A novel solution for counterfeit prevention in the wine industry based on IoT, smart tags, and crowd-sourced information

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1 Introduction

In the era of fast-moving consumer goods (FMCG) there is a world-wide problem of counterfeit products and brands [1]. The wine industry is not an exception and counterfeit wine is a real problem both for wine makers and wine consumers [2,3]. Counterfeit wine affects the wine maker's reputation and profit, but it can also be harmful for the consumers. The analysis of the wine market worldwide shows that the share of counterfeit market in wine industry falls in range of 0.2% to 1%, and some estimates go as high as 4-5% [4,5]. Even more dramatic estimates come from China where the market share of counterfeit wine imported from Europe is estimated to be around 20% and in some instances even higher, while wine consumption is on the rise making China the fastest growing wine market, ahead of the US and Russia [3,6,7].

The most common way of wine counterfeiting is printing a fake label which resembles an original wine label with subtle changes in brand name and company logo in order to fool wine consumers. Sometimes, counterfeiters use the authentic labels removed from more expensive wines and place them on cheaper wine with similar bottles. Finally, in some situations the drink inside bottles is fake wine, which poses a big health concern, as well [7]. This is a real problem in Montenegro, as well as the rest of Southeastern Europe, which was one of the main motivations for this project. Figure 1 illustrates examples of counterfeits of Montenegrin wines being sold in the Western Balkans and Eastern Europe. In these instances, labels with similar appearances to the originals were used. An especially peculiar example is a 5 liter bottle of the wine that was never sold in 5 liter packaging.

Food security is a major issue and it is becoming more and more critical due to the increase of the world population and the current way of agriculture production [8,9]. The Internet of Things (IoT) technology is a new game changer in agriculture and the overall food supply chain. Combined with other information technology (IT) mega-trends, it will play a key role in the digital transformation of farming and food production by using smart networks of connected objects that can be identified, sensed, and controlled remotely [10-12]. The main developments of IoT applications in food production and delivery are expected in precision agriculture, food tracking and tracing, safety and quality management, food processing and manufacturing, and consumer food awareness [8]. Food traceability systems, often forced by relevant laws, are typically still achieved using conventional systems, within a single company or a specific part of the food supply chain using basic technologies and paper trails [13].

Figure 1. Examples of Montenegrin counterfeit wines sold in the Western Balkans and Eastern Europe (images obtained from the company 13. jul Plantaže).

The need to fight against counterfeit goods in the global supply chain is very well recognized and various techniques and technologies to approach this problem have been proposed [1,2]. These techniques are applicable in the wine industry [2,14]. There are RFID-tag based solutions that may be highly platform dependent, as RFID readers are not broadly available [15,16]. On the other hand, ink-based solutions are much more flexible in terms of implementation [17,18], but they are easier to imitate [14]. Some researchers propose the use of solutions based on fluorescence materials [19] or random patterns [20], but there is a lack for wider support for these techniques. A wine track and trace solution based on reading individual wine bottle numbers using OCR technique is possible, but the drawback is accuracy of the readings and the use of various fonts and numbering schemes for different types of wines [21]. Systems for product traceability and anti-counterfeiting based on the use of QR codes are well received by the consumers and they usually require only a smartphone with a camera [22,23]. Blockchain technology is also finding it's use in supply chain management applications [24,25], and its distributed ledger technology could provide for an alternative to cloud based systems in the near future.

This paper describes the implementation of a pilot project that uses a combination of techniques to implement a system for brand protection and counterfeit prevention in the wine industry. The approach is driven by the IoT, cloud storage and data analysis, mobile apps, and specially designed smart tags based on dynamic QR codes. The use of smart tags creates an ecosystem of connected objects, where each product instance is identifiable, leveraged by technology provided by the Horizon 2020 TagItSmart! project [26,27]. Please note that traditional barcodes identify the type of product but do not provide information about the individual items [28]. It is worth mentioning that the GS1 Digital Link Standard has been co-developed in TagItSmart! project and and offers brands the use of a QR code, radio-frequency identification (RFID), near-field communication (NFC), and even Bluetooth to deliver information to their customers [29]. The idea behind the standard is to provide web-enabling barcodes in order to enhance the shopping experience for consumers, strengthen brand loyalty, and improve supply chain traceability and efficiencies.

The novelty of the use of smart tags is that everyday mass-market objects that are not normally considered a part of IoT ecosystem can be equipped with smart tags allowing them to dynamically change their individual status depending on the environmental changes [30,31]. Another important aspect of the presented approach is the human-centric sensing enabled by the ubiquitous presence of smartphones with their cameras [32]. The solution provides a mobile app that interacts with consumers in a way that every time users scan a QR code uniquely identifying a product instant (i.e. wine bottle), they provide an update on the status and location of that particular bottle. Therefore, each bottle is individually tracked and traced throughout the supply chain and these information updates can be used to identify whether there is a potential counterfeit issue with that particular bottle.

2 System objectives and implementation approach

The main objective of the pilot system described in this study was to combine tools and technologies aimed at brand protection, digital products, and life cycle management provided by the TagItSmart! ecosystem in order to create a solution for counterfeit prevention in the wine industry (Figure 2). Using a simple mobile app, with just a few clicks, the end user, in this case the wine consumer, can differentiate the original and counterfeit wines that may appear as identical products, while simultaneously providing the wine maker with alerts, location, and statistics on their product authenticity issues.

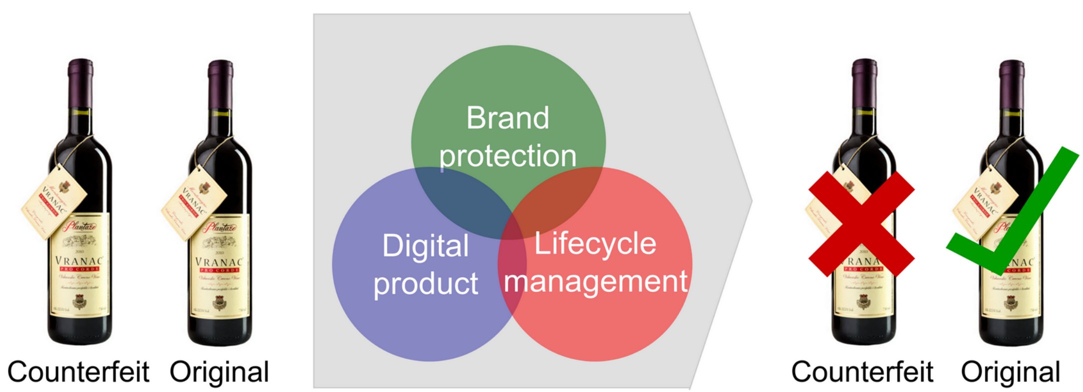

Figure 2. Counterfeit wine detection based on tools for brand protection, digital product, and life cycle management.

The proposed system improves brand protection and wine counterfeit detection and illustrates the use case for a large wine maker. Project goals included the technical analysis and evaluation of the components and performance of the selected technology. In addition, the pilot system was used to consider business models and projections for the use of this system by regional wine makers of all sizes.

