A real-time risk control and monitoring system for incident handling in wine storage


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ABSTRACT

Due to the fact that wine is highly sensitive to storage conditions such as temperature and humidity, it is a challenging task for a regional distribution hub to provide reliable wine storage facilities for maintaining wine quality during storage. This is especially true when an incident occurs unexpectedly that violates the criteria of suitable storage conditions. Improper incident handling and storage conditions may cause damage to the taste of wine, resulting in depreciation of the wine's value. Therefore, controlling and monitoring risk in real-time during wine storage is critical to providing a quick response to prevent the wine quality from deterioration. In this paper, a RFID-based risk control and monitoring system (RCMS), which integrates radio frequency identification (RFID) technology and case-based reasoning (CBR), is proposed for monitoring real-time physical storage conditions and for formulating an immediate action plan for handling incidents. In the retrieval process of the CBR engine, genetic algorithms (GA) are applied to search for case clusters by considering the best combination of multi-dimensional parameters. With the help of RCMS, a shortlist of critical control actions, possible causes of incidents and corresponding actions can be generated to reduce the risk of deteriorating wine quality and possible compensation costs being incurred, while customer satisfaction can be maintained.

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1. Introduction

In recent years, the global demand for wine has shifted from traditional wine consumption markets such as Europe and America to Asia, while the demand for wine is forecast to grow further in the coming years. However, due to lack of suitable conditions for wine production in most Asian countries, wine is usually imported from Europe markets to fulfill the increasing demand. Thus, the need for regional wine distribution hubs, that can serve a wide geographic region, has raised the concern to centralize business activities for achieving global economies of scale (Garcia, Marchette, Camargo, Morel, & Forradellas, 2012; Oum & Park, 2004).

Classified as a high value product, wine is expensive in price and of a high standard in terms of quality. Besides, in the current trend, wine is not only purchased for direct consumption, increasing demand is focused on long term investment and private collection. As shown in Fig. 1, wine can be classified into two categories, which are commercial wine and fine wine. Commercial wine is usually made for fast consumption and has a fast turnover rate and short storage time. Most fine wine is used for private collections and undergoes long term storage. Such wine may further improve its taste and quality by being stored under proper storage conditions. In addition, both of the wines are highly sensitive to both internal and external environments, and are especially affected by temperature, humidity, light and vibration. If they are not handled properly during storage and transportation, not only the taste of wine will be damaged, it could also cause depreciation of wine's value (Pullmand, Maloni, & Dillard, 2010). Therefore, having reliable wine storage facilities in a regional wine distribution hub is critical to maintaining the value and taste of wine along the wine supply chain. Based on the special characteristics of wine, the wine distribution hub should be (i) able to handle both commercial and fine wine at the same time, (ii) able to provide appropriate infrastructures that prevent excessive light and vibration affecting the quality of the wine, (iii) able to closely monitor the physical conditions of the storage area (i.e. temperature and humidity) to ensure the quality of the wine, and (iv) able to provide a quick response and take immediate action when any incident occurs.

Fig. 2 shows the existing incident handling problem caused by inadequate physical condition monitoring operations. According to HKQAA (2010), there are different temperature and humidity requirements specified for fine wine and commercial wine. The temperature for fine wine and commercial wine are 11–17 °C and 22 °C respectively while the humidity at any point inside the storage area are 55%–80% and smaller than 50% respectively.
the two categories of wine should be kept separately in designated locations where electronic sensors are installed in fixed places to continuously monitor the physical storage conditions. However, only the room temperature and humidity where the sensors are located can be measured while blind spots can still exist in a huge storage zone even with sufficient refrigerating facilities. If fine wine is put in the wrong commercial wine storage area, the existing sensor system is unable to notify and measure the actual temperature and humidity. The wine could then deteriorate rapidly and depreciate in value. On the other hand, as the actual physical conditions of particular wine cannot be measured in real-time conditions, the necessary action cannot be taken immediately if an incident occurs. Thus, the distribution hub may suffer loss. In addition, without the information on the possible cause of incident, it may take a long time to formulate follow-up action to mitigate such risks.

In this paper, a RFID-based risk control and monitoring system (RCMS), which integrates radio frequency identification (RFID) technology and the case-based reasoning (CBR) technique, is proposed to monitor real-time physical storage conditions and formulate a follow-up action plan when an incident occurs. By applying the RFID technology, temperature and humidity for each SKU of wine is captured and monitored in real-time so that immediate action can be taken when storage conditions change abnormally. Besides, CBR technology is applied to formulate an appropriate solution which includes corrective and preventive action plan by retrieving past relevant knowledge. With the help of RCMS, a shortlist of critical control actions, possible causes of incidents and corresponding actions can be generated to reduce the risk of deteriorating wine quality and possible compensation cost incurred while customer satisfaction can be maintained. This paper is organized as follows. In Section 2, literature related to recent developments in the wine industry, risk control and monitoring of quality measures, RFID and the CBR technique are studied. Section 3 presents the system architecture of RCMS. In Section 4, a case study is presented to demonstrate the implementation procedures of the system. In Section 5 the results and benefits of launching the system are discussed while a conclusion is drawn in Section 6.

