the data size for processing, the consumption has been grouped to represent the hourly rate instead of the minute unit rate, which further reduced the records to 500,000. The dataset was divided into 5 folds for processing. Apriori association rules mining algorithm is applied by an apriori tool (Land & Fischer, 2012) with the following settings:

- Required number of rules: 1000000.
- The metric to rank the rules: Confidence
- Minimum Confidence = 0.9
- Upper bound minimum support = 1.0
- Lower bound minimum support = 0.5

Remove missing values' records = checked.

According to the data sample under test, the priority sorting of the appliances (excluding the fridge) was as follows: microwave, washing machine, TV, and boiler. The A total of 23750 rules was generated. Focusing on the associations with confidence above 90% and focusing on the required schemas, 56 rules are considered strong associations and the behavioral schemas are highlighted. The sample is illustrated in table 1 and the results summary is shown in table 2.

Table 1. A Sample Association Rule for Each Schema

Schema	Example	Confidence
App_1-$house_i$,…, App_n-$house_i$ → App_m-$house_i$, App_k-$house_i$	Fridge1=40-50→ Microwave1=30-40 TV1=10-20	0.9333
App_1-$house_i$,…, App_1-$house_j$ → App_1-$house_k$, App_1-$house_m$	Washing machine1=0-10 Washing Machine2=80-90→ Washing Machine2=0-10	0.90323
$house_i$,…, $house_j$ → $house_k$, $house_m$	House1=200-300 House2=200-300→ House3=200-300	0.9524

A consumption threshold was set to minimize the maximum consumption rate with 10% as a primary test. A feature selection step is applied based on a mining technique to highlight the most effective appliances that have a high impact on the consumption rate. Then the associations are utilized to detect the main time, house and related appliances as a parameter to determine the downgrading plan.

Table 2. Results summary

No. of Required Rules	100000
No. of Generated Rules	23750
No. of Rules with Confidence > 90%	56
Average Confidence for the Selected Rules	93.7%

According to the data sample under test, the priority sorting of the appliances (excluding the fridge) was as follows: microwave, washing machine, TV, and boiler. Then the detected associations provided additional information. For example, a highlight on downgrading the microwave was presented by confidence of 92% in house 1.

Applying the explored associations on the consumption data has been performed. The results are then illustrated as follows: Figure 4 illustrates the appliances that will migrate down the current consumption for minimizing the consumption rate.

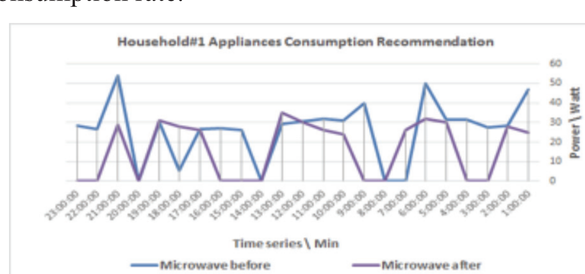

Fig. 4. The Present and Recommended Consumption Status in House 1

One of the main targets is to provide a collaboration map for the houses' appliances. The collaboration targets the sharing of the available appliances to minimize the consumption cost. As an example of following the associations of the washing machine, the recommended plan for washing machine consumption distribution for the house is illustrated in figure 5. The recommended plan was initiated based on the consumption rate of the washing machine in the houses for the provided dataset's time frame.

The explored associations on the second dataset are then applied. The association between the microwave and the TV is confirmed with a confidence of 90.1 % in this dataset, which provides a road map to the home appliances' usage. Figure 6 provides the whole road map for the house appliances in the second dataset.

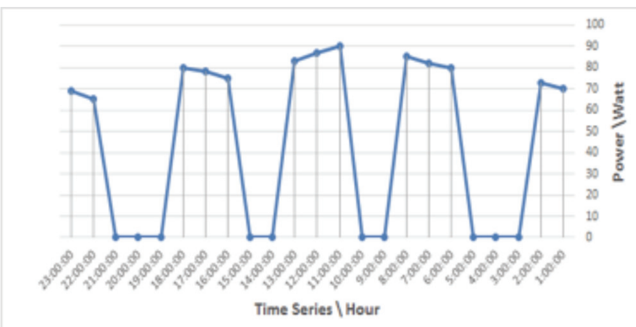

Fig. 5. Washing Machine Usage Recommended Plan

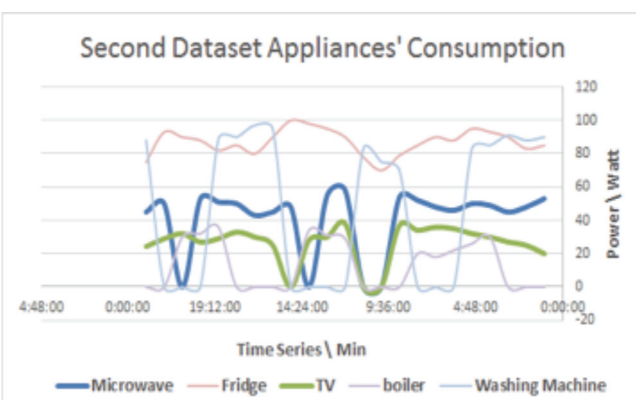

Fig. 6. Road Map for the House Appliances in the Second Dataset

6. Conclusion and Future Research

Energy consumption is a critical issue for all societies. It has been the focus of many studies in different perspectives; the industry role, the government role, and the technology role have all been considered. However, this research highlights the required role of individuals for contributing to the minimizing of energy consumption.

The authors argue that the collaboration among individuals is one of the successful approaches for saving energy, which depends on sharing the resources targeting to find the most suitable resources' usage. The research proposed a resources collaborative approach which aims at minimizing the energy consumption for individuals' houses. The main idea is to explore the effective relations among parties, including the individuals' behavior, the appliances' consumption, usage frequency, and time. Exploring the utilization map which illustrates these relations was the main contribution of this research. The research was based on detecting these relations by applying the associations rule mining, including the appliances' consumption rate over time, the overall consumption rate of the houses, the individual's behavior, and the usage peaks, as well as the usage gaps. The detected associations were the pillar of the proposed recommendations in minimizing the utilization behavior by providing two directions, proposing the utilization schema as well as detecting the appliances' peaks targeting to systematic recommendations in these peaks. The research aimed at applying the proposed approach on two datasets to prove its applicability. As a result, a total of 56 associations have been considered with a confidence average equal to 93.7%. according to the explored association. The recommendations are provided as a collaborative plan among the houses in appliances' operating with considering a set of criteria which included the individuals' usage timing and the appliances' peaks. The experiment evaluation reached an accuracy of 90.1% in the targeted plan.

The researchers propose different recommendations for providing more contributions in the same direction. The subject has many perspectives, from the technological view. The Internet of Things field is one of the efficient contributors in this direction, as the utilization map could be applied as the controller in the IoT schema with no human interference, which provides more efficiency in applying the required actions. From the scientific perspective, more experimental research could be applied to recent data covering different regional segments with more appliances' selections. Considering the appliances' natural relations is also a target instead of considering the appliances as individuals. Moreover, the inequality in the appliances' usage must be dealt with. Another direction is to consider the contribution of more mining techniques for providing a clearer exploration for the utilization map.

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