2.1 Concept and approach

The concept and approach to implementation considered the end-to-end life cycle of wine and various points in wine production as depicted in Figure 3.

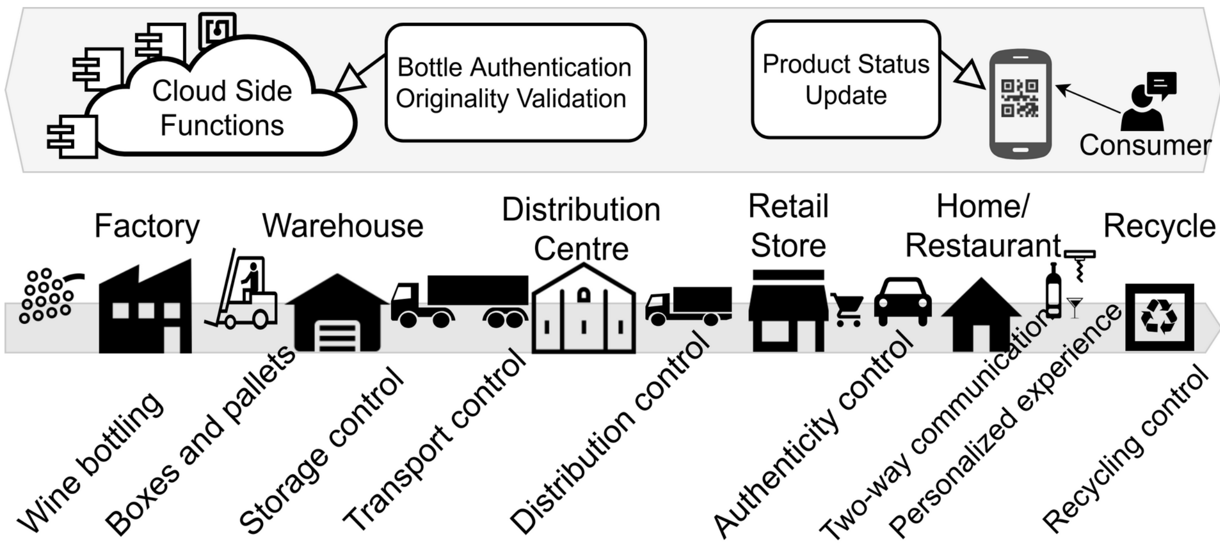

Figure 3. Concept view: the mobile app and cloud side functions applied throughout the whole life cycle of each wine bottle.

For the pilot system, the focus was narrowed to wine bottling, tracking and tracing of each bottle after it leaves production, and two-way communication with consumers. Each bottle was digitalized and assigned it's virtual identity, while it was physically labeled with a corresponding smart tag. The system consisted of cloud side functions providing bottle authentication and originality validation functions and a mobile app providing two-way communication with the consumer in order to update the product status for each bottle. This two-way communication with consumers serves as a human-centric sensor platform in which users provide the input on the status of each scanned wine bottle, while concurrently informing the users more about the product, it's origin, and authenticity. Finally, wine makers interact with the system using a web-based app in order to create QR codes for production batches, and to properly track scans on visualization dashboards to detect possible authenticity and counterfeit situations.

2.2 Smart tags and technology selection

As for the use of smart tags in this TagItSmart! project, their purpose was to "smartify" products and allow them to be tagged in a way that their status could dynamically change in response to a variety of factors, and seamlessly tracked during their life cycle [27].

The idea for using electronic tags or QR codes to bridge physical and virtual worlds is not new [33,34]. There are even examples of using QR codes for product authentication and counterfeit prevention [33]. In our case, for wine brand protection and counterfeit prevention, we conceived a new smart tag that combines a QR code, photochromatic functional ink printing, and heuristics on the Cloud side of the system [36]. The design of these new wine tags is depicted in Figure 4.

Figure 4. Smart tag design that consists of a QR code and letter code printed in photosensitive invisible ink.

The QR code provides a unique identifier for each wine bottle, which is combined with an invisible print of a letter code. These photochromatic prints have two states: inactive (normal, invisible) and activated (excited, visible). The activated state of the tag is achieved by illuminating the tag using LED light (i.e. mobile phone flash) with UV spectrum. During the use of the mobile app, the invisible print is read together with the QR code and tag is validated. For this design, we used reversible ink, which means that after the source of illumination is gone, the tag will revert back to its inactive state. A photochromatic ink with a non-reversible activated state was also considered for marking the bottle of wine as consumed to prevent refilling the authentic bottle. However, this functionality is replaced by collecting the information on the product status (“in store”, “on the table”, “consumed”) from the user via mobile app during each scan of the bottle.

2.3 Main functions

The functional specifications of the proposed system are summarized through architecture-significant use cases as shown in Figure 5. The main stakeholders of such a system would be:

- Wine makers – to protect their brand, reduce losses, improve the quality of the product and services;
- Customers – to get better information on the product and make sure it is original;
- Distributors – to validate waybills and improve transportation;
- Retailers – to provide an attractive service to their shoppers and increase sales;
- Service providers – as the implementer of an anti-counterfeiting system.

For the pilot system, the focus was on wine makers and customers as main actors. The customer uses the system to perform *Wine Bottle Authentication* use case, which includes providing *Wine Information* to the customer. The implementation of this function utilizes a funneling approach to get the user to provide the information needed to *Update Bottle Status* in each scan. The authentication use case implementation is extended with *Rate Product* in order to provide customer feedback to wine producers. An additional value is proposed to the system with an *Extended User Experience* function such as allowing customers to use the platform to implement text and/or multimedia messages similar to greeting cards (Happy Birthday, Anniversary, etc). As for the wine maker, they perform the *Product Tagging*, most importantly individual bottle tagging, but also box/pallet tagging, and additional NFC based tags for expensive wines. Throughout the usage of the system, the wine maker is allowed to perform *Product Track and Trace*, which provides insight about each individual bottle and an overall summary about the wine that left the production.