2. Literature review

Wine has a unique and complex nature compared to other fast moving consumption goods as there is a specific wine production cycle, while the production highly depends on the climatic conditions, origin and quality of the grapes (Bernabeu, Brugarolas, Martinez-Carrasco, & Diaz, 2008; Getz & Brown, 2006; Hollebeek, Jaeger, Brodie, & Balemi, 2007). Regions that are able to provide suitable conditions for wine production are limited. Generally, wine can be classified into two categories according to the countries where it is produced, which are the "Old World" including France, Italy and Spain, and "New World" such as the United States, Australia, Chile and New Zealand (Campbell & Guibert, 2006). Other non-wine producing countries can only import wine to fulfill the increasing demand for wine (Somogyi, Li, Johnson, Bruwer, & Bastian, 2011). The wine supply chain has therefore shifted from the local market to external markets. Wines are shipped to target markets for consumption. Hence, the establishment of a regional distribution center to serve a wider geographic region is critical in order to lower the total logistics cost and increase the sales volume (Hussain, Cholette, & Castaldi, 2008; Cholette, 2009; Cusmano, Morrison, & Rabellotti, 2010). However, as there are strict requirements for handling wine, which is fragile and sensitive to the external environment, it is a challenge to manage the operational conditions during storage.

Different from general food and beverage products with a limited shelf life, wine has the special characteristic of aging potential
that allows it to be stored for a long time. Its value and quality may improve over time if certain reactions occur between chemical compounds and volatile substances in wine in a suitable environment (Parr, Mouret, Blackmore, Pelquest-Hunt, & Urdapilleta, 2011; Silva, Julien, Jourdes, & Teissedre, 2011). However, the composition of wine may also change for the worse under inappropriate storage conditions. In particular the quality of red wine can deteriorate easily (Blake, Kotseridis, Brindle, Inglis, & Pickering, 2010; Gomez-Plaza, Gil-Munoz, Lopez-Roca, & Martinez, 2000). According to previous studies, there are a number of factors that have a negative impact on wine quality, such as temperature, humidity, light exposure and vibration (Butzké, Vogt, & Chacon-Rodriguez, 2012; Chung, Son, Park, Kim, & Lim, 2008; Gomez-Plaza, Gil-Munoz, Lopez-Roca, & Martinez, 1999). These factors bring potential risks that may affect the wine quality. It is important to control and manage these risks in the storage environment to maintain the quality of wine during storage (Marin, Jorgensen, Kennedy, & Ferrier, 2007; Verdu Jover, Montes, & Fuentes, 2004). In addition, different types of wine have particular logistics activities and storage specification, which further increase the risk for quality deterioration (Dollet & Diaz, 2010; Roy & Corderoy, 2010). However, most of research focuses on how the composition of wine changed under different storage conditions; studies related to managing risks under storage conditions and to maintaining the quality of the wine, are limited. Particularly, when an incident occurs unexpectedly that violates the storage criteria, the product quality is likely to deteriorate and cause depreciation in value. Providing a quick response with respect to corrective and follow-up actions is essential to reduce loss in wine quality and to maintain customer satisfaction. With such limited time available for formulating an immediate action plan to deal with the incidents, it is hard to find out the cause of incidents and evaluate whether the wine is affected, without appropriate guidelines being given at the time. Thus, past similar record and prior knowledge become important to provide quick and reliable reference for decision making in the current situation.

Case-based reasoning (CBR) is one of the problem-solving techniques which have the capability of self-learning to improve decision making. CBR captures prior experience and turns it into explicit knowledge in the form of problem description and solutions which is expected to be useful for solving new problems (Craw, Wiratunga, & Rowe, 2006). CBR is widely adopted to solve various types of problem, including both risk and non-risk problems (Kim, Im, & Park, 2010; Li & Sun, 2011; Oztekin & Luxhoj, 2010). According to Castro, Navarro, Sanchez, and Zurita (2011), CBR is a useful tool to solve problems with associated risk, as past similar situations can be retrieved to reduce significant error and the chance of the incident leading to serious consequences. Goh and Chua (2009) applied the CBR approach to construction hazard identification in which the past knowledge is presented in the form of incident cases and risk assessment methods. Yurin (2012) proposed using CBR as an effective and successful aid to solving problems in the prevention of repeated failures in the safe operation of mechanical systems. Chow, Choy, Lee, and Lau (2006) applied CBR to formulate the most suitable resource usage packages for handling warehouse operation orders and found that the proposed CBR engine can retrieve and analyze useful knowledge in a time saving and cost effective manner. However, the case retrieval process relies mainly on the input of data, inaccurate records may be obtained if wrong data is input manually. In addition, the CBR approach has not been integrated with any identification technology. This means it may not be able to formulate a solution promptly for an urgent situation that requires a quick response. With the fact that wine handling is sensitive to the external environment, therefore, it is vital to integrate CBR with real-time monitoring technology of its storage conditions so that immediate action can be provided when unusual situations arise.

Radio Frequency Identification (RFID) is one of the emerging technologies that allows automatic identification and real-time data capturing (Grununger, Shapiro, Fox, & Wepner, 2010; Sarac, Absi, & Dauzere-Peres, 2010). It can detect and identify objects by transmitting radio wave signals to enable communication between reader and tags. This technology has been adopted in various industries to reduce inventory losses (Bottani & Rizzi, 2008; Deh-oratius & Raman, 2008), increase the operations efficiency (Chow et al. 2006; Poon, Choy, & Lau, 2009) and improve information accuracy (Agrawal, Sengupta, & Shanker, 2009; Delen, Hardgrave, & Sharda, 2007; Piramuthu, 2007). In order to detect and prevent quality problems, Lyu, Chang, and Chen (2009) designed a quality assurance system by the adoption of RFID to inspect product quality so that the production process can be monitored in real-time. Lao et al. (2012) proposed a RFID-based food operations assignment system with passive tags on incoming food to help the distribution center to control food safety activities such that the inventory quality can be improved significantly. Apart from identifying tagged objects, RFID tags with sensor embedded have been developed recently to capture various real-time data such as temperature and humidity (Abad et al., 2009; Amador & Emond, 2010). Such technology is useful when handling goods such as perishable products, fresh food and pharmaceuticals, that are sensitive to the storage and transportation environment (Cakici, Groenevelt, & Seidmann, 2011; Jedermann & Lang, 2007). As temperature is the most critical factor affecting the safety and quality of perishable foods, Kang, Jin, Pyou, and Lee (2012) developed a RFID sensor tag-based cold chain system to keep track of the timestamps and temperature data of frozen foods during storage and transportation. Wine, is one of the most valuable goods which is also sensitive to the external environment. It is worth applying RFID technology to the real-time monitoring to wine to prevent quality deterioration because it is one of the most profitable fast moving consumer goods (Sellitto, 2009). Hu and Cole (2010) suggested embedding the RFID tag into the plastic cover of the bottle closure such that bottle packaged wine products can be detected efficiently using the UHF RFID system. Singh, Li, and Li (2011) applied the RFID tags on the wine bottles to ensure security and privacy protection of wine during the transportation process. Wang, Kwok, and Ip (2012) proposed an RFID-based quality evaluation system to monitor the whole wine supply chain where all information from wine production to sales in market is recorded to prevent counterfeit. However, most of the research only applied RFID technology in wine for anti-counterfeit and information tracking within the supply chain. The consideration of temperature and humidity measures with RFID technology to ensure appropriate conditions for wine storage is limited.

With the above studies, it can be concluded that wine handling with special care is required to maintain the wine quality during storage due to its uniqueness, high value and high sensitivity to the external environment. In order to avoid the risks from wine deterioration when incidents occur, this study attempts to integrate RFID technology with CBR to develop the RFID-based risk control and monitoring system (RCMS) for incident handling in wine storage.

3. RFID-based risk control and monitoring system (RCMS)

In this section, a RFID-based risk control and monitoring system (RCMS) is presented to monitor the wine storage conditions such as temperature and humidity in real-time, and formulate an immediate action plan when incidents occur. Fig. 3 shows the system architecture of RCMS. The first module is the front-end module
which is used to capture the SKU details and storage information using RFID technology such that the physical conditions of wine can be monitoring in real-time. The second module is the back-end module which comprises two tiers: (i) Tier 1 – data sorting and (ii) Tier 2 – follow-up action plan formulation.

3.1. Front-end module: real-time data capturing

In this module, the RFID technology is applied to collect real-time wine storage conditions to visualize the current status of each SKU. As wine is highly sensitive to temperature and humidity, a semi-passive RFID tag with temperature and humidity sensors is attached to each SKU of wine to report the current storage conditions to the system. The tag contains a built-in power battery that uses its own power source to emit signals and communicate with the RFID reader. However, the battery is usually used to assist in collecting environmental parameters using the sensor. Unlike general passive RFID tags, semi-passive tags can avoid the chance that the important data is missed due to insufficient energy received to give a response to the reader. In order to effectively monitor the storage conditions of wine, two types of data are stored in the RFID tag, which are static and dynamic data. Static data refers to the details of the SKU that is stored in the tag during the inbound operations such as SKU number, type of wine, physical dimension of SKU, quantity and vintage year. Dynamic data refers to the data of storage conditions including temperature and humidity. This type of data varies over time. With such information, the storage conditions for each SKU can be noticed even though wine is placed in the wrong storage area. Fig. 4 shows the setting of RFID equipment for real-time data capturing.