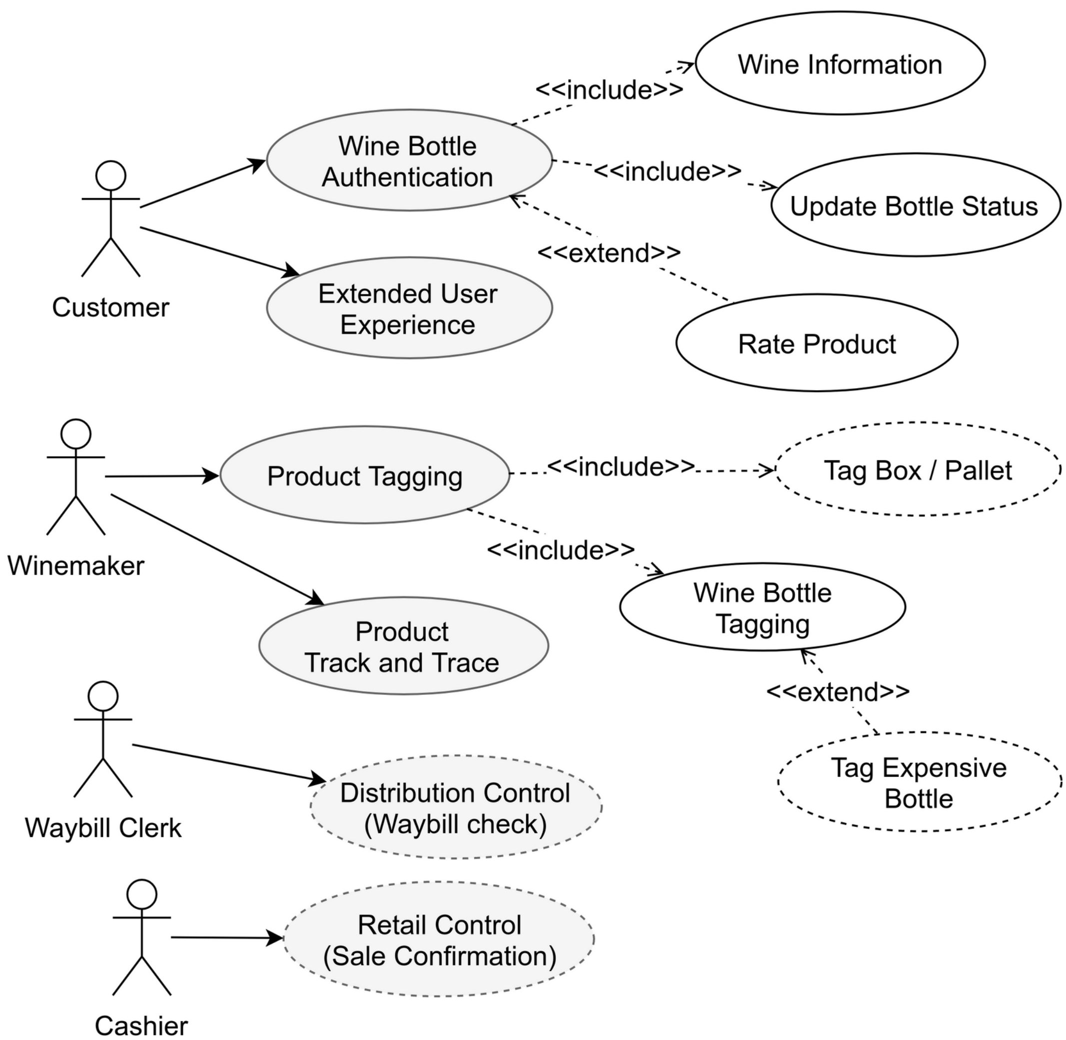

Figure 5. Use case diagram: an overview of the architecture-significant system functions.

3 System architecture and implementation

3.1 Overall system architecture

Figure 6 illustrates the implementation approach to the pilot wine track and trace system for the purpose of counterfeit detection. The diagram depicts the main components of the pilot and provides a high-level connection between them. The cloud platform services "glues" all of the end user applications together. The end user applications include:

- A mobile app for providing the main experience for the wine consumers, which is used to perform wine bottle authentication. This app is also responsible for obtaining feedback from the users on the status of the bottle (unsold, sold, opened, empty) and to obtain customer satisfaction (product rating);
- A web application at the wine maker's site is utilized to support tagging of the bottled products. A nice to have feature would be to interface this component with the existing wine maker's information system in order to extract information on the current product batch, as well as to support the automated integration with waybill creation for boxes/pallets. Winemakers will have access to the platform via a dashboard type visualization of product life cycles for a given period of time providing information on the type of the products, number of scans, possible counterfeit issues, etc.
- A mobile app for distributors provides an optional and nice to have functionality to scan/control the content of the shipment received at the distributor's site. This module would provide track and trace information during the distribution of the product.
- A mobile app or point-of-sale module for the retailer provides an optional and nice to have function to provide sales confirmation to the platform. The status for each bottle sold would be labeled at the register in stores. In addition, this feature can be achieved with an integration/interface between retailer's information system and the counterfeit prevention. In this pilot, this functionality was replaced by collecting the information on product status each time the end user scans the wine bottle.

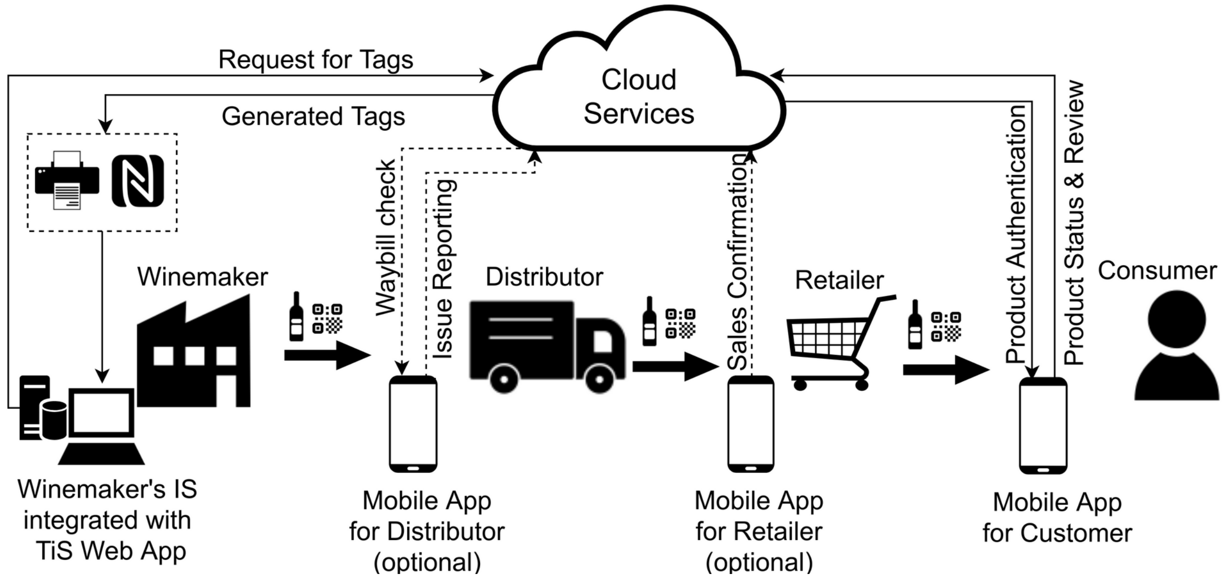

Figure 6. Implementation approach and proposed system architecture.

3.2 Process view and cloud side heuristics

The overall workflow of the proposed solution is depicted in process diagram in Figure 7. The wine maker uses the system to generate smart tags for each product batch. The tags are then printed and applied to each bottle in the batch. Once equipped with a smart tag, each bottle is ready for shipping and made "smart", in order to tell users more about the wine type, origin, originality and its own history while moving through the life cycle. Both the distributor and retailer confirm the product update upon reception and the bottles end up shelved in stores. The consumer performs product authentication using the scan feature on the mobile app, which scans both the QR code and functional ink letter code on the smart tag.