3.2. Back-end module: data management

Data collected in the front-end module is passed to the back-end module for data management. By identifying the data that may violate the control measures of wine storage, the risk level is evaluated and follow-up action is formulated. In addition, a shortlist of critical control actions, possible causes of incidents and corresponding actions can be generated to reduce the risk of the wine deteriorating.

3.2.1. Tier 1 – data sorting

In this tier, the data collected by the RFID technology is first passed to the middleware to decode the electronic signals and transform them into meaningful information, such as item number, type of wine, temperature and humidity data, and date/time of measurement. Hence, data is stored in the database as a record. On the other hand, as there are different specifications in temperature and humidity for fine wine and commercial wine, the requirements for each type of wine are also recorded in the database. By comparing the real-time temperature and humidity data collected with the specifications required for storage, notification
can be given if there is a large fluctuation range or if the current temperature or humidity exceeds the allowable range and will probably cause the wine to deteriorate.

3.2.2. Tier 2 – follow-up action plan formulation

With the physical data obtained by the RFID technology, the new incident data is passed to the case-based reasoning engine, which performs the process of case retrieval, case reuse, case revision and case retention, for follow-up action planning. In order to divide past cases into different clusters with similar characteristics, multi-dimensional attributes are taken into consideration. Hence, the case retrieval model proposed in Lam, Choy, Ho, and Chung (2012) is applied here to formulate a feasible corrective and preventive action plan.

(i) Case clustering by GA approach.

In the case-based reasoning engine, past cases stored in the case library are divided into clusters by using the GA k-mean clustering approach which prevents the searching process falling into the local optima. Fig. 5 shows the mechanism of case clustering using the GA approach.

(a) Chromosome encoding and population initialization

The environmental parameters including temperature and humidity are important to the maintenance of a good condition for red wine storage. The loss in quality and value can be reduced if appropriate follow-up action can be formulated when an incident occurs unexpectedly. Therefore, a hierarchical tree structure based on the wine storage conditions in the distribution hub and wine information is constructed for chromosome encoding. As shown in Fig. 6, the wine storage conditions refers to the real-time physically measured factors such as temperature, fluctuation in temperature and humidity while wine information refers to the details of the SKU that may be affected by the incident such as wine quantity and value.

The attributes of past incident cases are shown in the form of a hierarchical tree structure. Now the values of each attribute should be determined in order to divide similar past cases into clusters. As the first step of GA operations, the chromosome is encoded to represent the case features and values of the cluster centers. The chromosome is divided into two parts which are (i) the dimensions (D) and parameters (P) region, \( F_{x_1, x_2, \ldots, x_6} \), and (ii) case-value (V) region, \( V_{x_1, x_2, \ldots, x_6} \). The dimensions and parameters region is encoded with binary numbers to denote whether the parameters are included as a key features in the cluster. The case-value region is encoded with real numbers which shows the numeric value of the corresponding parameter. Both the dimensions and parameters region and case-value region are repeated by the number of clusters pre-defined, \( n \), to form a chromosome. Fig. 7 shows a chromosome containing \( n \) clusters, with \( a \) dimensions and \( b \) parameters in each cluster. After that, the population size, \( s \), is defined to control the number of chromosomes selected for generations.

(b) Fitness function evaluation

Once the population of chromosomes is formed, the fitness value for each chromosome is calculated to evaluate the case similarity for the assigned case cluster. In order to divide cases into groups, the fitness function minimizes the weighted distances between past cases and the cluster center, and takes into consideration the importance of the parameters as shown in Eq. (1)

\[
\text{Min} \sum_{i=1}^{n} \sum_{k=1}^{P} \sum_{l=1}^{b} \sum_{p=1}^{a} \sqrt{z_{ik} \times (O_{i,k}; x_1, x_2, \ldots, x_6) - R_{i,k}; x_1, x_2, \ldots, x_6} \times A_l
\]

(1)