Each time the bottle of wine is scanned by the consumer/buyer, the current status of the bottle is updated and evaluated against the historical data for that specific bottle. This is the responsibility of heuristics for counterfeit detection. The mandatory requirement in order to receive authenticity confirmation is to successfully match the QR code – letter code pair with the original information stored in the database at the time of the tag creation. The system recognizes situations in which the encoded bottle ID carried by QR code cannot be found in the database or the recognized letter does not match the information stored into the database for the given bottle.

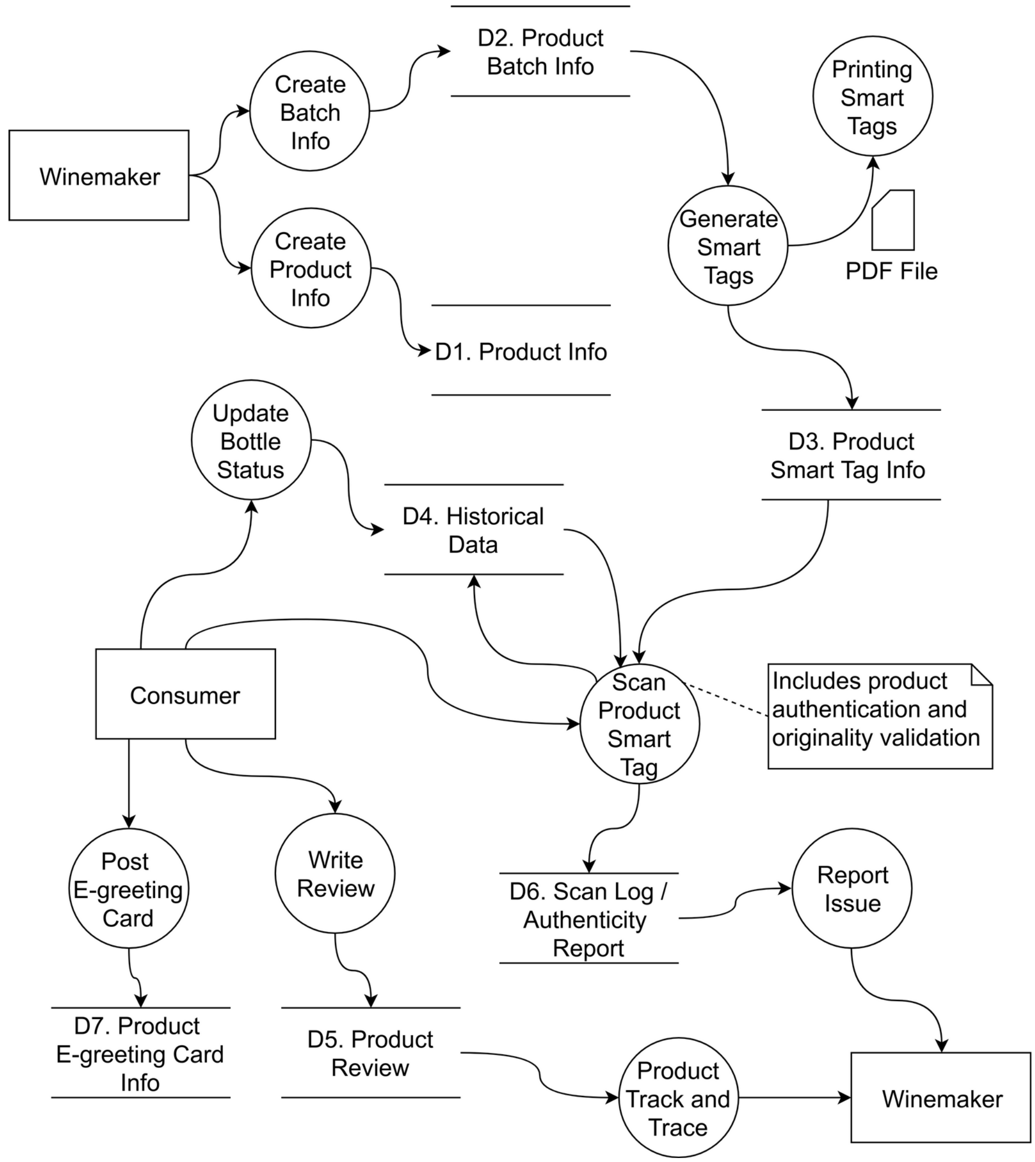

Figure 7. Data flow diagram: the main processes of the system.

Besides these obvious problems, there are several other cases that require additional attention. For example, if the consumer scans the bottle which he or she marks with the “in the store” status, and that bottle has already been marked as “sold” or “consumed” in the database, the system should raise the flag for the possible reuse of the original bottle or its Smart tag. On the other hand, the user should not be able to send feedback to rate the wine for the bottle that had not been marked as sold, etc. That is why the validation against the historical data is a very significant step in authenticity confirmation process.

Authenticity control heuristic should also be able to tackle the issue of users with malicious intent. For this purpose, the unique mobile device ID is attached on every request posted to the Cloud, so that possible malicious activities can be identified, blocked, and prevented.

The product authentication process flow implemented for the pilot execution is illustrated in Figure 8.