\( z_{ik} \) is a binary number where \( \sum_{i \in P} z_{ik} = 1 \), \( \forall k \in P \), so as to limit the number of past cases that can be classified into one cluster only. \( z_{ik} \) is equal to 1 if the case \( k \) belongs to cluster \( i \), otherwise, \( z_{ik} \) is equal to 0. \( O_{i,k}; x_1, x_2, \ldots, x_6 \) refers to the case parameters and their values in the \( k \)-th case record, while \( R_{i,k}; x_1, x_2, \ldots, x_6 \) represents the \( i \)-th cluster center with the value of \( F_{x_1, x_2, \ldots, x_6} \times V_{x_1, x_2, \ldots, x_6} \). As this
algorithm can be applied to select multi-dimensional attributes and search for the best combination of attributes, the distance is expected to be large if more attributes are considered together. Therefore, an adjustment factor \( A_i \), \( A_i = \frac{\text{total number of case parameters}}{\text{number of case parameters considered}} \), is proposed in the fitness function to compensate for the value increase when more than one case parameter is considered at the same time. Prior to the fitness function evaluation, it should be noted that bias may occur when calculating the fitness of attributes in a different range. The distance between the cluster center and the attribute with a large range of value is always larger than the attribute with a small range of value, which limits the chance for consideration. Therefore, the values of each attribute should be normalized first to avoid large differences between different attributes. This is calculated with Eq. (2).

\[
x_{ab}' = \frac{x_{ab} - y_{\min}}{y_{\max} - y_{\min}}
\]  

(c) Genetic operations

In order to provide new offspring for GA generations, crossover and mutation are two methods that are commonly used. Crossover operates by exchanging some of chromosomes with others. Random numbers between 0 and 1 are generated for each chromosome in the population. The chromosome with a random number that is smaller than the crossover probability is then selected to perform crossover with another parent chromosome to form the offspring. Unlike crossover, mutation is performed within the gene of the chromosome. By generating random numbers to select the gene to perform mutation, the value of the selected gene is changed according to its property. The value is changed between 0 and 1 if the region for binary numbers is selected while a random number with the pre-defined range is generated for the value with real numbers. After crossover and mutation, the chromosome is then repaired to remain consistent with the solution. The fitness function of the new chromosome is evaluated again to check if it can overcome all constraints and has a smaller value of fitness value.
(d) Termination criteria and case assignment.

The GA process is stopped when it meets the pre-defined termination criteria. In this study, the number of generations is selected as the criteria to control the process so that the chromosome with best fitness value is generated once the maximum number of generations is reached. The output of the chromosome provides the result of the cluster centers, including which parameters are considered in the cluster and the value of the corresponding parameters. In such cases, past cases are divided into clusters by assigning them to the cluster the smallest distance.

(i) Case retrieval

After dividing the past cases into clusters, the cluster, which contains the greatest number of past similar cases, with the greatest number of features that are similar to the features in the new incident problem, can be selected using Eq. (3).

\[ \sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} \text{sim}(O_i, O_{new}) \]

where \( w_{ij} \) refers to the weighting defined for the case parameter and a larger number is assigned to indicate the high importance of the case parameter; \( \text{sim}(O_i, O_{new}) \) denotes the similarity value for the parameter value of Cluster \( O_i \) and new problem \( O_{new} \). The similarity value is equal to zero when the parameter compared is not included as the cluster center. By calculating the similarity value between each case cluster and new problem, the case cluster with the largest similarity value is retrieved.

(ii) Case reuse

The potential cases are then ranked in descending order according to their similarity to the new problem. For the similarity measures, both textual and numeric parameters are considered and it is calculated by Fig. 4.

\[ \sum_{i=1}^{n} \sum_{j=1}^{m} w_{ij} \text{sim}(O_i, O_{new}) \]

For textual parameters of past cases \( O_i \) in cluster \( i \) and new problem \( O_{new} \), the similarity value is measured by the construction of similarity table among various attributes, while the similarity for numeric parameters is calculated based on the distance between two values. The past case with the highest similarity value is retrieved as the most significant case for action formulation. Other cases with lower similarity values can serve as a reference only in the revision stage.

(iii) Case revision

With the most similar past case retrieved by the CBR engine, the problem situation found in past incident records and its corresponding follow-up action is listed for suggestions. Modifications such as editing the solution can be carried out if necessary to fit the actual situation.

(iv) Case retention

Once the action plan for new incident problem is formulated, the revised report and new case details including the problem situation are sent to the case library for storage. It then serves as a past reference case for future use.

4. Case study

In order to validate the performance of RCMS, a pilot test was carried out in a Hong Kong-based logistics company that specializes in wine storage and distribution services. The company has established its own wine warehousing facilities, which can hold up to 30,000 cartons of wine, to consolidate the wine imported from overseas and distribute it to the local market. It is certified under the HKQAA for both fine wine and commercial wine storage. Designated areas are assigned to store the wine as it has to be kept under different temperatures and different ranges of humidity. Currently, the company relies on electronic sensors to monitor both the temperature and humidity measures in the storage areas. However, as the electronic sensors are installed in fixed locations, only the room temperature and humidity can be measured which cannot reflect the actual wine storage conditions. In addition, there is a lack of wine identification technology in the storage area. Once the wine is stored in the wrong area where the physical conditions are not appropriate for storage, the wine can deteriorate easily. Besides, it is hard for the staff in the wine warehouse to notice the deterioration of wine until a periodic stock check is performed and, therefore, it takes a long time for them to respond. As wine is one of the most valuable goods which are very sensitive to storage conditions, controlling and managing the kind of risks mentioned is the most important factor in reducing the product defect rate and in maintaining customer satisfaction. Thus, the proposed system, RCMS, is implemented in the company to keep track of the wine status and provide follow-up action when necessary.