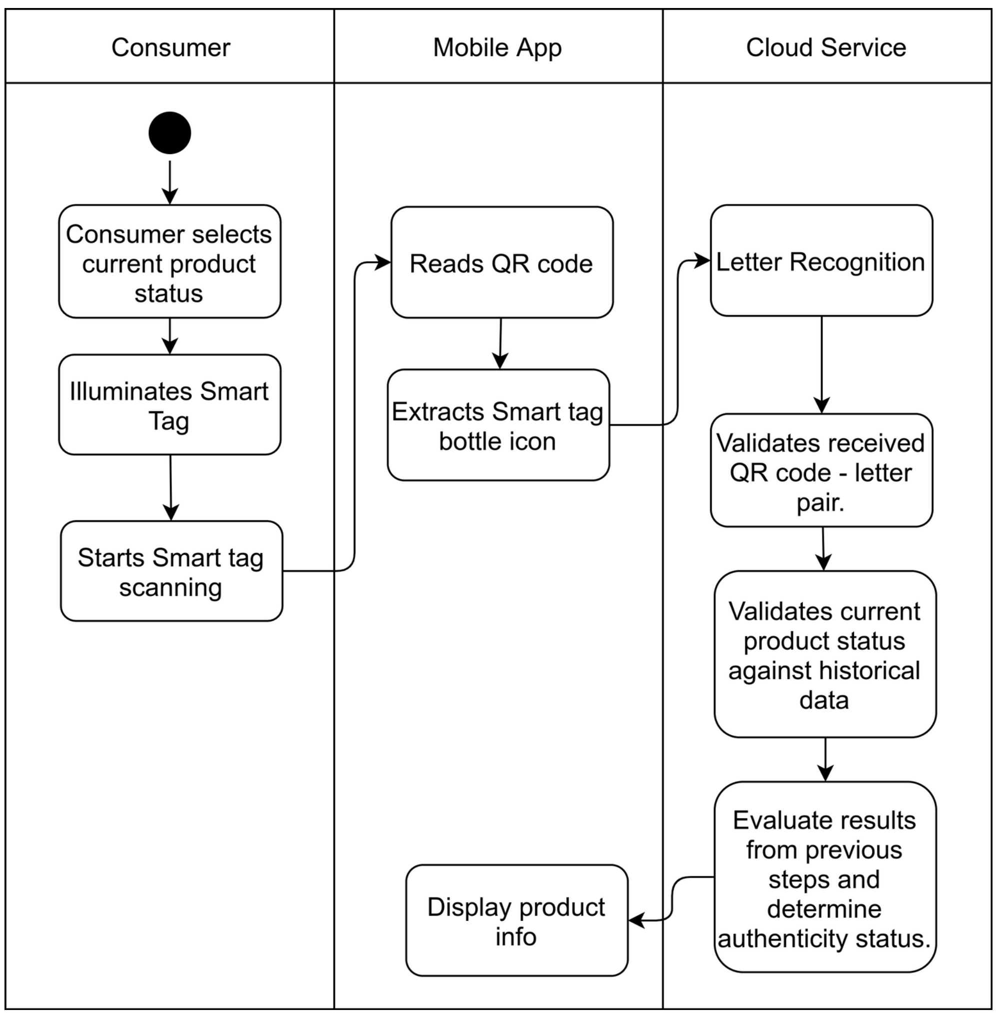

Figure 8. Activity diagram that displays the wine bottle authentication process.

3.3 System Components

The main components of the system and their organization are shown in Figure 9. The cloud platform is implemented using the Azure Cloud server. The server hosts the key back-end components such as management of smart tags, product authentication and review modules, as well as the implementation of APIs needed to interact with the mobile app. The wine maker web app is implemented as a web application hosted on the same server. The mobile app was created for Android and iOS platforms, and made available for download via app stores.

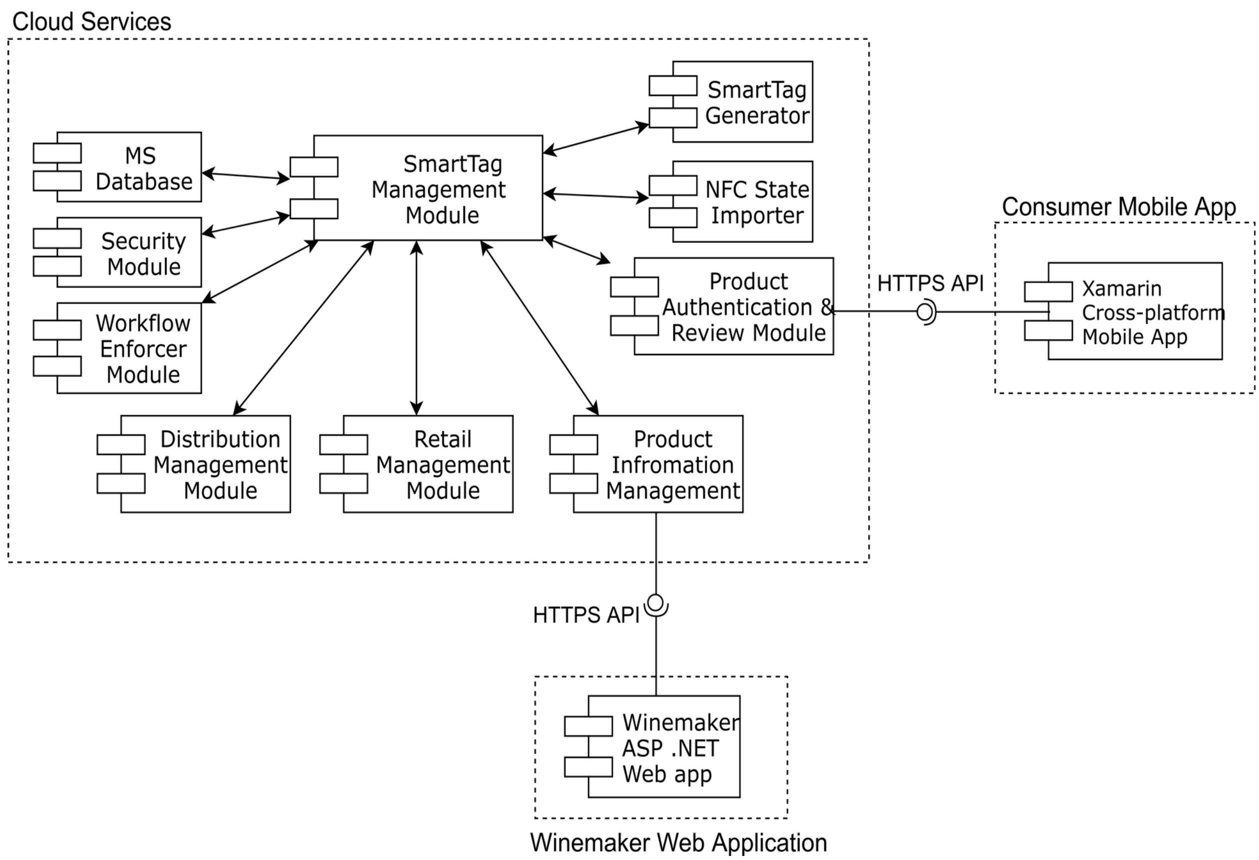

Figure 9. Component view: system components and their interconnection.

3.3.1 Consumer mobile app

The consumer mobile app has been developed using the Xamarin cross-platform development framework in order to shorten the time of development of applications for both Android and iOS based mobile phones [37,38]. Xamarin makes writing native applications easier since shared logic can be written only once and then transpiled to the appropriate platforms. Although Xamarin does not restrict developers in terms of using platform-specific libraries and features, sometimes an additional effort is required in order to adjust platform-specific code. This is especially noticeable when dealing with hardware support (i.e. mobile phone flash and camera control).

The mobile app is built to provide consumers with a user interface for the *Wine Bottle Authentication* use case. The user interface relies on collecting data from the end user about the product status using an information “funneling” concept. Every time the product is to be scanned for originality, the app asks the user to provide the information on bottle status (“in the store”, “in the restaurant”, “on the table”). Additionally, the app collects the actual scan location (GPS coordinates, anonymized device ID) that are sent to the Cloud. The user interface is designed with the intention to consent the end user to provide as much information as possible, which in turn defines the status of the wine bottle that has been scanned (Figure 10).

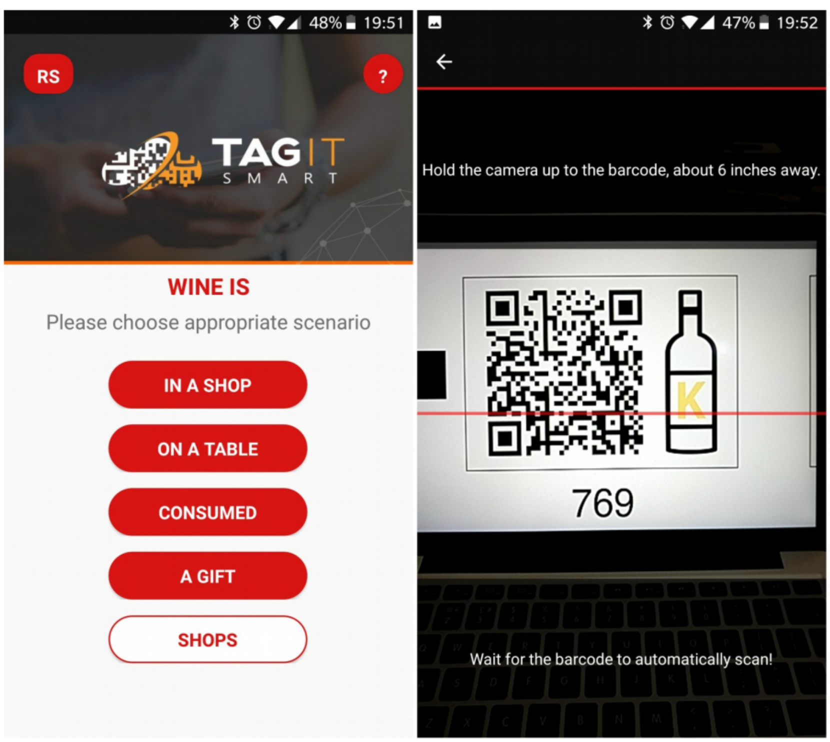

Figure 10. Mobile app user interface: funneling information from consumers and smart tag scanning.

As a result of collecting all of this data, the wine makers have a better insight of what happens with their wines once it leaves the factory, as well as the ability to detect possible counterfeiting patterns, and problematic areas and retail locations.

For the sake of the pilot implementation, the end user was warned if an authenticity issue has arisen. However, the system could be tuned so that only wine makers get the information about possible counterfeits and plan their response accordingly.

3.3.2 Wine maker web app

As mentioned before, the wine maker web app is used for requesting and creating QR codes for the wine production batch. The result of this operation is a set of stickers that correspond to specific wine bottling batch. QR codes are matched with the type of wine, vintage, origin, and other relevant information that is made visible to consumers during their use of mobile app at later time.

For the sake of pilot supervision, the wine makers were provided with dashboard screens that allowed them to easily track scans and assess the situation with respect to authenticity issues identified while the system was operational (Figures 11 and 12).

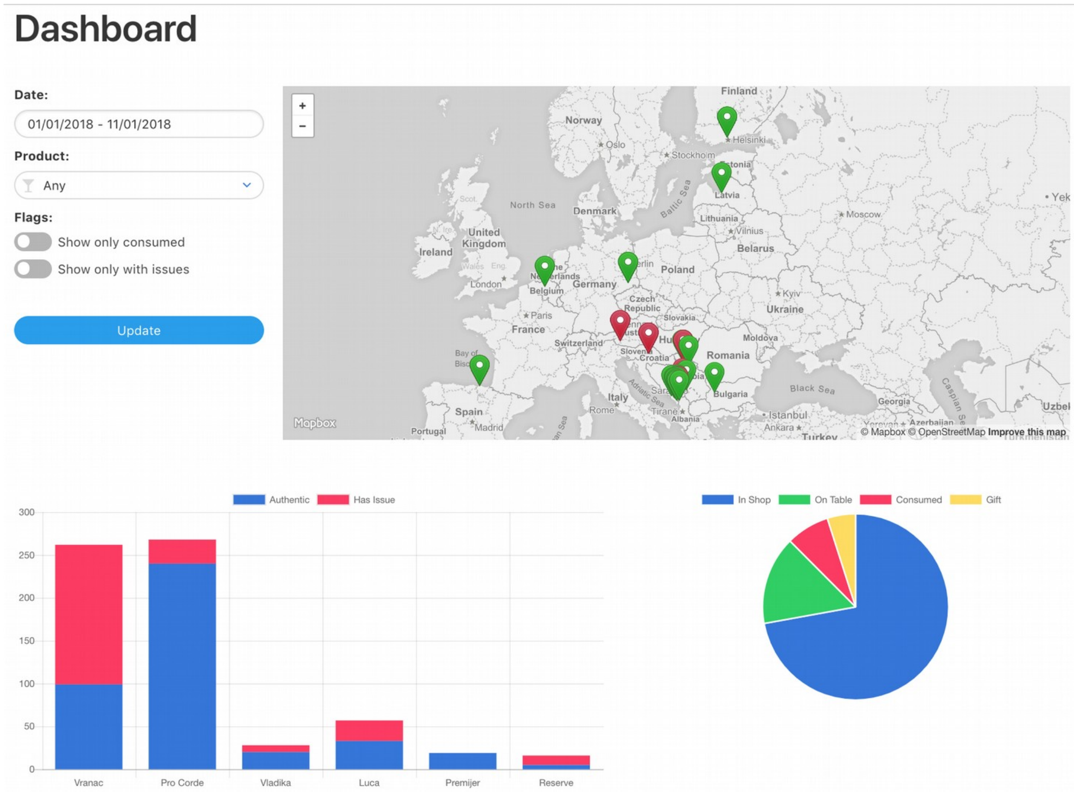

Figure 11. Wine maker web app dashboard: an overview of the system operation for a given time period.