4.1. Roadmap of RCMS implementation

As shown in Fig. 8, the implementation roadmap of RCMS consists of four main steps. By setting up the RFID equipment in the wine warehouse, real-time inventory information with temperature and humidity measures can be obtained to monitor the storage conditions. Once the environmental measures exceed the allowable range, an incident alert is given and the information is passed to the CBR engine to search for past similar follow-up action plans.

(i) Step 1: Physical set up of RFID equipment.

In order to obtain the real-time data in the storage environment, RFID equipment including the RFID reader, antenna and passive RFID tags with temperature and humidity sensors, are set up in the wine warehouse. Fig. 9 shows the RFID setting in the wine

![Fig. 8. Implementation roadmap of RCMS.](image-url)
distribution hub. As shown in the figure, wine is stored in the wooden cartons and it is usually packed in the same carton for delivery. In order to keep track of the actual storage conditions of the wine, the RFID tag with temperature and humidity sensors is attached to the wine carton so that the wine information and storage location can be recorded automatically by the reader. The RFID reader and antenna are installed in each level of the storage rack so that the whole area can be covered by the RF emitted by the antenna. The RFID tag records the temperature and humidity data continuously and transmits the stored data to the reader when it receives RF signals from the antenna. The information is then compared with the defined order specification to ensure that the storage conditions meet the requirements. Table 1 shows the storage specification for fine wine and commercial wine in HKQAA standard. If either one of the environmental measures exceeds the allowable range, an incident alert is given (in Fig. 10) and the information is passed to the CBR engine to search for past, similar, follow-up action plans.

(ii) Step 2: Construction of CBR engine.

When constructing the CBR engine, two types of information are required which are specific parameters for case clustering and the weighting to show the importance of parameters for case retrieval. Using the case clustering by GA approach, past cases stored in the case library are first divided into five clusters based on five key numeric parameters, namely: temperature, fluctuation in temperature, humidity, quantity and total wine value. In order to avoid large differences between parameter values, data in the past cases are normalized so that they range from 0 to 100. Fig. 11 shows the processing status of case clustering using the GA approach. Software evolver, developed by the Palisade Corporation, is adopted to search for the optimum cluster centers in MS Excel. In the dimensions and parameters region, binary numbers of 0 and 1 are allowed for adjustment to indicate whether the parameter is considered as the cluster center or not. In the case-value region, real integer numbers between 0 and 100 are used to limit the range for crossover and mutation. Eq. (1) is applied in the MS Excel to minimize the fitness function for the GA search. The adjustment index, $A_i$, is set as 5, 3, 1.5, 1.2 and 1 respectively for considering up to five parameters together. The parameter settings for GA generations are defined as follows: population size = 200, number of generations = 2000, crossover rate = 0.9 and mutation rate = 0.05.

To obtain the minimum fitness value, GA searches for the best combination of case parameters and their corresponding normalized values and uses these to create the centre of the cluster. Table 2 shows the result of five cluster centers after performing 2000 generations with GA. Take cluster 1 as an example, it shows that only the parameters “Temperature”, “Humidity” and “Quantity” are significant to represent the center of case cluster 1. The values which correspond to the three parameters are 52, 21 and 58 respectively. The centre of each cluster is represented by a different set of parameters and values, which successfully divides the past cases into five groups.

(iii) Step 3: Case retrieval.

With the data captured by the RFID technology, the wine information such as the name, type of wine and storage conditions including temperature and humidity values are obtained. This
information is then compared to that of the five cluster centers to find out the cluster with the largest similarity value by Eq. (3). Table 3 shows the importance of the parameters assigned to the new case and Fig. 12 shows the case retrieval process of RCMS. The similarity value of the new problem and cluster 4 is found to be 0.83, which is the highest value among all clusters. Therefore, past cases in cluster 4 are retrieved and they are ranked in descending order based on their similarity value to the new problem.

(iv) Step 4: Case revise and retain.

Fig. 13 shows the procedure for follow-up action plan formulation by retrieval of a past similar reference case. The case ranked with the highest similarity value is considered as the most significant solution to the new problem. The solution to the past case can be modified to be the new action plan for the new situation. The additional and missing checking steps for finding the root cause can be added while some redundant information can be removed to suit the current needs. After designing the appropriate solution for the new problem, the case is saved and stored in the case library as a case for future use.