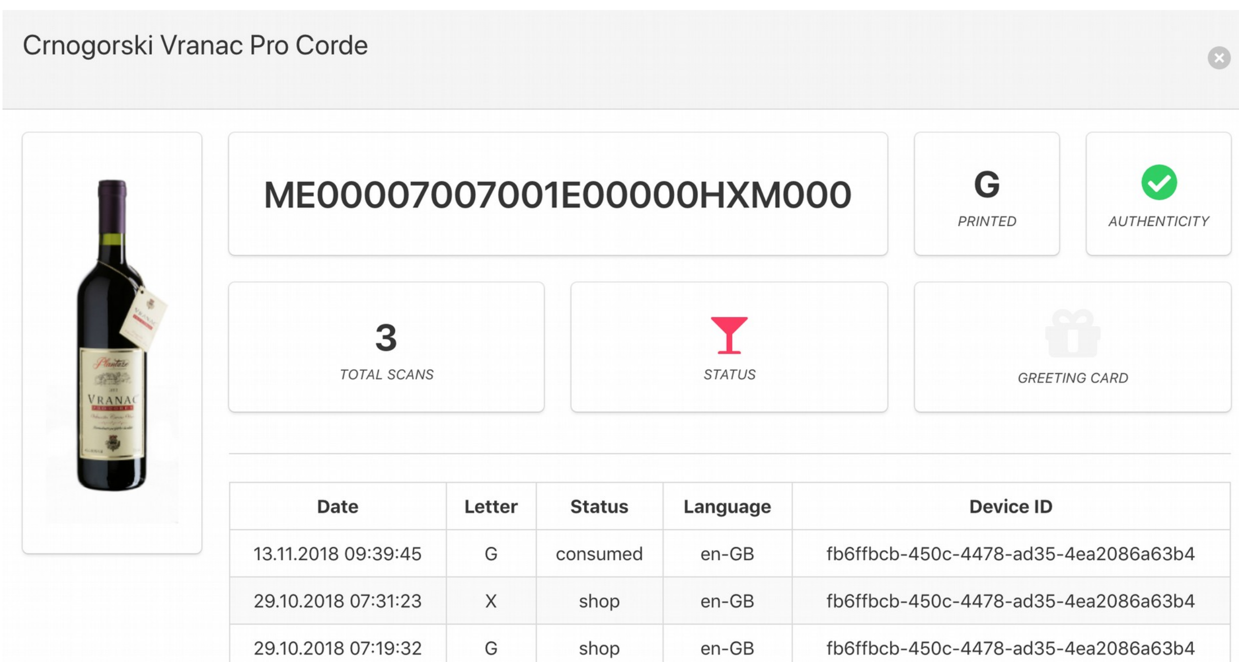

Figure 12. Wine maker web app dashboard: information on individual scans for each bottle.

3.3.3 Cloud service

The Cloud services component glues the system's functions together and integrates end users and the mobile app on one end, and the wine maker web portal on the other. Some of the functions and techniques for counterfeit prevention could be implemented without the cloud, especially if we used the QR code technique alone. However, in the proposed system we added another layer of functionality to the system that combines a QR code equipped with functional ink, and crowd-sourced human sensing data collected via mobile app. This approach enabled the development and use of heuristics that evaluate crowd-sourced data about each individual bottle in order to improve wine authentication and originality. For example, we implemented logic that can detect a situation where an original bottle and SmartTag are reused with fake wine or wine with lower quality. In addition, the proposed cloud based system could serve as a foundation for further development of more advanced counterfeit detection functions, but also for new usage scenarios. There is a possibility that the cloud part of the solution could be replaced by Blockchain distributed ledger technology at some point.

The main cloud-side functions include:

1) QR code batch preparation: one of the services is to interface to the product database and create unique QR codes for each batch of wine in the bottling process. Every batch belongs to a certain type of wine, location of origin, year made, description, and a range of unique ID numbers that will result in a QR code smart tag for each bottle. Furthermore, each tag is paired with a specific letter that will be later printed with invisible ink. The result of this operation is two types of paired PDF files with QR codes which are printed and used to individually identify each bottle, and a companion PDF file which is used for functional ink printing. An additional outcome of this service is that each bottle ends up with its "virtual twin" in the information system that will resemble and mimic the state of each bottle as it moves through its life cycle;

2) Smart tag reading and validation: the pattern recognition of the letter printed with the invisible, photochromatic ink is also done at the cloud side using Azure Custom Vision service, which is a part of Microsoft's Cognitive Services. The training set, with over 200 snapshots of the Smart tags, has been uploaded and the letter recognition component has been trained. Every time a bottle equipped with a smart tag is scanned, its QR code is read and matched with the letter print in order to validate the tag. Each scanning procedure includes collecting information from the end user and mobile device in order to maintain the history about each bottle in the scan log database;

3. Wine authentication and originality: finally, the heuristic for counterfeit detection resides on the cloud side of the system. Each time the bottle of wine is scanned, the current status of the bottle is updated and evaluated against the historical data for that specific bottle. The mandatory requirement in order to receive authenticity confirmation is to successfully match the QR code – letter code pair with the original information stored in the database at the time of the tag creation. In addition, various custom heuristics can be devised. For example, if the bottle was already labeled as opened and empty, it should raise a warning if it is found in stores again. The same goes for bottles with product rating, e.g. consumed and rated with 4 stars.

4 Pilot execution results and discussion

4.1 Pilot execution

The tags were printed at Durst (QR code) and at VTT (photochromatic ink). For printing of the photochromatic ink VTT used its high throughput roll-to-roll printing line ROKO with 10 m/min printing speed. The smart tags were laminated to protect them from degradation, and the tags were kiss-cut to form labels. Thereby, over 15,000 smart tags based on QR code and photochromatic functional ink have been applied to bottles of six types of wines (Figure 13).

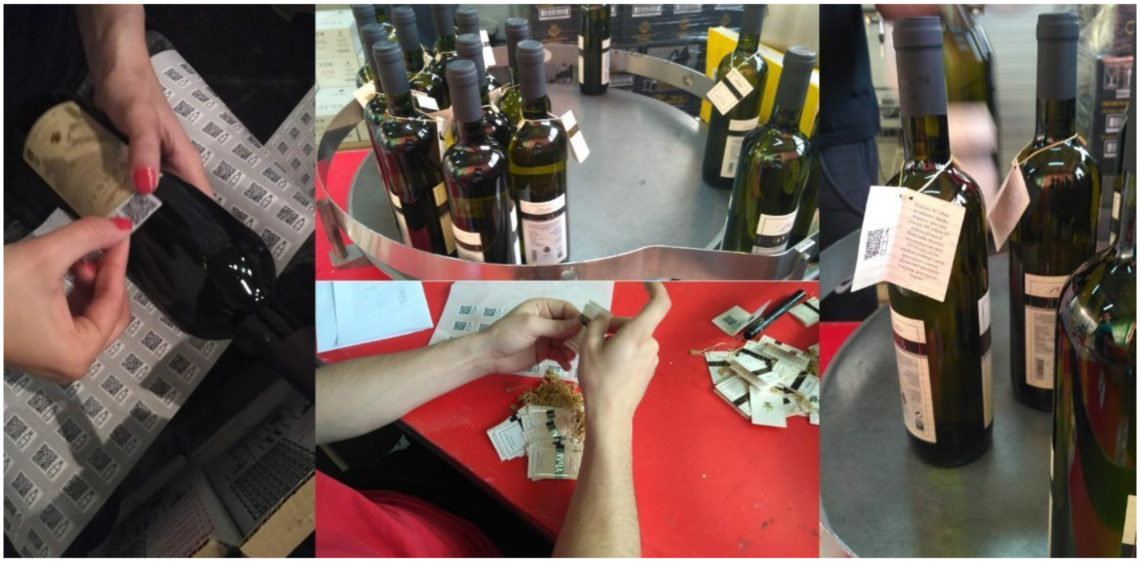

Figure 13. Pilot execution: applying smart tags to bottles in the wine production line.

Prior to the pilot execution, we performed in-house testing of the system with over 100 mobile app downloads and experimentation with several different scenarios. We tried the system with real-life usage scenarios including intentionally incorrect input data simulating situations where the same wine bottle would be labeled as sold or consumed and then “re-appeared” in store again. This lab testing helped us fine tune the technical side of the system and evaluate its behavior where issues with the product were expected to be detected.