5. Results and discussion

To verify the contribution of the RCMS, the prototype was developed and given a trial run in the wine warehouse of the case
company. During the period of the trial run, previous incident handling records from the past two years are first input into the system as past reference cases. With such preliminary work, the past cases can be classified into a number of groups according to the need of efficient retrieval. Through the case clustering process, multi-parameters for indexing the case were considered to obtain the significant parameters with corresponding values for each case group. It allowed the wine warehouse manager to have better knowledge of the key features of each case group that led to the incidents.

5.1. Advantages of RCMS

With the help of RCMS, it is found that the performances in follow-up action formulation and customer satisfaction are improved and do reduce the risk of deteriorating wine quality.

(i) Improvement in follow-up action formulation.

Table 4 shows the improvement in formulating the follow-up action plan. With the adoption of RFID technology, the incident affected area can be easily located by the RFID tags attached to the wine cartons. Compared with the previous practice where electronic sensors are set in fixed places to measure the storage condition for a larger area, the time to locate the wine that may be affected by the incident is reduced by 83.3%. This is because the RFID technology provides such information up to an item level so that the wine cartons with abnormal measures can be easily identified. Besides, with the help of the CBR engine in the RCMS, the time required to formulate a follow-up plan is reduced significantly. The manager no longer needs to spend much time to create the shortlist of critical control actions, possible causes of incidents and corresponding actions manually. Instead, such information can be generated by retrieving past similar cases as a reference.

(ii) Improvement in customer satisfaction and reduction in wine damage.

The RCMS allows the real-time storage conditions to be measured and provides an action plan to effectively manage the

Table 3

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Type of parameters</th>
<th>Rank</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Numeric</td>
<td>Most important</td>
<td>1</td>
</tr>
<tr>
<td>Fluctuation in</td>
<td>Numeric</td>
<td>Less important</td>
<td>0.5</td>
</tr>
<tr>
<td>Humidity</td>
<td>Numeric</td>
<td>Least relevant</td>
<td>0.1</td>
</tr>
<tr>
<td>Quantity</td>
<td>Numeric</td>
<td>Least relevant</td>
<td>0.1</td>
</tr>
<tr>
<td>Value</td>
<td>Numeric</td>
<td>Less important</td>
<td>0.5</td>
</tr>
<tr>
<td>Type of wine</td>
<td>Textual</td>
<td>Important</td>
<td>0.7</td>
</tr>
<tr>
<td>Country of origin</td>
<td>Textual</td>
<td>Relevant</td>
<td>0.3</td>
</tr>
<tr>
<td>Storage zone</td>
<td>Textual</td>
<td>Less important</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Fig. 12. User interface of RCMS for retrieving similar past cases.
risk incurred. Table 5 shows the improvement in customer satisfaction and reduction in wine damage. Before the launch of RCMS, it took longer for the staff to notice the deterioration of wine as there was no control to ensure that the wine was stored in the right storage area until the periodic stock taking process was carried out. With the use of RCMS, the RFID tag can be used to keep the item and location information. An alert is provided if the wine is placed in the wrong location and if the measured storage condition is out of the allowable range. Thus, the damage frequency of wine and the number of customer complaints are also reduced by 87.5% and 66.7% respectively.

5.2. Discussion on the case clustering approach

The case clustering approach applied in the case based reasoning engine divides past cases stored in the case library into groups by considering multi-dimensional parameters while the best combination of parameters for the groups is selected. During the clustering process, GA has to search whether or not the parameters are included as key features in the cluster. Therefore, the number and type of parameters included in each cluster is different. In order to show that the selection of different parameters for each cluster can improve the performance in retrieving past similar cases, a test was carried out to compare the similarity value of cases retrieved the two approaches. Figs. 14 and 15 show the result of five cluster centers where different combinations of parameters and all five parameters respectively were considered. The similarity measures for selecting the case cluster with the highest value among the two approaches were calculated. As shown in Table 6, it was found that

<table>
<thead>
<tr>
<th>Case ID</th>
<th>Type of Wine</th>
<th>Similarity Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>T110219</td>
<td>Fine Wine</td>
<td>85%</td>
</tr>
<tr>
<td>T129031</td>
<td>Fine Wine</td>
<td>92%</td>
</tr>
<tr>
<td>T117283</td>
<td>Commercial Wine</td>
<td>89%</td>
</tr>
<tr>
<td>T102734</td>
<td>Fine Wine</td>
<td>89%</td>
</tr>
<tr>
<td>T091863</td>
<td>Commercial Wine</td>
<td>85%</td>
</tr>
</tbody>
</table>

Table 5

Improvement in customer satisfaction and reduction in wine damage.

<table>
<thead>
<tr>
<th>Before (manual)</th>
<th>After (with RCMS)</th>
<th>Percentage of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damage frequency (number of incidents of deteriorated wine per month)</td>
<td>120</td>
<td>15</td>
</tr>
<tr>
<td>Customer complaints due to slow response (per month)</td>
<td>6</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 13. Formulation of follow-up action plan using a past reference case.
the clusters selected were different for the two approaches. In the first approach that considers different combinations of parameters as the cluster center, cluster 4 is selected with 83.1% similarity. For the second approach that considers all five parameters, cluster 5 is selected with the highest value. Besides, the result also shows that the similarity measures of the five clusters and new case in the
second approach are similar in that they range from 69% to 82%. It is difficult to decide whether the cases belonging to the selected cluster are suitable for solving the new problem. After that, the potential cases are ranked in descending order by comparing the similarity between new problem and the selected case cluster. Fig. 16 shows the result of a comparison of the case clustering approach with and without considering different combinations of parameters. It is found that the average similarity value for the first approach that considers different combinations of parameters is 88% while the average similarity value for the second approach is 79%. The past cases retrieved in the case cluster with different combinations of parameters also get a higher value compared to that with no selection on the set of parameters. Therefore, the result shows that the performance in retrieving past similar cases by the clustering approach with the consideration of parameters selection for the groups is better than that without parameter selection.

6. Conclusion

Wine is recognized as one of the high value products, is well-known to be expensive and requires special care to maintain its quality during storage. It is highly sensitive to the storage environment and needs to be kept under specific conditions. Sudden change that violates the storage criteria may be a risk for wine quality deterioration and value depreciation. Therefore, reliable storage facilities with appropriate risk management procedures in place are crucial for providing a stable and suitable environment for wine storage. However, formulating the follow-up action plan for incident handling in order to mitigate the effect caused by such risks is always a challenge to wine distribution hubs. This paper has proposed a RFID-based risk control and monitoring system (RCMS) that integrates radio frequency identification (RFID) technology and the technique of case-based reasoning (CBR) to monitor real-time physical conditions and formulate immediate action plans for coping with incidents. The RFID tag with temperature and humidity sensor allows the actual storage condition of each SKU of wine to be measured while general information about the wine and its location can also be captured so that the wine cartons with abnormal measurements can be found easily. With the knowledge-based CBR engine, a shortlist of critical control actions, possible causes of incidents and corresponding actions can be generated based on past similar incident cases. By launching the RCMS, effective follow-up action plans can be formulated, and improvement in customer satisfaction and reduction in the wine damage rate can be achieved.

Table 6
Similarity measures for retrieving case clusters with the two approaches.

<table>
<thead>
<tr>
<th>Weighting</th>
<th>Temperature Fluctuation in temperature</th>
<th>Humidity</th>
<th>Quantity</th>
<th>Value</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Case</td>
<td>1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

(i) Considering different combinations of parameters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Weighting</th>
<th>Temperature Fluctuation</th>
<th>Humidity</th>
<th>Quantity</th>
<th>Value</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>52</td>
<td>–</td>
<td>21</td>
<td>58</td>
<td>–</td>
<td>43.5%</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>75</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>88</td>
<td>52.7%</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>46</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>32</td>
<td>51.7%</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>65</td>
<td>8</td>
<td>–</td>
<td>–</td>
<td>66</td>
<td>83.1%</td>
</tr>
<tr>
<td>Cluster 5</td>
<td>57</td>
<td>61</td>
<td>71</td>
<td>40</td>
<td>–</td>
<td>60.6%</td>
</tr>
</tbody>
</table>

(ii) Considering all five parameters

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Weighting</th>
<th>Temperature Fluctuation</th>
<th>Humidity</th>
<th>Quantity</th>
<th>Value</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cluster 1</td>
<td>59</td>
<td>31</td>
<td>42</td>
<td>61</td>
<td>29</td>
<td>81.4%</td>
</tr>
<tr>
<td>Cluster 2</td>
<td>47</td>
<td>56</td>
<td>23</td>
<td>32</td>
<td>23</td>
<td>69.5%</td>
</tr>
<tr>
<td>Cluster 3</td>
<td>38</td>
<td>15</td>
<td>64</td>
<td>46</td>
<td>60</td>
<td>77.7%</td>
</tr>
<tr>
<td>Cluster 4</td>
<td>49</td>
<td>54</td>
<td>20</td>
<td>66</td>
<td>69</td>
<td>79.6%</td>
</tr>
<tr>
<td>Cluster 5</td>
<td>54</td>
<td>57</td>
<td>57</td>
<td>51</td>
<td>70</td>
<td>82.3%</td>
</tr>
</tbody>
</table>

Fig. 16. Comparison of the case clustering approach with and without considering different combinations of parameters.
Acknowledgement

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References