In order to disseminate the project and pilot execution, several demonstration events have been organized. The two main demonstrations took place in the stores that belong to the biggest supermarket retail chain in Montenegro. A total of nine demo events were organized over the course of three months. In addition to these demo events, 3,500 booklets in a form of bottle neck hanger manuals were printed for the purpose of promoting the mobile app and its purpose. There was over 200 unique mobile app downloads for Android and iOS during the pilot execution and over 600 “organic” scans of tags with product update. By “organic” we mean scans performed by end users after we finished the in-house testing and by other people that are not from the project team. We received 51 product quality ratings and 109 surveys via mobile app. In addition, a total number of 26 wine makers and distributors were surveyed via interviews.

4.2 Surveying End Users

During the pilot execution both customers and wine makers were surveyed. The customer survey was embedded inside the mobile app and it is displayed only once during the first Smart Tag scan. The results are summarized in Table 1.

Table 1. Results of the customer survey.

Question	5	4	3	2	1	Average
Do you think that application was easy to use?	101	5	1	0	2	4.86
How likely you will recommend this application to your friends?	92	8	4	3	2	4.70
Do you think that information provided by application was useful or interesting for you?	99	6	2	1	1	4.84
Do you think that information about the wine and its authenticity influenced your purchase?	91	9	4	2	3	4.68
Do you think that you would use the application whenever wine shopping?	84	11	5	0	9	4.48
TOTAL:	109					

In addition, the wine makers and distributors were surveyed on several occasions, mostly during wine fairs and similar events. The survey for wine makers was designed to assess crucial topics regarding wine counterfeiting, project viability, and the possibility to integrate wine anti-counterfeit solutions with existing information systems used by wine makers. There was a total of 28 companies that were surveyed during the pilot execution, mainly from the Westen Balkan countries. Most of the wine makers expressed their interest in the use of technology to prevent or reduce counterfeiting of their products. However, most of them were not aware whether or not they were a target of counterfeiting, nor were they aware of their possible losses or effects to their brand due to counterfeiting. The most interesting finding of the wine maker survey was that the small wine makers were much more open to the adoption of the counterfeit prevention system and ready to pay more for it (per bottle cost).

4.3 Business models

It is not an easy task to estimate the cumulative loss due to wine counterfeiting issues. In addition to the direct impact on revenue when consumers buy counterfeit products, there is also loss due to brand reputation damage, which is much harder to estimate. Regular consumers might stop buying products if they stumble upon a single counterfeit product with poor quality. Therefore, very rough estimates will be used to depict loss caused by counterfeit market. Several studies have shown that the share of the counterfeit market in wine industry falls in range between 0.5% and 5%, and maybe even higher in Asia [4,5]. Taking these percentages into account, it can be easily derived that a company that produces 10 million wine bottles annually can easily have a loss due to counterfeiting in the range measured in hundreds of thousands of Euros. Investing in an anti-counterfeiting and brand protection solution could bring benefit to wine producers on multiple levels. Based on a relatively small sample of surveyed wine producers, three basic business models have been identified and discussed during the course of this pilot project:

1) A Freemium model: the basic services offered for free to wine makers and consumers, and the expenses of implementing and maintaining the system will be covered through advertising through the platform;

2) A Service model: the wine makers pay for the system implementation and service (i.e. by purchasing certain number of printed smart tags) and the consumers use the mobile app for free. Different pricing can be offered depending on the number of bottles and the size of the wine producing company that pays for the service;

3) A Stand-alone model: the wine maker implements a fully customized in-house system, which is attractive to larger wine makers. Additional benefits of such a business model would be the possibility to integrate the solution with existing information systems in the company, create additional data analytics, and business intelligence based on the customer feedback obtained through the solution.

The data set collected from users during the pilot execution, both from wine producers and consumers, is not sufficient for plausible estimates with respect to which of the business models may be the best. Also, as the survey showed, different types of wine makers may have different needs and preferences. During this pilot execution, the number of scanned products falls between 3 and 4%. This is not negligent considering that not much advertisement of the anti-counterfeiting system has been done. In addition, it is not an easy task to estimate the rate of success of the system meaning that even if the system is put in place it would not guarantee a 100% prevention of wine counterfeits, but even a smaller success rate such as 20-30% could generate a significant benefit for producers, both in terms of reducing profit losses and brand protection.

4.4 Lessons learned

From the technical standpoint, it has been noted that due to gradual photochromatic ink functionality loss, Smart tags with limited shelf-time are not the best match for products with unlimited shelf-time such as wine. The first batch of printed smart tags showed complete loss of ink function after 5-6 months, especially when exposed to the sunlight for a long period of time. The issues were expected since these tags were first of their kind to ever be printed, and further modification of the ink formulation would be necessary. Thereby, it is anticipated that the technology of functional inks will improve in the near future. Different ways to protect the smart tags from degradation besides lamination could be evaluated in order to improve shelf-life of the smart tags. Most importantly, the concept was very well accepted by both the consumers and wine makers.

On the business side, the survey results have shown significant readiness of wine producers to implement anti-counterfeiting solutions. Small-size wine producers were ready to pay even a higher price, between 0.5€–1€ per smart tag, while large-size wine producers suggested a price below 0.05€ per Smart tag. Several business models have been considered and described earlier.

During the pilot execution, a smart tag scan rate drop has been noted after initial kick-off demo days. Therefore, appropriate bottle neck hangers with scan instructions have been printed and placed on bottles with Smart tag. This resulted in increased user engagement. However, if any of consumer-based business models are to be considered, there must be appropriate marketing coverage in order to get consumers familiar with Smart tag features and their purpose.

5 Conclusions

This paper describes the implementation of a novel solution for counterfeit prevention and brand protection in the wine industry. The proposed system is based on state-of-the-art technology including smart tags, IoT, Cloud, and human sensing network. The main objective of this research effort was to implement a fully functional pilot system, which was then used to perform the evaluation of the proposed technology, but also to collect feedback from end users, namely wine consumers and wine makers.

For this system, a special type of smart tags were created combining QR code and photochromatic ink in order to uniquely identify, track, and trace each wine bottle during its end-to-end life cycle. The implementation of the system combined the use of smart tags with IoT, Cloud computing, a mobile app, and crowd-sourced information collected from consumer. The main contribution of the research is the demonstration of the combination of techniques for individual product identification, and gathering information on the product status supported by the mobile app and centralized cloud system. As shown, this platform can be used to implement a product authenticity solution aimed at brand protection and counterfeit prevention in the food and wine industry. Even though functional ink printing technology showed some weaknesses in this pilot, the use of unique identifiers for each product instance was critical to implement track and trace capability supported by human-centric sensing and the cloud system.

The pilot execution and surveying of the end users showed a great interest in the possibility of implementing such a system, added value for the users, and the potential of the concept to increase profits, support brand protection, and reduce possible health hazards. The research outlined three possible business models to be further explored as a basis for implementation of an actual system in the production environment. It is also important to note that the benefits of implementing such solutions is not only counterfeit prevention and securing profits for producers, but also to engage consumers and raise awareness about food safety and it's effects on health.

Further research will explore the use of different types of smart tags and IoT sensors, employment of machine learning models that could be developed using the historical data collected over time, as well as the use of blockchain technology to store the product information and status updates.

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